Chapter 1 Exploring Life
Lecture Outline

Overview: Biology's Most Exciting Era

- Biology is the scientific study of life.
- You are starting your study of biology during its most exciting era.
- The largest and best-equipped community of scientists in history is beginning to solve problems that once seemed unsolvable.
  - Biology is an ongoing inquiry about the nature of life.
- Biologists are moving closer to understanding:
  - How a single cell develops into an adult animal or plant.
  - How plants convert solar energy into the chemical energy of food.
  - How the human mind works.
  - How living things interact in biological communities.
  - How the diversity of life evolved from the first microbes.
- Research breakthroughs in genetics and cell biology are transforming medicine and agriculture.
  - Neuroscience and evolutionary biology are reshaping psychology and sociology.
  - Molecular biology is providing new tools for anthropology and criminology.
  - New models in ecology are helping society to evaluate environmental issues, such as the causes and biological consequences of global warming.
- Unifying themes pervade all of biology.

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

- Life's basic characteristic is a high degree of order.
- Each level of biological organization has emergent properties.
- Biological organization is based on a hierarchy of structural levels, each building on the levels below.
  - At the lowest level are atoms that are ordered into complex biological molecules.
  - Biological molecules are organized into structures called organelles, the components of cells.

- Cells are the fundamental unit of structure and function of living things.
- Some organisms consist of a single cell; others are multicellular aggregates of specialized cells.
- Whether multicellular or unicellular, all organisms must accomplish the same functions: uptake and processing of nutrients, excretion of wastes, response to environmental stimuli, and reproduction.
  - Multicellular organisms exhibit three major structural levels above the cell: similar cells are grouped into tissues, several tissues coordinate to form organs, and several organs form an organ system.
- For example, to coordinate locomotory movements, sensory information travels from sense organs to the brain, where nervous tissues composed of billions of interconnected neurons—supported by connective tissue—coordinate signals that travel via other neurons to the individual muscle cells.
  - Organisms belong to populations, localized groups of organisms belonging to the same species.
  - Populations of several species in the same area comprise a biological community.
  - Populations interact with their physical environment to form an ecosystem.
  - The biosphere consists of all the environments on Earth that are inhabited by life.

Organisms interact continuously with their environment.

- Each organism interacts with its environment, which includes other organisms as well as nonliving factors.
- Both organism and environment are affected by the interactions between them.
- The dynamics of any ecosystem include two major processes: the cycling of nutrients and the flow of energy from sunlight to producers to consumers.
  - In most ecosystems, producers are plants and other photosynthetic organisms that convert light energy to chemical energy.
  - Consumers are organisms that feed on producers and other consumers.
- All the activities of life require organisms to perform work, and

work requires a source of energy.
  - The exchange of energy between an organism and its environment often involves the transformation of energy from one form to another.
  - In all energy transformations, some energy is lost to the surroundings as heat.
  - In contrast to chemical nutrients, which recycle within an ecosystem, energy flows through an ecosystem, usually entering as light and exiting as heat.

Cells are an organism's basic unit of structure and function.

- The cell is the lowest level of structure that is capable of performing all the activities of life.
  - For example, the ability of cells to divide is the basis of all reproduction and the basis of growth and repair of multicellular organisms.
- Understanding how cells work is a major research focus of modern biology.
- At some point, all cells contain deoxyribonucleic acid, or DNA, the heritable material that directs the cell's activities.
  - DNA is the substance of genes, the units of inheritance that transmit information from parents to offspring.
- Each of us began life as a single cell stocked with DNA inherited from our parents.
  - DNA in human cells is organized into chromosomes.
  - Each chromosome has one very long DNA molecule, with hundreds or thousands of genes arranged along its length.
  - The DNA of chromosomes replicates as a cell prepares to divide.
  - Each of the two cellular offspring inherits a complete set of genes.
- In each cell, the genes along the length of DNA molecules encode the information for building the cell's other molecules.
  - DNA thus directs the development and maintenance of the entire organism.
- Most genes program the cell's production of proteins.
- Each DNA molecule is made up of two long chains arranged in a double helix.
  - Each link of a chain is one of four nucleotides, encoding the cell's information in chemical letters.

- The sequence of nucleotides along each gene codes for a specific protein with a unique shape and function.
  - Almost all cellular activities involve the action of one or more proteins.
  - DNA provides the heritable blueprints, but proteins are the tools that actually build and maintain the cell.
- All forms of life employ essentially the same genetic code.
  - Because the genetic code is universal, it is possible to engineer cells to produce proteins normally found only in some other organism.
- The library of genetic instructions that an organism inherits is called its genome.
  - The chromosomes of each human cell contain about 3 billion nucleotides, including genes coding for more than 70,000 kinds of proteins, each with a specific function.
- Every cell is enclosed by a membrane that regulates the passage of material between a cell and its surroundings.
  - Every cell uses DNA as its genetic material.
- There are two basic types of cells: prokaryotic cells and eukaryotic cells.
- The cells of the microorganisms called bacteria and archaea are prokaryotic.
- All other forms of life have more complex eukaryotic cells.
- Eukaryotic cells are subdivided by internal membranes into various organelles.
  - In most eukaryotic cells, the largest organelle is the nucleus, which contains the cell's DNA as chromosomes.
  - The other organelles are located in the cytoplasm, the entire region between the nucleus and outer membrane of the cell.
- Prokaryotic cells are much simpler and smaller than eukaryotic cells.
  - In a prokaryotic cell, DNA is not separated from the cytoplasm in a nucleus.
  - There are no membrane-enclosed organelles in the cytoplasm.
- All cells, regardless of size, shape, or structural complexity, are highly ordered structures that carry out complicated processes necessary for life.

Concept 1.2 Biological systems are much more than the sum of

their parts

- "The whole is greater than the sum of its parts."
- The combination of components can form a more complex organization called a system.
  - Examples of biological systems are cells, organisms, and ecosystems.
- Consider the levels of life.
  - With each step upward in the hierarchy of biological order, novel properties emerge that are not present at lower levels.
- These emergent properties result from the arrangements and interactions between components as complexity increases.
  - A cell is much more than a bag of molecules.
  - Our thoughts and memories are emergent properties of a complex network of neurons.
- This theme of emergent properties accents the importance of structural arrangement.
- The emergent properties of life are not supernatural or unique to life but simply reflect a hierarchy of structural organization.
  - The emergent properties of life are particularly challenging because of the unparalleled complexity of living systems.
- The complex organization of life presents a dilemma to scientists seeking to understand biological processes.
  - We cannot fully explain a higher level of organization by breaking it down into its component parts.
  - At the same time, it is futile to try to analyze something as complex as an organism or cell without taking it apart.
- Reductionism, reducing complex systems to simpler components, is a powerful strategy in biology.
  - The Human Genome Project—the sequencing of the genome of humans and many other species—is heralded as one of the greatest scientific achievements ever.
  - Research is now moving on to investigate the function of genes and the coordination of the activity of gene products.
- Biologists are beginning to complement reductionism with new strategies for understanding the emergent properties of life—how all of the parts of biological systems are functionally integrated.
- The ultimate goal of systems biology is to model the dynamic behavior of whole biological systems.

    - Accurate models allow biologists to predict how a change in one or more variables will impact other components and the whole system.
- Scientists investigating ecosystems pioneered this approach in the 1960s with elaborate models diagramming the interactions of species and nonliving components in ecosystems.
- Systems biology is now becoming increasingly important in cellular and molecular biology, driven in part by the deluge of data from the sequencing of genomes and our increased understanding of protein functions.
    - In 2003, a large research team published a network of protein interactions within a cell of a fruit fly.
- Three key research developments have led to the increased importance of systems biology.
    1. **High-throughput technology.** Systems biology depends on methods that can analyze biological materials very quickly and produce enormous amounts of data. An example is the automatic DNA-sequencing machines used by the Human Genome Project.
    2. **Bioinformatics.** The huge databases from high-throughput methods require computing power, software, and mathematical models to process and integrate information.
    3. **Interdisciplinary research teams.** Systems biology teams may include engineers, medical scientists, physicists, chemists, mathematicians, and computer scientists as well as biologists.

Regulatory mechanisms ensure a dynamic balance in living systems.

- Chemical processes within cells are accelerated, or catalyzed, by specialized protein molecules, called enzymes.
- Each type of enzyme catalyzes a specific chemical reaction.
    - In many cases, reactions are linked into chemical pathways, each step with its own enzyme.
- How does a cell coordinate its various chemical pathways?
    - Many biological processes are self-regulating: the output or product of a process regulates that very process.
    - In negative feedback, or feedback inhibition, accumulation of an end product of a process slows or stops that process.
- Though less common, some biological processes are regulated by positive feedback, in which an end product speeds up its own production.

- Feedback is common to life at all levels, from the molecular level to the biosphere.

- Such regulation is an example of the integration that makes living systems much greater than the sum of their parts.

Concept 1.3 Biologists explore life across its great diversity of species

- Biology can be viewed as having two dimensions: a "vertical" dimension covering the size scale from atoms to the biosphere and a "horizontal" dimension that stretches across the diversity of life.
  - The latter includes not only present-day organisms, but also those that have existed throughout life's history.

Living things show diversity and unity.

- Life is enormously diverse.
  - Biologists have identified and named about 1.8 million species.
- This diversity includes 5,200 known species of prokaryotes, 100,000 fungi, 290,000 plants, 50,000 vertebrates, and 1,000,000 insects.
- Thousands of newly identified species are added each year.
  - Estimates of the total species count range from 10 million to more than 200 million.
- In the face of this complexity, humans are inclined to categorize diverse items into a smaller number of groups.
  - Taxonomy is the branch of biology that names and classifies species into a hierarchical order.
- Until the past decade, biologists divided the diversity of life into five kingdoms.
- New methods, including comparisons of DNA among organisms, have led to a reassessment of the number and boundaries of the kingdoms.
- Various classification schemes now include six, eight, or even dozens of kingdoms.
- Coming from this debate has been the recognition that there are three even higher levels of classifications, the domains.
  - The three domains are Bacteria, Archaea, and Eukarya.

    - The first two domains, domain Bacteria and domain Archaea, consist of prokaryotes.
- All the eukaryotes are now grouped into various kingdoms of the domain Eukarya.
    - The recent taxonomic trend has been to split the single-celled eukaryotes and their close relatives into several kingdoms.
    - Domain Eukarya also includes the three kingdoms of multicellular eukaryotes: the kingdoms Plantae, Fungi, and Animalia.
- These kingdoms are distinguished partly by their modes of nutrition.
    - Most plants produce their own sugars and food by photosynthesis.
    - Most fungi are decomposers that absorb nutrients by breaking down dead organisms and organic wastes.
    - Animals obtain food by ingesting other organisms.
- Underlying the diversity of life is a striking unity, especially at the lower levels of organization.
    - The universal genetic language of DNA unites prokaryotes and eukaryotes.
    - Among eukaryotes, unity is evident in many details of cell structure.
    - Above the cellular level, organisms are variously adapted to their ways of life.
- How do we account for life's dual nature of unity and diversity?
    - The process of evolution explains both the similarities and differences among living things.

Concept 1.4 Evolution accounts for life's unity and diversity

- The history of life is a saga of a changing Earth billions of years old, inhabited by a changing cast of living forms.
- Charles Darwin brought evolution into focus in 1859 when he presented two main concepts in one of the most important and controversial books ever written, On the Origin of Species by Natural Selection.
- Darwin's first point was that contemporary species arose from a succession of ancestors through "descent with modification."
    - This term captured the duality of life's unity and diversity: unity in the kinship among species that descended from common ancestors and diversity in the modifications that evolved as

species branched from their common ancestors.

- Darwin's second point was his mechanism for descent with modification: natural selection.
- Darwin inferred natural selection by connecting two observations:
    - Observation 1: Individual variation. Individuals in a population of any species vary in many heritable traits.
    - Observation 2: Overpopulation and competition. Any population can potentially produce far more offspring than the environment can support. This creates a struggle for existence among variant members of a population.
    - Inference: Unequal reproductive success. Darwin inferred that those individuals with traits best suited to the local environment would leave more healthy, fertile offspring.
    - Inference: Evolutionary adaptation. Unequal reproductive success can lead to adaptation of a population to its environment. Over generations, heritable traits that enhance survival and reproductive success will tend to increase in frequency among a population's individuals. The population evolves.
- Natural selection, by its cumulative effects over vast spans of time, can produce new species from ancestral species.
    - For example, a population fragmented into several isolated populations in different environments may gradually diversify into many species as each population adapts over many generations to different environmental problems.
- Fourteen species of finches found on the Galápagos Islands diversified after an ancestral finch species reached the archipelago from the South American mainland.
    - Each species is adapted to exploit different food sources on different islands.
- Biologists' diagrams of evolutionary relationships generally take a treelike form.
- Just as individuals have a family tree, each species is one twig of a branching tree of life.
    - Similar species like the Galápagos finches share a recent common ancestor.
    - Finches share a more distant ancestor with all other birds.
    - The common ancestor of all vertebrates is even more ancient.
    - Trace life back far enough, and there is a shared ancestor of all living things.

- All of life is connected through its long evolutionary history.

Concept 1.5 Biologists use various forms of inquiry to explore life

- The word science is derived from a Latin verb meaning "to know."
- At the heart of science is inquiry, people asking questions about nature and focusing on specific questions that can be answered.
- The process of science blends two types of exploration: discovery science and hypothesis-based science.
  - Discovery science is mostly about discovering nature.
  - Hypothesis-based science is mostly about explaining nature.
  - Most scientific inquiry combines the two approaches.
- Discovery science describes natural structures and processes as accurately as possible through careful observation and analysis of data.
  - Discovery science built our understanding of cell structure and is expanding our databases of genomes of diverse species.
- Observation is the use of the senses to gather information, which is recorded as data.
- Data can be qualitative or quantitative.
  - Quantitative data are numerical measurements.
  - Qualitative data may be in the form of recorded descriptions.
  - Jane Goodall has spent decades recording her observations of chimpanzee behavior during field research in Gambia.
- She has also collected volumes of quantitative data over that time.
- Discovery science can lead to important conclusions based on inductive reasoning.
  - Through induction, we derive generalizations based on a large number of specific observations.
- In science, inquiry frequently involves the proposing and testing of hypotheses.
  - A hypothesis is a tentative answer to a well-framed question.
- It is usually an educated postulate, based on past experience and the available data of discovery science.
- A scientific hypothesis makes predictions that can be tested by recording additional observations or by designing experiments.
- A type of logic called deduction is built into hypothesis-based science.

- In deductive reasoning, reasoning flows from the general to the specific.
- From general premises, we extrapolate to a specific result that we should expect if the premises are true.

- In hypothesis-based science, deduction usually takes the form of predictions about what we should expect if a particular hypothesis is correct.
  - We test the hypothesis by performing the experiment to see whether or not the results are as predicted.
  - Deductive logic takes the form of "If . . . then" logic.
- Scientific hypotheses must be testable.
  - There must be some way to check the validity of the idea.
- Scientific hypotheses must be falsifiable.
  - There must be some observation or experiment that could reveal if a hypothesis is actually not true.
- The ideal in hypothesis-based science is to frame two or more alternative hypotheses and design experiments to falsify them.
- No amount of experimental testing can prove a hypothesis.
- A hypothesis gains support by surviving various tests that could falsify it, while testing falsifies alternative hypotheses.
- Facts, in the form of verifiable observations and repeatable experimental results, are the prerequisites of science.

We can explore the scientific method.

- There is an idealized process of inquiry called the scientific method.
  - Very few scientific inquiries adhere rigidly to the sequence of steps prescribed by the textbook scientific method.
  - Discovery science has contributed a great deal to our understanding of nature without most of the steps of the so-called scientific method.
- We will consider a case study of scientific research.
- This case begins with a set of observations and generalizations from discovery science.
- Many poisonous animals have warning coloration that signals danger to potential predators.
  - Imposter species mimic poisonous species, although they are harmless.
  - An example is the bee fly, a nonstinging insect that mimics a honeybee.

- What is the function of such mimicry? What advantage does it give the mimic?
- In 1862, Henry Bates proposed that mimics benefit when predators mistake them for harmful species.
  - This deception may lower the mimic's risk of predation.
- In 2001, David and Karin Pfennig and William Harcombe of the University of North Carolina designed a set of field experiments to test Bates's mimicry hypothesis.
- In North and South Carolina, a poisonous snake called the eastern coral snake has warning red, yellow, and black coloration.
- Predators avoid these snakes. It is unlikely that predators learn to avoid coral snakes, as a strike is usually lethal.
- Natural selection may have favored an instinctive recognition and avoidance of the warning coloration of the coral snake.
- The nonpoisonous scarlet king snake mimics the ringed coloration of the coral snake.
- Both king snakes and coral snake live in the Carolinas, but the king snake's range also extends into areas without coral snakes.
- The distribution of these two species allowed the Pfennigs and Harcombe to test a key prediction of the mimicry hypothesis.
  - Mimicry should protect the king snake from predators, but only in regions where coral snakes live.
  - Predators in non–coral snake areas should attack king snakes more frequently than predators that live in areas where coral snakes are present.
- To test the mimicry hypothesis, Harcombe made hundreds of artificial snakes.
  - The experimental group had the red, black, and yellow ring pattern of king snakes.
  - The control group had plain, brown coloring.
- Equal numbers of both types were placed at field sites, including areas where coral snakes are absent.
- After four weeks, the scientists retrieved the fake snakes and counted bite or claw marks.
  - Foxes, coyotes, raccoons, and black bears attacked snake models.
- The data fit the predictions of the mimicry hypothesis.
  - The ringed snakes were attacked by predators less frequently than the brown snakes only within the geographic range of the coral snakes.

- The snake mimicry experiment provides an example of how scientists design experiments to test the effect of one variable by canceling out the effects of unwanted variables.
  - The design is called a controlled experiment.
  - An experimental group (artificial king snakes) is compared with a control group (artificial brown snakes).
  - The experimental and control groups differ only in the one factor the experiment is designed to test—the effect of the snake's coloration on the behavior of predators.
  - The brown artificial snakes allowed the scientists to rule out such variables as predator density and temperature as possible determinants of number of predator attacks.
- Scientists do not control the experimental environment by keeping all variables constant.
  - Researchers usually "control" unwanted variables, not by eliminating them but by canceling their effects using control groups.

Let's look at the nature of science.

- There are limitations to the kinds of questions that science can address.
- These limits are set by science's requirements that hypotheses are testable and falsifiable and that observations and experimental results be repeatable.
- The limitations of science are set by its naturalism.
  - Science seeks natural causes for natural phenomena.
  - Science cannot support or falsify supernatural explanations, which are outside the bounds of science.
- Everyday use of the term theory implies an untested speculation.
- The term theory has a very different meaning in science.
- A scientific theory is much broader in scope than a hypothesis.
  - This is a hypothesis: "Mimicking poisonous snakes is an adaptation that protects nonpoisonous snakes from predators."
  - This is a theory: "Evolutionary adaptations evolve by natural selection."
- A theory is general enough to generate many new, specific hypotheses that can be tested.
- Compared to any one hypothesis, a theory is generally supported by a much more massive body of evidence.

- The theories that become widely adopted in science (such as the theory of adaptation by natural selection) explain many observations and are supported by a great deal of evidence.
- In spite of the body of evidence supporting a widely accepted theory, scientists may have to modify or reject theories when new evidence is found.
  - As an example, the five-kingdom theory of biological diversity eroded as new molecular methods made it possible to test some of the hypotheses about the relationships between living organisms.
- Scientists may construct models in the form of diagrams, graphs, computer programs, or mathematical equations.
  - Models may range from lifelike representations to symbolic schematics.
- Science is an intensely social activity.
  - Most scientists work in teams, which often include graduate and undergraduate students.
- Both cooperation and competition characterize scientific culture.
  - Scientists attempt to confirm each other's observations and may repeat experiments.
  - They share information through publications, seminars, meetings, and personal communication.
  - Scientists may be very competitive when converging on the same research question.
- Science as a whole is embedded in the culture of its times.
  - For example, recent increases in the proportion of women in biology have had an impact on the research being performed.
- For instance, there has been a switch in focus in studies of the mating behavior of animals from competition among males for access to females to the role that females play in choosing mates.
  - Recent research has revealed that females prefer bright coloration that "advertises" a male's vigorous health, a behavior that enhances a female's probability of having healthy offspring.
- Some philosophers of science argue that scientists are so influenced by cultural and political values that science is no more objective than other ways of "knowing nature."
  - At the other extreme are those who view scientific theories as though they were natural laws.
- The reality of science is somewhere in between.

- The cultural milieu affects scientific fashion, but need for repeatability in observation and hypothesis testing distinguishes science from other fields.
- If there is "truth" in science, it is based on a preponderance of the available evidence.

Science and technology are functions of society.

- Although science and technology may employ similar inquiry patterns, their basic goals differ.
  - The goal of science is to understand natural phenomena.
  - Technology applies scientific knowledge for some specific purpose.
- Technology results from scientific discoveries applied to the development of goods and services.
- Scientists put new technology to work in their research.
- Science and technology are interdependent.
- The discovery of the structure of DNA by Watson and Crick sparked an explosion of scientific activity.
  - These discoveries made it possible to manipulate DNA, enabling genetic technologists to transplant foreign genes into microorganisms and mass-produce valuable products.
  - DNA technology and biotechnology have revolutionized the pharmaceutical industry.
  - They have had an important impact on agriculture and the legal profession.
- The direction that technology takes depends less on science than it does on the needs of humans and the values of society.
  - Debates about technology center more on "should we do it" than "can we do it."
- With advances in technology come difficult choices, informed as much by politics, economics, and cultural values as by science.
- Scientists should educate politicians, bureaucrats, corporate leaders, and voters about how science works and about the potential benefits and hazards of specific technologies.

Concept 1.6 A set of themes connects the concepts of biology

- In some ways, biology is the most demanding of all sciences, partly because living systems are so complex and partly because biology is a multidisciplinary science that requires knowledge of chemistry, physics, and mathematics.

- Biology is also the science most connected to the humanities and social sciences.
-