Chapter 1

Introduction: Evolution and the Foundations of Biology

Chapter Focus

This chapter outlines the broad scope of biology, describes themes that unify the study of life, and examines the scientific construction of biological knowledge. A course in biology is neither a vocabulary course nor a classification exercise for the diverse forms of life. Biology is a collection of facts and concepts structured within theories and organizing principles. Recognizing the common themes within biology will help you structure your knowledge of the fascinating and challenging study of life.

Chapter Review

Biology is the scientific study of life, with **evolution,** the process of change that has shaped life from its origin on Earth to today's diversity, as its organizing principle.

1.1 Studying the diverse forms of life reveals common themes

Theme: New properties emerge at successive levels of biological organization The scale of biology extends from the biosphere to molecules.

FOCUS QUESTION 1.1

Write a brief description of each of the following levels of biological organization.

a. biosphere

b. ecosystem

c. community

d. population

e. organism

f. organs and organ systems

g. tissues

h. cells

i. organelles

j. molecules

Interactions among components at each level of biological organization lead to the emergence of novel properties at the next level. These **emergent properties** result from the structural arrangement and interaction of parts.

Biology today combines the powerful and pragmatic strategy of *reductionism*, which breaks down complex systems into simpler components, with **systems biology,** which studies the interactions of the parts of a biological system and models the system's dynamic behavior.

The form of a biological structure is usually well matched to its function. Form fits function at all of life's structural levels.

The cell is an organism's basic unit of structure and function—the lowest structural level capable of performing all the activities of life. The simpler and smaller **prokaryotic cell,** unique to bacteria and archaea, lacks both a nucleus to enclose its DNA and other membrane-enclosed organelles. The **eukaryotic cell**—with a nucleus containing DNA, and numerous organelles—is typical of all other living organisms.

Theme: Life's Processes Involve the Expression and Transmission of Genetic Information The genetic information of a cell is coded in **DNA**

(deoxyribonucleic acid), the substance of genes. **Genes** are the units of inheritance that transmit information from parents to offspring. Genes are located on chromosomes, long DNA molecules that replicate before cell division and provide identical copies to daughter cells.

The biological instructions for the development and functioning of organisms are coded in the arrangement of the four kinds of nucleotides on the two strands of a DNA double helix. Most genes program the cell's production of proteins, and almost all cellular structures and actions involve one or more proteins.

Gene expression is the process by which a gene's information is transcribed to RNA and then translated into a protein. Genes also code for RNAs that serve other functions, such as regulating gene expression. All forms of life use essentially the same genetic code of nucleotides.

FOCUS QUESTION 1.2

Describe the pathway from DNA nucleotides to proteins.

All the genetic instructions an organism inherits make up its **genome.** One set of human chromosomes contains about 3 billion nucleotide pairs, and codes for the production of about 75,000 proteins and a large number of non-protein-coding RNA molecules.

The sequences of nucleotides in the human genome and the genomes of many other organisms have been determined. Using a systems approach called **genomics,** scientists study whole sets of genes in one or more species.

Three research developments contribute to genomics: "high-throughput" technology that can analyze biological materials rapidly; **bioinformatics,** which provides the computational tools to process and analyze the resulting data; and interdisciplinary research teams with specialists from many diverse scientific fields.

Theme: Life Requires Transfer and Transformation of Energy and Matter Life requires energy. Producers transform light energy to the chemical energy in sugars, which powers the cellular activities of plants. Consumers eat plants and other organisms, using the chemical energy in their foods to power their movement, growth, and other activities. In each energy transformation, some energy is lost to the surroundings as heat.

FOCUS QUESTION 1.3

Compare the movement of chemical nutrients and energy in an ecosystem.

Theme: Organisms Interact with Other Organisms and the Physical Environment Both organisms and the environment are affected by interactions between them. Interactions between organisms may be mutually beneficial or may harm one or both participants.

Evolution, the Core Theme of Biology Evolution explains how diverse organisms of the past and the present are related through descent from common ancestors, and how organisms become adapted to their environment.

1.2 The Core Theme: Evolution accounts for the unity and diversity of life

Classifying the Diversity of Life: The Three Domains of Life Of an estimated total of 10–100 million species, only about 1.8 million species have been identified and named. Biologists have grouped species into ever broader categories, from genera to family, order, class, phylum, and kingdom.

The number of kingdoms is an ongoing debate, but all of life is now grouped into three domains. The prokaryotes are divided into domains **Bacteria** and **Archaea.** All eukaryotes are placed in domain **Eukarya.** The mostly unicellular protists are being reorganized to better reflect evolutionary relationships.

Within this diversity of life, organisms share many similarities, including a universal genetic language of DNA.

FOCUS QUESTION 1.4

What is a commonly used criterion for placing plants, fungi, and animals into separate kingdoms?

Charles Darwin and the Theory of Natural Selection In *On the Origin of Species,* published in 1859, Charles Darwin presented his case for "descent with modification," the idea that present forms have diverged from a

succession of ancestral forms. Darwin proposed **natural selection** as the mechanism of evolution by drawing an inference from three observations: Individuals vary in many heritable traits, the overproduction of offspring sets up a competition for survival, and species are generally matched to their environments. From this, Darwin inferred that individuals with traits best suited to the environment leave more offspring than do less-fit individuals. This natural selection, or unequal reproductive success within a population, results in the gradual accumulation of favorable adaptations to the environment.

The Tree of Life The underlying unity seen in the structures of related species, both living and in the fossil record, reflects the inheritance of those structures from a common ancestor. The diversity of species results from natural selection acting over millions of generations as populations adapted to different environments. The tree-like diagrams of evolutionary relationships reflect the branching genealogy extending from ancestral species. Similar species share a common ancestor at a more recent branch point on the tree of life. Distantly related species share a more ancient common ancestor.

FOCUS QUESTION 1.5

Describe in your own words Darwin's theory of natural selection as the mechanism of evolutionary adaptation and the origin of new species.

1.3 Biological inquiry entails forming and testing hypotheses based on observations of nature

Science is an approach to understanding the natural world that involves **inquiry,** the search for information by asking questions and endeavoring to answer them.

Making Observations Careful and verifiable observation and analysis of data are the basis of scientific inquiry. Observations involve our senses and tools that extend our senses; **data,** both *quantitative* and *qualitative,* are recorded observations. Using **inductive reasoning,** generalizations can often be drawn from collections of observations.

Forming and Testing Hypotheses Observations and inductions lead to the search for natural causes and explanations. A **hypothesis** is a tentative answer to a question or an explanation of observations, and it leads to predictions that can be tested. **Deductive reasoning** uses *"if . . . then"* logic to proceed from the general to the specific—from a general hypothesis to specific predictions of results if the general premise is correct.

In science, the ideal is to frame two or more alternative hypotheses and design experiments to test each candidate explanation. A hypothesis cannot be *proven* true; the more attempts to falsify it that fail, however, the more a hypothesis gains credibility.

Science seeks natural causes for natural phenomena; it does not address questions of the supernatural.

A Case Study in Scientific Inquiry: Investigating Coat Coloration in Mouse Populations Beach and mainland mice are found in two distinct habitats in Florida and differ in coloration, although they are members of the same species. H. Hoekstra and her students tested the hypothesis that coloration patterns evolved as adaptations that protect mice from predation. To test the prediction that mice with coloration that did not match their habitat would be preyed on more than mice that were camouflaged by their coloration, they set out models of beach and mainland mice in both habitats. After recording signs of predation, they calculated the proportion of attacked mice in each habitat. In both cases, the mice whose coloration did not match their habitat had a higher predation rate. Thus, their experiment supports the camouflage hypothesis.

This experimental design illustrates a **controlled experiment** in which subjects are divided into an *experimental* group and a *control* group. Both groups are alike except for the one variable that the experiment is trying to test.

FOCUS QUESTION 1.6

a. Identify the control and experimental groups in the mouse camouflage experiment.

b. Why were the results of this study presented as the proportion of attacks on camouflaged and non-camouflaged mice in each area rather than as the total number of attacks on non-camouflaged mice?

Theories in Science A **theory** is broader in scope than a hypothesis, generates many specific hypotheses, and is supported by a large body of evidence. Still, a theory can be modified or even rejected when results and new evidence no longer support it.

Science as a Social Process: Community and Diversity Most scientists work in teams and share their results with a broader research community in seminars, publications, and websites. Scientists often attempt to confirm the observations and experimental results of other colleagues. Science is distinguished by adherence to the criteria of verifiable observations and hypotheses that are testable and falsifiable.

Science and technology are interdependent: The information generated by science is applied by **technology** for specific purposes, and technological advances are used to extend scientific knowledge.

Women and many racial and ethnic groups have been underrepresented in scientific professions. A diversity of backgrounds and viewpoints is important to the progress of science.

FOCUS QUESTION 1.7

a. Compare hypotheses and theories.

b. Compare science and technology.

Word Roots

bio- = life (*biology:* the scientific study of life; *bioinformatics:* the use of computers, software, and mathematical models to process and integrate biological information from large data sets)

eu- = true; **karyo-** = nucleus (*eukaryotic cell:* a type of cell with a membrane-enclosed nucleus and organelles)

pro- = before (*prokaryotic cell:* a type of cell lacking a membrane-enclosed nucleus and organelles)

Structure Your Knowledge

1. Briefly describe in your own words each of the five unifying themes of biology presented in this chapter:
   a. emergent properties and levels of biological organization
   b. expression and transmission of genetic information
   c. the transfer and transformation of energy and matter
   d. interaction with other organisms and the physical environment
   e. evolution

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. The core idea that makes sense of the unity and the diversity of life is
   a. the scientific method.
   b. inductive reasoning.
   c. deductive reasoning.
   d. evolution.
   e. systems biology.

2. Suppose that, in an experiment similar to the mice study described in this chapter, a researcher found that more total predator attacks occurred on model beach mice placed in a beach habitat than in a mainland habitat. From this the researcher concluded that
   a. the camouflage hypothesis is false.
   b. the predators in the beach habitat were hungrier than the predators in the mainland habitat.
   c. model beach mice do not resemble living beach mice enough to protect them from attack.
   d. the data that should be compared to draw a conclusion must include a control—a comparison with the number of attacks on model mainland mice in both habitats.
   e. more data must be collected before a conclusion can be drawn.

3. Why can a hypothesis never be "proven" to be true?
   a. One can never collect enough data to be 100% sure.
   b. There may always be alternative untested hypotheses that might account for the results.
   c. Science is limited by our senses.
   d. Experimental error is involved in every research project.
   e. Science "evolves"; hypotheses and even theories are always changing.

4. In a pond sample, you find a unicellular organism that has numerous chloroplasts and a whiplike flagellum. In which of the following groups do you think it should be classified?
   a. plant
   b. animal
   c. domain Archaea
   d. one of the proposed kingdoms of protists
   e. You cannot tell unless you see if it has a nucleus.

5. What is DNA?
   a. the substance of heredity
   b. a double helix made of four types of nucleotides
   c. a code for protein synthesis
   d. a component of chromosomes
   e. all of the above

6. Which of the following sequences correctly lists life's hierarchical levels from lowest to highest?
   a. organ, tissue, organ system, organism, population
   b. organism, community, population, ecosystem, biosphere
   c. molecule, organelle, cell, tissue, organ, organism
   d. tissue, cell, organ, organism, community
   e. Both b and c are correct sequences.

7. Which of the following themes of biology is most related to the goals and practices of systems biology?
   a. Evolution accounts for the unity and diversity of life.
   b. Organisms interact with other organisms and the physical environment.
   c. Life's processes involve the expression and transmission of genetic information.
   d. Life requires energy transfer and transformation.
   e. New properties emerge at successive levels of biological organization.