Introduction:

Evolution and the Foundations of Biology

- Overview: Inquiring About Life
- An organism's adaptations to its environment are the result of evolution
  - For example, a beach mouse's light, dappled fur acts as camouflage, allowing the mouse to blend into its surroundings
  - Inland mice of the same species are darker in color, matching their surroundings
- **Evolution** is the process of change that has transformed life on Earth
- Figures 1.1-1.2
- **Biology** is the scientific study of life
- Biologists ask questions such as
  - How does a single cell develop into an organism?
  - How does the human mind work?
  - How do different forms of life in a forest interact?
- Concept 1.1: The study of life reveals common themes
- To organize and make sense of all the information encountered in biology, focus on a few big ideas
- These unifying themes help to organize biological information:
  - Organization
  - Information
  - Energy and Matter
  - Interactions
  - Evolution
- Theme: New Properties Emerge at Successive Levels of Biological Organization
- Life can be studied at different levels, from molecules to the entire living planet
- The study of life can be divided into different levels of biological organization
- In reductionism, complex systems are reduced to simpler components to make them more manageable to study
- Figure 1.3
- *Emergent Properties*
- **Emergent properties** result from the arrangement and interaction of parts within a system
- Emergent properties characterize nonbiological entities as well
  - For example, a functioning bicycle emerges only when all of the necessary parts connect in the correct way
- Biologists today complement reductionism with **systems biology**, the exploration of a biological system by analyzing the interactions among its parts
- The systems approach poses questions such as
  - How do networks of genes in our cells function to generate our 24-hour cycle of wakefulness and sleep?
  - How does increasing CO_2 alter the biosphere?
- *Structure and Function*
- At each level of the biological hierarchy we find a correlation between structure and function
- Analyzing a biological structure can give clues about what it does and how it works
- *The Cell: An Organism's Basic Unit of Structure and Function*
- The cell is the smallest unit of life that can perform all the required activities
- All cells share certain characteristics, such as being enclosed by a membrane
- The two main forms of cells are prokaryotic and eukaryotic
- A **eukaryotic cell** contains membrane-enclosed organelles, including a DNA-containing nucleus
- Some organelles, such as the chloroplast, are limited only to certain cell types, that is, those that carry out photosynthesis
- **Prokaryotic cells** lack a nucleus or other membrane-bound organelles and are generally smaller than eukaryotic cells

- Figure 1.4
- Theme: Life's Processes Involve the Expression and Transmission of Genetic Information
- Chromosomes contain most of a cell's genetic material in the form of **DNA** (deoxyribonucleic acid)
- Figure 1.5
- *DNA, the Genetic Material*
- A DNA molecule holds hundreds or thousands of genes, each a stretch of DNA along the chromosome
- **Genes** are the units of inheritance that transmit information from parents to offspring
- As cells grow and divide, the genetic information encoded by DNA directs their development
- Figure 1.6
- A DNA molecule is made of two long chains (strands) arranged in a double helix
- Each link of a chain is one of four kinds of chemical building blocks called nucleotides, abbreviated A, T, C, and G
- Figure 1.7
- DNA provides blueprints for making proteins, the major players in building and maintaining a cell
- Genes control protein production indirectly, using RNA as an intermediary
- **Gene expression** is the process of converting information from gene to cellular product
- Figure 1.8
- *Genomics: Large-Scale Analysis of DNA Sequences*
- An organism's **genome** is its entire set of genetic instructions
- **Genomics** is the study of sets of genes within and between species
- **Proteomics** refers to the study of sets of proteins and their properties
- The entire set of proteins expressed by a cell or group of cells is called a **proteome**
- "High-throughput" technology refers to tools that can analyze biological samples very rapidly
- **Bioinformatics** is the use of computational tools to store, organize, and analyze the huge volume of data
- Interdisciplinary research teams aim to learn how activities of all proteins and noncoding RNAs are coordinated in cells and whole organisms
- Theme: Life Requires the Transfer and Transformation of Energy and Matter
- Input of energy, mainly from the sun, and transformation of energy from one form to another make life possible
- Plants and other photosynthetic organisms convert the energy of sunlight into the chemical energy of sugars
- This chemical energy of these producers is then passed to consumers that feed on the producers
- Energy flows through an ecosystem, generally entering as light and exiting as heat
- Chemical elements are recycled within an ecosystem
- Figure 1.9
- Theme: Organisms Interact with Other Organisms and the Physical Environment
- Every organism interacts with other organisms and with physical factors in its environment
- Both organisms and their environments are affected by the interactions between them
    - For example, a plant takes up water and minerals from the soil and carbon dioxide from the air; the tree releases oxygen to the air, and roots help form soil
- Interactions between organisms include those that benefit both organisms and those in which both organisms are harmed
- Interactions affect individual organisms and the way that populations evolve over time
- Figure 1.10
- Scientists calculate that the CO_2 that human activities have added to the atmosphere has increased the average temperature of the planet by 1°C since 1900
- **Climate change** is a directional change in global climate that lasts three decades or more
- Climate change has already affected organisms and their habitats all over the planet
- Figure 1.11
- Evolution, the Core Theme of Biology
- Evolution makes sense of everything we know about living organisms
- **Evolution** explains patterns of unity and diversity in living organisms

- Similar traits among organisms are explained by descent from common ancestors
- Differences among organisms are explained by the accumulation of heritable changes
- Concept 1.2: The Core Theme: Evolution accounts for the unity and diversity of life
- The remarkably diverse forms of life on this planet arose by evolutionary processes
- Classifying the Diversity of Life
- Humans group diverse items according to their similarities and relationships to each other
- Careful analysis of form and function has been used to classify life-forms
- New methods of assessing species relationships, especially comparisons of DNA sequences, have led to a reevaluation of larger groupings
- Biologists currently divide the kingdoms of life into three domains: Bacteria, Archaea, and Eukarya
- Domains **Bacteria** and **Archaea** are prokaryotes
- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes three multicellular kingdoms: Plantae, Fungi, and Animalia
    - Plants produce their own food by photosynthesis
    - Fungi absorb nutrients
    - Animals ingest their food
- Figure 1.12
- *Unity in the Diversity of Life*
- A striking unity underlies the diversity of life
- For example, DNA is the universal genetic language common to all organisms
- Similarities between organisms are evident at all levels of the biological hierarchy
- Fossils and other evidence document the evolution of life on Earth over billions of years
- Figure 1.13
- Charles Darwin and the Theory of Natural Selection
- Charles Darwin published *On the Origin of Species by Means of Natural Selection* in 1859
- Darwin made two main points
    - Species showed evidence of “descent with modification” from common ancestors
    - Natural selection is the mechanism behind “descent with modification”
- Darwin’s theory captured the duality of unity and diversity
- Figures 1.14, 1.15
- Darwin observed that
    - Individuals in a population vary in their traits, many of which are heritable
    - More offspring are produced than survive, and competition is inevitable
    - Species generally suit their environment
- Darwin inferred that
    - Individuals that are best suited to their environment are more likely to survive and reproduce
    - Over time, more individuals in a population will have the advantageous traits
- In other words, the environment “selects” for the propagation of beneficial traits
- Darwin called this process **natural selection**
- Figure 1.16-s4
- Videos: Albatross Courtship, Soaring Hawk, Boobies Courtship, Galápagos Islands, Marine Iguana, Sea Lion, Tortoise
- The Tree of Life
- The forelimb of a human, foreleg of a horse, flipper of a whale, and wing of a bat all share a common skeletal architecture
- The shared anatomy of mammalian limbs reflects inheritance of a limb structure from a common ancestor
- The diversity of mammalian limbs results from modification by natural selection over millions of years
- Darwin proposed that natural selection could cause an ancestral species to give rise to two or more descendent species

    - For example, the finch species of the Galápagos Islands are descended from a common ancestor
- Evolutionary relationships are often illustrated with treelike diagrams that show ancestors and their descendants
- Figure 1.17
- Concept 1.3: In studying nature, scientists form and test hypotheses
- The word **science** is derived from a Latin verb meaning "to know"
- **Inquiry** is the search for information and explanation
- The scientific process includes making observations, forming logical hypotheses, and testing them
- Exploration and Discovery
- Biology begins with careful observations
- Biologists describe natural structures and processes
- By reading about and understanding past studies, scientists can build on the foundations of existing knowledge
- Gathering and Analyzing Data
- Recorded observations are called **data**
- Data fall into two categories
    - Qualitative data, or descriptions rather than measurements
        - For example, Jane Goodall's observations of chimpanzee behavior
    - Quantitative data, or recorded measurements, which are sometimes organized into tables and graphs
- Figure 1.18
- **Inductive reasoning** draws conclusions through the logical process of induction
- Through induction, generalizations are drawn from a large number of observations
    - For example, "all organisms are made of cells" was based on two centuries of microscopic observations
- Forming and Testing Hypotheses
- In science, a **hypothesis** is a rational accounting for a set of observations, guided by inductive reasoning
- It is an explanation on trial
- A scientific hypothesis leads to predictions that can be tested with additional observations or an experiment
- An **experiment** is a scientific test, often carried out under controlled conditions
- The initial observations may lead to multiple hypotheses to be tested
- For example
    - Observation: Your desk lamp doesn't work
    - Question: Why doesn't your lamp work?
    - Hypothesis 1: The bulb is burnt out
    - Hypothesis 2: The lamp is broken
- Both these hypotheses are testable
- *Deductive Reasoning*
- **Deductive reasoning** extrapolates from general premises to specific predictions
- The hypothesis is then tested experimentally
- A hypothesis can never be conclusively proven to be true because we can never test all the alternatives
- Hypotheses gain credibility by surviving multiple attempts at falsification, while alternative hypotheses are eliminated by testing
- *Questions That Can and Cannot Be Addressed by Science*
- A hypothesis must be testable and falsifiable
    - For example, hypotheses involving supernatural explanations cannot be tested
- Such explanations are outside the bounds of science
- The Flexibility of the Scientific Process
- Very few scientific studies adhere rigidly to the sequence of steps typically used to describe the scientific method
- Figures 1.19, 1.19-1 through 1.19-8

- *A Case Study in Scientific Inquiry*: Investigating Coat Coloration in Mouse Populations
- Color patterns in animals vary widely in nature, even among members of the same species
- Two mouse populations that reside in different habitats have different coat colors
- What accounts for the "match" between the coat colors of the mice and the color of the sand or soil in their habitats?
- Figure 1.20
- The natural predators of the mice are all visual hunters
- Francis Bertody Sumner hypothesized that the color patterns in the mice had evolved as adaptations that camouflage the mice to protect them from predation
- Recently Hopi Hoekstra and a group of her students tested the predictions of this hypothesis
- Prediction: Mice with coloration that does not match the habitat should suffer heavier predation than the native, well-matched mice
- The group built many models of mice that resembled either beach or inland mice and placed equal numbers of models randomly in both habitats
- The results showed that the camouflaged models suffered much lower rates of predation than the mismatched ones
- Figure 1.21
- Experimental Variables and Controls
- A **controlled experiment** compares an experimental group (the non-camouflaged mice) with a control group (the camouflaged mice)
- The factor that is manipulated and the effect of the factor on the system are both experimental **variables**
- The factor manipulated by the researchers—color—is called the **independent variable**
- The effect of the manipulated factor—amount of predation—is called the **dependent variable**
- Theories in Science
- In the context of science, a **theory** is
    - Broader in scope than a hypothesis
    - General enough to lead to new testable hypotheses
    - Supported by a large body of evidence in comparison to a hypothesis
- Science as a Social Process
- Anyone who becomes a scientist benefits from the rich storehouse of discoveries by others who have come before
- Most scientists work in teams
- Scientists working in the same research field often check one another's claims by attempting to confirm observations or repeat experiments
- The relationship between science and society is clearer when technology is considered
- The goal of **technology** is to apply scientific knowledge for some specific purpose
- Science and technology are interdependent