

Chapter 1

Overview: Inquiring About Life

- An organism's adaptations to its environment are the result of evolution
 - For example, the ghost plant is adapted to conserving water; this helps it to survive in the crevices of rock walls
- **Evolution** is the process of change that has transformed life on Earth
- **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 living things interact in communities?
- Life defies a simple, one-sentence definition
- Life is recognized by what living things do

Concept 1.1: The themes of this book make connections across different areas of biology

- Biology consists of more than memorizing factual details
- Themes help to organize biological information

Theme: New Properties Emerge at Each Level in the Biological Hierarchy

- 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

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

The Power and Limitations of Reductionism

- Reductionism is the reduction of complex systems to simpler components that are more manageable to study
 - For example, studying the molecular structure of DNA helps us to understand the chemical basis of inheritance
- An understanding of biology balances reductionism with the study of emergent properties
 - For example, new understanding comes from studying the interactions of DNA with other molecules

Systems Biology

- A system is a combination of components that function together
- **Systems biology** constructs models for the dynamic behavior of whole biological systems
- The systems approach poses questions such as
 - How does a drug for blood pressure affect other organs?
 - How does increasing CO₂ alter the biosphere?

Theme: Organisms Interact with Other Organisms and the Physical Environment

- Every organism interacts with its environment, including nonliving factors and other organisms
- Both organisms and their environments are affected by the interactions between them

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- For example, a tree 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
- Humans have modified our environment
 - For example, half the human-generated CO₂ stays in the atmosphere and contributes to global warming
- Global warming is a major aspect of **global climate change**
- It is important to understand the effects of global climate change on the Earth and its populations

Theme: Life Requires Energy Transfer and Transformation

- A fundamental characteristic of living organisms is their use of energy to carry out life's activities
- Work, including moving, growing, and reproducing, requires a source of energy
- Living organisms transform energy from one form to another
 - For example, light energy is converted to chemical energy, then kinetic energy
- Energy flows through an ecosystem, usually entering as light and exiting as heat

Theme: Structure and Function Are Correlated at All Levels of Biological

Organization

- Structure and function of living organisms are closely related
 - For example, a leaf is thin and flat, maximizing the capture of light by chloroplasts
 - For example, the structure of a bird's wing is adapted to flight

Theme: The Cell Is an Organism's Basic Unit of Structure and Function

- The cell is the lowest level of organization that can perform all activities required for life
- All cells
 - Are enclosed by a membrane
 - Use DNA as their genetic information
- A **eukaryotic cell** has membrane-enclosed organelles, the largest of which is usually the nucleus
- By comparison, a **prokaryotic cell** is simpler and usually smaller, and does not contain a nucleus or other membrane-enclosed organelles

Theme: The Continuity of Life Is Based on Heritable Information in the Form of DNA

- Chromosomes contain most of a cell's genetic material in the form of **DNA** (deoxyribonucleic acid)
- DNA is the substance of genes
- **Genes** are the units of inheritance that transmit information from parents to offspring
- The ability of cells to divide is the basis of all reproduction, growth, and repair of multicellular organisms

DNA Structure and Function

- Each chromosome has one long DNA molecule with hundreds or thousands of genes
- Genes encode information for building proteins

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- DNA is inherited by offspring from their parents
- DNA controls the development and maintenance of organisms

- Each DNA molecule is made up of two long chains arranged in a double helix
- Each link of a chain is one of four kinds of chemical building blocks called nucleotides and nicknamed A, G, C, and T
- Genes control protein production indirectly
- DNA is transcribed into RNA then translated into a protein
- **Gene expression** is the process of converting information from gene to cellular product

Genomics: Large-Scale Analysis of DNA Sequences

- An organism's **genome** is its entire set of genetic instructions
- The human genome and those of many other organisms have been sequenced using DNA-sequencing machines
- **Genomics** is the study of sets of genes within and between species
- The genomics approach depends on
 - “High-throughput” technology, which yields enormous amounts of data
 - **Bioinformatics**, which is the use of computational tools to process a large volume of data
 - Interdisciplinary research teams

Theme: Feedback Mechanisms Regulate Biological Systems

- Feedback mechanisms allow biological processes to self-regulate
- **Negative feedback** means that as more of a product accumulates, the process that creates it slows and less of the product is produced
- **Positive feedback** means that as more of a product accumulates, the process that creates it speeds up and more of the product is produced

Evolution, the Overarching Theme of Biology

- Evolution makes sense of everything we know about biology
- Organisms are modified descendants of common ancestors

- 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

- “Nothing in biology makes sense except in the light of evolution”—Theodosius Dobzhansky
- Evolution unifies biology at different scales of size throughout the history of life on Earth

Classifying the Diversity of Life

- Approximately 1.8 million species have been identified and named to date, and thousands more are identified each year
- Estimates of the total number of species that actually exist range from 10 million to over 100 million

Grouping Species: The Basic Idea

- Taxonomy is the branch of biology that names and classifies species into groups of

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increasing breadth

- Domains, followed by kingdoms, are the broadest units of classification

The Three Domains of Life

- Organisms are divided into three domains
- Domain **Bacteria** and domain **Archaea** compose the prokaryotes
- Most prokaryotes are single-celled and microscopic
- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes three multicellular kingdoms
 - Plants, which produce their own food by photosynthesis
 - Fungi, which absorb nutrients
 - Animals, which ingest their food
- Other eukaryotic organisms were formerly grouped into the Protist kingdom, though these are now often grouped into many separate groups

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
 - Unity is evident in many features of cell structure

Charles Darwin and the Theory of Natural Selection

- Fossils and other evidence document the evolution of life on Earth over billions of years
- 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 explained the duality of unity and diversity
- 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
- Evolution occurs as the unequal reproductive success of individuals
- In other words, the environment “selects” for the propagation of beneficial traits
- Darwin called this process **natural selection**
- Natural selection results in the adaptation of organisms to their environment
 - For example, bat wings are an example of adaptation

The Tree of Life

- “Unity in diversity” arises from “descent with modification”
 - For example, the forelimb of the bat, human, and horse and the whale flipper all share a common skeletal architecture
- Fossils provide additional evidence of anatomical unity from descent with modification

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- 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

Concept 1.3: In studying nature, scientists make observations and then form and test hypotheses

- The word **science** is derived from Latin and means “to know”
- **Inquiry** is the search for information and explanation
- The scientific process includes making observations, forming logical hypotheses, and testing them

Making Observations

- Biologists describe natural structures and processes
- This approach is based on observation and the analysis of data

Types of Data

- **Data** are recorded observations or items of information; these 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

Inductive Reasoning

- **Inductive reasoning** draws conclusions through the logical process of induction
- Repeating specific observations can lead to important generalizations
 - For example, “the sun always rises in the east”

Forming and Testing Hypotheses

- Observations and inductive reasoning can lead us to ask questions and propose hypothetical explanations called hypotheses

The Role of Hypotheses in Inquiry

- A **hypothesis** is a tentative answer to a well-framed question
- A scientific hypothesis leads to predictions that can be tested by observation or experimentation
- For example,
 - Observation: Your flashlight doesn’t work
 - Question: Why doesn’t your flashlight work?
 - Hypothesis 1: The batteries are dead
 - Hypothesis 2: The bulb is burnt out
- Both these hypotheses are testable

Deductive Reasoning and Hypothesis Testing

- **Deductive reasoning** uses general premises to make specific predictions
- For example, if organisms are made of cells (premise 1), and humans are organisms (premise 2), then humans are composed of cells (deductive prediction)
- Hypothesis-based science often makes use of two or more alternative hypotheses

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- Failure to falsify a hypothesis does not prove that hypothesis
 - For example, you replace your flashlight bulb, and it now works; this supports the hypothesis that your bulb was burnt out, but does not prove it (perhaps the first bulb was inserted incorrectly)

Questions That Can and Cannot Be Addressed by Science

- A hypothesis must be testable and falsifiable
 - For example, a hypothesis that ghosts fooled with the flashlight cannot be tested
- Supernatural and religious explanations are outside the bounds of science

The Flexibility of the Scientific Method

- The scientific method is an idealized process of inquiry
- Hypothesis-based science is based on the “textbook” scientific method but rarely follows all the ordered steps

A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations

- Many poisonous species are brightly colored, which warns potential predators
- Mimics are harmless species that closely resemble poisonous species
- Henry Bates hypothesized that this mimicry evolved in harmless species as an evolutionary adaptation that reduces their chances of being eaten
- This hypothesis was tested with the venomous eastern coral snake and its mimic the nonvenomous scarlet kingsnake
- Both species live in the Carolinas, but the kingsnake is also found in regions without venomous coral snakes
- If predators inherit an avoidance of the coral snake’s coloration, then the colorful kingsnake will be attacked less often in the regions where coral snakes are present

Field Experiments with Artificial Snakes

- To test this mimicry hypothesis, researchers made hundreds of artificial snakes:
 - An experimental group resembling kingsnakes
 - A control group resembling plain brown snakes
- Equal numbers of both types were placed at field sites, including areas without poisonous coral snakes
- After four weeks, the scientists retrieved the artificial snakes and counted bite or claw marks
- The data fit the predictions of the mimicry hypothesis: the ringed snakes were attacked less frequently in the geographic region where coral snakes were found

Experimental Controls and Repeatability

- A **controlled experiment** compares an experimental group (the artificial kingsnakes) with a control group (the artificial brown snakes)
- Ideally, only the variable of interest (the effect of coloration on the behavior of predators) differs between the control and experimental groups
- A controlled experiment means that control groups are used to cancel the effects of unwanted variables
- A controlled experiment does not mean that all unwanted variables are kept constant
- In science, observations and experimental results must be repeatable

Theories in Science

- In the context of science, a **theory** is

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- Broader in scope than a hypothesis
- General, and can lead to new testable hypotheses
- Supported by a large body of evidence in comparison to a hypothesis

Concept 1.4: Science benefits from a cooperative approach and diverse viewpoints

- Most scientists work in teams, which often include graduate and undergraduate students
- Good communication is important in order to share results through seminars, publications, and websites

Building on the Work of Others

- Scientists check each others' claims by performing similar experiments
- It is not unusual for different scientists to work on the same research question
- Scientists cooperate by sharing data about **model organisms** (e.g., the fruit fly *Drosophila melanogaster*)

Science, Technology, and Society

- The goal of science is to understand natural phenomena
- The goal of **technology** is to apply scientific knowledge for some specific purpose
- Science and technology are interdependent
- Biology is marked by “discoveries,” while technology is marked by “inventions”
- The combination of science and technology has dramatic effects on society
 - For example, the discovery of DNA by James Watson and Francis Crick allowed for advances in DNA technology such as testing for hereditary diseases
- Ethical issues can arise from new technology, but have as much to do with politics, economics, and cultural values as with science and technology

The Value of Diverse Viewpoints in Science

- Many important inventions have occurred where different cultures and ideas mix
 - For example, the printing press relied on innovations from China (paper and ink) and Europe (mass production in mills)
- Science benefits from diverse views from different racial and ethnic groups, and from both women and men