Chapter 1

Exploring Life

Key Concepts

1.1 **Biologists explore life from the microscopic to the global scale**

1.2 **Biological systems are much more than the sum of their parts**

1.3 **Biologists explore life across its great diversity of species**

1.4 **Evolution accounts for life's unity and diversity**

1.5 **Biologists use various forms of inquiry to explore life**

1.6 **A set of themes connects the concepts of biology**

Framework

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 to structure your knowledge of this fascinating and challenging study of life.

Chapter Review

Biology is the scientific study of life. The properties and processes of life include highly ordered structure, evolutionary adaptation, response to the environment, regulation, energy processing, growth and development, and reproduction.

1.1 Biologists explore life from the microscopic to the global scale

A Hierarchy of Organization The levels of biological structure extend from the biosphere to molecules.

■ INTERACTIVE QUESTION 1.1

Write a brief description of each of these 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

A Closer Look at Ecosystems An ecosystem includes all the organisms and the nonliving factors in an area. Both organisms and the environment are affected by the interactions between them. The dynamics of an ecosystem include the cycling of nutrients and the flow of energy from sunlight to **producers** (photosynthesizers) to **consumers.** In each energy transformation, some energy is converted to thermal energy, which is dissipated to the surroundings as heat. Thus energy flows through ecosystems, entering as solar energy and exiting as heat.

A Closer Look at Cells The cell is the lowest structural level capable of performing all the activities of life. The heritable information of a cell is coded in **DNA, deoxyribonucleic acid,** the substance of genes. **Genes** are the units of inheritance, which 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 in DNA molecules. Most genes program the cell's production of proteins, and almost all cellular actions involve one or more proteins. Enzymes are proteins that catalyze a cell's chemical reactions.

All forms of life use essentially the same genetic code of nucleotides. This universal genetic code permits the engineering of cells to produce proteins of other organisms. All the genetic instructions an organism inherits are called its **genome.** The human genome is about 3 billion nucleotides long, and it codes for the production of more than 70,000 proteins, each with a specific function.

Every cell uses DNA as its genetic information and is enclosed by a membrane. The simpler and smaller **prokaryotic cell,** unique to bacteria and archaea, lacks both a nucleus to enclose its DNA and most cytoplasmic organelles. The **eukaryotic cell,** with a nucleus containing its DNA, and numerous membrane-bound organelles, is typical of all other living organisms.

■ **INTERACTIVE QUESTION 1.2**

How do DNA nucleotides relate to proteins?

1.2 Biological systems are much more than the sum of their parts

Biology attempts to understand the behavior of **systems,** the complex organization resulting from the integration of component parts.

The Emergent Properties of Systems Interactions among components at each level of biological organization lead to the emergence of novel properties at the next level. The structural arrangement and interactions of parts lead to these **emergent properties.**

The Power and Limitations of Reductionism Biology combines the powerful and pragmatic strategy of **reductionism,** which breaks down complex systems to simpler components, with the study of the highly complex organizational levels of life.

Systems Biology Many researchers are seeking to understand the emergent properties of life by looking at the functional integration of the parts of a system. **Systems biology** seeks to model biological systems and predict their responses as variables change. Systems biology is carrying this approach, already useful for analyzing ecosystem dynamics and physiological interactions in organisms, to the study of cellular and molecular interactons.

The first step of the systems strategy is to inventory all the known parts of a system. The second step is to explore how each part behaves in relation to others in the working system. Then data from many research teams are combined using computers and software to model a system network. Three research developments are contributing: high-throughput technology or mega-data-collection methods such as the automatic DNA-sequencing machines; **bioinformatics,** which provides the computing power, software, and mathematical models to process and integrate data from enormous data sets; and interdisciplinary research teams with diverse specialists from many scientific fields.

■ **INTERACTIVE QUESTION 1.3**

a. What types of diverse specialists might be involved in a systems biology team?

b. Give examples of how systems biology may impact medical practice or environmental policy making.

Feedback Regulation in Biological Systems Many biological systems self-regulate by a mechanism called feedback, in which the output or product of a process regulates the process. In **negative feedback,** an end-product slows down the process. In **positive feedback,** less common in biological processes, an end-product speeds up its own production. Regulatory mechanisms ensure a dynamic balance in living systems.

1.3 Biologists explore life across its great diversity of species

About 1.8 million species, out of an estimated total of 10–200 million, have been identified and named.

Grouping Species: The Basic Idea Taxonomy is the branch of biology that names organisms and groups species into ever broader categories from genera to family, order, class, phylum, kingdom, and domain.

The Three Domains of Life Traditionally, life-forms have been organized into five kingdoms, although schemes ranging from six to dozens of kingdoms have recently been proposed. These varying numbers of kingdoms are grouped, based primarily on molecular data, into three domains. The prokaryotes are divided into **domain Archaea** and **domain Bacteria,** and each of these includes multiple kingdoms. The eukaryotes are placed in **domain Eukarya.** Within the Eukarya, the traditional kingdom Protista contains mostly unicellular or simple multicellular forms. Biologists are currently debating how to split the protists into several kingdoms that would better represent evolution and diversity. The other three are plants, fungi, and animals.

Unity in the Diversity of Life Within this diversity, living forms share a universal genetic language of DNA and similarities in cell structure.

■ INTERACTIVE QUESTION 1.4

What are the main criteria for separating plants, fungi, and animals into kingdoms?

1.4 Evolution accounts for life's unity and diversity

Evolution connects all of the diverse forms of life by common ancestry. In *The Origin of Species,* published in 1859, Charles Darwin presented his case for evolution, or "descent with modification," that present forms evolved from a succession of ancestral forms.

Natural Selection Darwin synthesized the theory of natural selection as the mechanism of evolution by drawing an inference from two observations: Individuals vary in many heritable traits, and the overproduction of offspring sets up a competition. Individuals with traits best suited for an environment leave a larger proportion of offspring than do less fit individuals. This natural selection, or differential reproductive success within a population, results in the gradual accumulation of favorable adaptations to the challenges of an 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 that structure from a common ancestor. Their diversity results from natural selection acting over millions of generations in different environments. According to Darwin, natural selection could produce new species from ancestral ones when isolated populations diversify over time in response to different sets of environmental factors. The tree-like diagrams of evolutionary relationships reflect the branching genealogy extending from ancestral species. Similar species, such as the Galápagos finches, share a common ancestor at a more recent branch point on the tree of life. Birds and mammals share a more ancient common ancestor. And all of life traces back to the earliest ancestral forms.

■ INTERACTIVE QUESTION 1.5

Describe in your own words Darwin's theory of natural selection as the mechanism of evolution.

1.5 Biologists use various forms of inquiry to explore life

Science is a way of knowing that involves **inquiry,** searching for information by asking and endeavoring to answer questions about nature.

Discovery Science Careful and verifiable observation and analysis of data are the basis of **discovery science.** Observations involve our senses and tools that extend our senses; **data,** both quantitative and qualitative, are recorded observations. Using **inductive reasoning,** a generalized conclusion can often be drawn from collections of observations.

Hypothesis-Based Science Observations and inductions often lead to the search for explanations. Hypothesis-based science is the search for explanations. A **hypothesis** is a tentative answer to a question. Using "if . . . then" logic, **deductive reasoning** proceeds from the general to the specific, from a general hypothesis to specific predictions of results if the general premise is true. A hypothesis is usually tested by performing experiments or making observations to see whether predicted results occur.

A hypothesis must be testable and falsifiable—there must be some observation or experiment that could reveal if the hypothesis is actually not true. In hypothesis-based science, the ideal is to frame two or more alternative hypotheses and design experiments to falsify each candidate explanation. Hypotheses cannot be proven, they can simply be not eliminated through falsification. The more attempts to falsify it that fail, however, the more a hypothesis gains credibility.

The scientific method, as outlined by a structured series of steps, is rarely adhered to rigidly in a scientific inquiry. Scientists often backtrack to make more observations, or make progress on answering a question only after other research projects provide a new context. In some cases, research must be redirected and refocused by asking different or more productive questions.

A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations In 2001, D. and K. Pfennig designed field experiments to test the Batesian mimicry hypothesis that mimics benefit because predators avoid them, confusing them with the harmful species they resemble. The scarlet king snake mimics the ringed coloration of the highly poisonous coral snake. Predators rarely attack coral snakes, apparently as a result of an inherited instinctive ability to recognize the warning coloration. The Pfennigs tested the hypothesis that predators will attack king snakes more frequently in non–coral snake areas than in areas where predators have adapted to the warning coloration of coral snakes. They placed equal numbers of plain brown and ringed colored artificial king snakes in regions with and without coral snakes. Compared to the brown "control" snakes, the ringed "experimental" snakes were attacked less frequently only in field sites within the range of the poisonous coral snakes.

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

■ **INTERACTIVE QUESTION 1.6**

a. How did predators "learn" to avoid coral snakes?

b. Why were the results of the mimicry study presented as the percent of attacks on king snakes in each area rather than the total number of attacks?

Limitations of Science Scientific inquiry is limited by the requirements that hypotheses be testable and falsifiable and that observations and experimental results be repeatable. Science seeks natural causes for natural phenomena.

Theories in Science A **theory** is broader in scope than a hypothesis and is supported by a large body of evidence. Still, theories can be modified or even rejected through the testing of the specific, falsifiable hypotheses they generate.

Model Building in Science Scientific **models,** such as diagrams, graphs, computer programs, or mathematical equations, help explain ideas and processes. The test of a good model is that it fits available data, incorporates new observations, and makes accurate predictions of new experiments.

The Culture of Science Most scientists work in teams and share their results with a broader research community in seminars, publications and websites. The political and cultural environment influences the ways in which scientists approach their work. But the adherence to the criteria of verifiable observations and hypotheses that are testable and falsifiable sets science apart from other ways of "knowing nature."

Science, Technology, and Society Science and technology are interdependent as the information generated by science is applied by **technology** in the development of goods and services, and as technological advances are used to extend scientific knowledge. The uses of scientific knowledge and technologies are influenced by and will influence politics, economics, and cultural values.

1.6 A set of themes connects the concepts of biology

Biology is a demanding science—partly because living systems are so complex and partly because biology incorporates concepts from chemistry, physics, and math. This book presents a wealth of information. The basic themes of biology will help you understand, appreciate, and structure your growing knowledge of biology.

Word Roots

bio- = life (*biology:* the scientific study of life; biosphere: all the environments on Earth that are inhabited by life; *bioinformatics:* using information technology to extract useful information from large sets of biological data)

eu- = true (*eukaryotic cell:* a cell that has a true nucleus)
-ell = small (*organelle:* a small formed body with a specialized function found in the cytoplasm of eukaryotic cells)
pro- = before; **karyo-** = nucleus (*prokaryotic cell:* a cell that has no nucleus)

Structure Your Knowledge

1. This chapter presents eleven unifying themes of biology. Briefly describe each of these in your own words:
   a. the cell
   b. heritable information
   c. emergent properties of biological systems
   d. regulation
   e. interaction with the environment
   f. energy and life
   g. unity and diversity
   h. evolution
   i. structure and function
   j. scientific inquiry
   k. science, technology, and society

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

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

2. In an experiment similar to the mimicry experiment performed by the Pfennigs, a researcher found that there were more total predator attacks on model king snakes in areas with coral snakes than in areas outside the range of coral snakes. From this the researcher concluded that
   a. the mimicry hypothesis is false.
   b. there were more predators in the areas with coral snakes.
   c. king snakes do not resemble coral snakes 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 brown snakes.
   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 hypotheses that might account for the results and that were not tested.
   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. Which of the following is an example of positive feedback regulation?
   a. The hormones insulin and glucagon regulate blood-sugar levels.
   b. In the birth of a baby, uterine contractions stimulate release of chemicals that stimulate more uterine contractions.
   c. A rise in temperature when you exercise stimulates sweating and increased blood flow to the skin.
   d. When cells have sufficient energy available, the pathways that break down sugars are turned off.
   e. A rise in CO_2 in the atmosphere correlates with increasing global temperature.

5. Which of the following areas is mismatched with its description?
   a. discovery science—data collection and analysis; deductive reasoning
   b. hypothesis-based science—hypothesis generation; predictions; experiments or observations
   c. systems biology—high throughput technology, bioinformatics, interdisciplinary teams
   d. taxonomy—identify and name organisms; place in hierarchical categories
   e. technology—inventing practical uses of scientific knowledge

6. In a pond sample you find a unicellular organism that has numerous chloroplasts and a whiplike flagella. 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 or not.

7. 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

8. Which of the following represents the correct sequence in the life's hierarchical levels, proceeding upward?
   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.