Chapter 1

Introduction: Themes in the Study of Life

Lecture Outline

Overview: Inquiring About Life

- Organisms are adapted to the environments they live in.
- These adaptations are the result of **evolution**, the fundamental organizing principle of biology and the core theme of this book.
- Posing questions about the living world and seeking science-based answers are the central activities of **biology**, the scientific study of life.
- Biologists ask a wide variety of ambitious questions.
    - They may ask how a single cell becomes a tree or a dog, how the human mind works, or how the living things in a forest interact.
- Biologists can help answer questions that affect our lives in practical ways.
- What is life?
    - The phenomenon of life defies a simple, one-sentence definition.
    - We recognize life by what living things do.

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

- Eight unifying themes will help you organize and make sense of biological information.

Theme 1: New properties emerge at each level in the biological hierarchy.

- 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 make up populations, localized groups of organisms belonging to the same species.
  - Populations of several species in the same area combine to form 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.
- As we move from the molecular level to the biosphere, novel emergent properties arise at each level, properties that are not present at the preceding level.
  - **Emergent properties** are created by new arrangements and interactions of parts as complexity increases.
  - For example, photosynthesis can take place only when molecules are arranged in a specific way in an intact chloroplast.
  - If a serious head injury disrupts the intricate architecture of a human brain, the mind may cease to function properly even though all of the brain tissues are still present.
  - The cycling of chemical elements at the ecosystem level depends on a network of diverse organisms interacting with each other and with the soil, water, and air.
- Emergent properties are not unique to life: a set of bicycle parts won't take you anywhere, but if they are arranged in a certain way, you can pedal to your chosen destination on a working bicycle.
  - Compared to such nonliving examples, however, the unrivaled complexity of biological systems makes the emergent properties of life especially challenging to study.

Reductionism is a powerful strategy in biology.

- Reductionism is the approach of reducing complex systems to simpler components that are more manageable to study.
  - Biologists must balance the reductionist strategy with the larger-scale, holistic objective of understanding the emergent properties of life—how all the parts of biological systems are functionally integrated.
- Biologists are beginning to complement reductionism with new strategies for studying whole systems.
  - The ultimate goal of **systems biology** is to model the dynamic behavior of whole biological systems based on a study of the interactions among the system's parts.
  - Successful models allow biologists to predict how a change in one or more variables will affect other components as well as the whole system.
- The systems approach enables scientists to pose new kinds of questions.
  - How might a drug that lowers blood pressure affect the functions of organs throughout the human body?
  - How might increasing a crop's water supply affect processes in the plants, such as the storage of molecules essential for human nutrition?
  - How might a gradual increase in atmospheric carbon dioxide alter ecosystems and the entire biosphere?
- The ultimate aim of systems biology is to answer large-scale questions like the last one.
- Scientists investigating ecosystems pioneered the systems approach in the 1960s with elaborate models diagramming the interactions of species and nonliving components in ecosystems such as salt marshes.
- Systems biology is now becoming increasingly important in cellular and molecular biology.

Theme 2: Organisms interact with other organisms and the physical environment.

- Each organism interacts with its environment, which includes both other organisms and physical factors.
- Both organism and environment are affected by the interactions between them.
  - A plant takes up water and minerals from the soil through its roots, and its roots help form soil by breaking up rocks.
  - On a global scale, plants and other photosynthetic organisms have generated all the oxygen in the air.
- A tree also interacts with other organisms, such as soil microorganisms associated with its roots, insects that live in the tree, and animals that eat its leaves and fruit.
- Interactions between organisms ultimately result in the cycling of nutrients in ecosystems.
  - The minerals acquired by a tree are eventually returned to the soil by organisms that decompose leaf litter, dead roots, and other organic debris.
  - The minerals are then available to be taken up by plants again.
- Humans also interact with our environment, sometimes with drastic consequences.
  - Since the Industrial Revolution in the 1800s, the burning of fossil fuels (coal, oil, and gas) has been increasing at an ever-accelerating pace.
  - This releases gaseous compounds into the atmosphere, including huge amounts of carbon dioxide (CO_2).
- About half the human-generated CO_2 stays in the atmosphere, absorbing heat from the sun and acting like a reflective blanket over the planet that prevents heat from radiating into outer space.
  - Scientists estimate the average temperature of the planet has risen 1°C since 1900 due to this "greenhouse effect," and they project a possible additional 5°C to 10°C increase in parts of the Arctic over the course of the 21st century.
- This global warming, a major aspect of **global climate change**, has already had dire effects on life forms and their habitats all over planet Earth.
  - Polar bears have lost much of the ice platform from which they hunt, some small rodents and plant species have shifted their ranges to higher altitudes, bird populations have altered their migration schedules, and in several ecosystems, predator populations have declined as their prey has disappeared.
- Only time will reveal the consequences of these and other changes. Scientists predict that even if we stopped burning fossil fuels today, it would take several centuries to return to pre-industrial CO_2 levels.
- We must learn all we can about the effects of global climate change on the Earth and its populations.

Theme 3: Life requires energy transfer and transformation.

- The input of energy from the sun makes life possible: a fundamental characteristic of living organisms is their use of energy to carry out life's activities.
- Living organisms often transform one form of energy to another.
  - Chlorophyll molecules within the tree's leaves harness the energy of sunlight and use it to drive photosynthesis, converting water and carbon dioxide to sugar and oxygen.
  - The chemical energy in sugar is then passed along by plants and other photosynthetic organisms (producers) to consumers.
  - Consumers are organisms, such as animals, that feed on producers and other consumers.
- An animal's muscle cells use sugar as fuel to power movements, converting chemical energy to kinetic energy, the energy of motion.

  - The cells in a leaf use sugar to drive the process of cell division during leaf growth, transforming stored chemical energy into cellular work.
- In every energy transformation, some energy is converted to thermal energy, which dissipates to the surroundings as heat.
- While chemical nutrients recycle within an ecosystem, energy flows through an ecosystem, usually entering as light and exiting as heat.

Theme 4: Structure and function are correlated at all levels of biological organization.

- Form fits function; how a device works is correlated with its structure.
  - Applied to biology, this theme is a guide to the anatomy of life at all its structural levels.
  - For example, the thin, flat shape of a leaf maximizes the amount of sunlight that can be captured by its chloroplasts.

Theme 5: Cells are an organism's basic units of structure and function.

- The cell is the lowest level of structure that can perform all the activities of life.
- The activities of organisms are all based on cell activities.
- Understanding how cells work is a major research focus of modern biology.
- All cells share certain characteristics.
  - Every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings.
  - Every cell uses DNA as its genetic information.
- There are two basic types of cells: prokaryotic cells and eukaryotic cells.
  - The cells of the two groups of microorganisms called bacteria and archaea are prokaryotic.
  - All other forms of life have more complex eukaryotic cells.
- A **eukaryotic cell** is subdivided by internal membranes into various membrane-enclosed 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 the 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.
- Whether an organism has prokaryotic or eukaryotic cells, its properties depend on the structure and function of its cells.

Theme 6: The continuity of life is based on heritable information in the form of DNA.

- The division of cells to form new cells is the foundation for all reproduction and for the growth and repair of multicellular organisms.
- Inside the dividing cells is 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.
- 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 genes encode the information necessary to build other molecules in the cell, including the proteins that are responsible for carrying out most of the work of a cell.

- The DNA of chromosomes replicates as a cell prepares to divide.
    - Each of the two cellular offspring inherits a complete set of genes with information identical to that of the parent cell.
- Each of us began life as a single cell stocked with DNA inherited from our parents.
    - Replication of that DNA with each round of cell division transmitted copies of those genes to our trillions of cells.
- In each cell, the genes along the length of DNA molecules encode the information for building the cell's other molecules.
    - DNA is a central database that directs the development and maintenance of the entire organism.
- Each DNA molecule is made up of two long chains, called strands, arranged in a double helix.
    - Each chain is made up of four kinds of nucleotides called A, G, C, and T.
- We can think of nucleotides as a four-letter alphabet of inheritance.
    - Specific sequential arrangements of these four nucleotide letters encode the precise information in genes, which are typically hundreds or thousands of nucleotides long.
- DNA provides the blueprints for making proteins, and proteins serve as the tools that actually build and maintain the cell and carry out its activities.
    - For instance, the information carried in a bacterial gene may specify a certain protein in a bacterial cell membrane, while the information in a human gene may denote a protein hormone that stimulates growth.
    - Other human proteins include proteins in a muscle cell that drive contraction and the defensive proteins called antibodies.
    - Enzymes, which catalyze (speed up) specific chemical reactions, are mostly proteins and are crucial to all cells.
- DNA controls protein production indirectly, using a related kind of molecule called RNA as an intermediary.
    - The sequence of nucleotides along a gene is transcribed into RNA, which is then translated into a specific protein with a unique shape and function.
    - This entire process, by which the information in a gene is converted into a cellular product, is called **gene expression**.
- In translating genes to proteins, all forms of life employ essentially the same genetic code.
    - A particular sequence of nucleotides says the same thing to one organism as it says to another.
- Recently, scientists have discovered whole new classes of RNA that are not translated into protein.
    - Some RNA molecules regulate the functioning of protein-coding genes.

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 about 75,000 kinds of proteins, each with a specific function.
- The entire sequence of nucleotides in the human genome is now known.
    - Scientists have also learned the genome sequences of many other organisms, including bacteria, archaea, fungi, plants, and animals.

- The sequencing of the human genome was a major scientific and technological achievement.
  - The challenge now is to learn how the activities of the proteins encoded by DNA are coordinated in cells and organisms.
- 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 the growing catalog of known protein functions.
- Rather than investigating a single gene at a time, researchers have shifted to studying whole sets of genes of a species as well as comparing genomes between species—an approach called **genomics**.
- 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 the use of computational tools to store, organize, and analyze the huge volume of data.
  3. **Interdisciplinary research teams.** Systems biology teams may include engineers, medical scientists, physicists, chemists, mathematicians, and computer scientists as well as biologists.

Theme 7: Feedback mechanisms regulate biological 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, with each step having 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 same process.
- In **negative feedback**, the accumulation of an end product of a process slows down that process.
  - For example, the cell's breakdown of sugar generates chemical energy in the form of a substance called ATP.
  - When a cell makes more ATP than it can use, the excess ATP "feeds back" and inhibits an enzyme near the beginning of the pathway
- Though less common, some biological processes are regulated by **positive feedback**, in which an end product *speeds up* its own production.
  - The clotting of blood in response to injury is an example.
  - When a blood vessel is damaged, structures in the blood called platelets begin to aggregate at the site.
  - Positive feedback occurs as chemicals released by the platelets attract *more* platelets.
  - The platelet pileup then initiates a complex process that seals the wound with a clot.
- Feedback is common to life at all levels, from the molecular level to the biosphere.
- Regulation via feedback is an example of the integration that makes living systems much more than the sum of their parts.

Theme 8: Evolution is the overarching theme of biology.

- Life has been evolving on Earth for billions of years, resulting in a vast diversity of past and present organisms.

- At the same time, living things share certain features.
- The scientific explanation for this unity and diversity—and for the suitability of organisms for their environments—is evolution: the idea that the organisms living on Earth today are the modified descendants of common ancestors.
  - In other words, scientists can explain traits shared by two organisms with the idea that they have descended from a common ancestor, and scientists can account for differences with the idea that heritable changes have occurred along the way.

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

- Evolutionary biologist Theodosius Dobzhansky said, "Nothing in biology makes sense except in the light of evolution."

Living things show both diversity and unity.

- Life is enormously diverse.
  - Biologists have identified and named about 1.8 million species.
  - These species include 100,000 fungi, 290,000 plants, 52,000 vertebrates, and 1,000,000 insects, as well as myriad single-celled organisms.
- Thousands of newly identified species are added each year.
  - Estimates of the total species count range from 10 million to over 100 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.
- Historically, scientists have classified the diversity of life forms into kingdoms and finer groupings.
- New research methods, including comparisons of DNA among organisms, have led to an ongoing reevaluation of the number and boundaries of living kingdoms.
  - Various classification schemes have proposed anywhere from six kingdoms to dozens of kingdoms.
- This debate has brought about the recognition that there are three even higher levels of classification: the domains Bacteria, Archaea, and Eukarya.
- The first two domains, **domain Bacteria** and **domain Archaea**, consist of prokaryotes.
  - Most prokaryotes are single-celled and microscopic.
- All the eukaryotes are now grouped in **domain Eukarya**.
- Domain Eukarya includes the three kingdoms of multicellular eukaryotes, Plantae, Fungi, and Animalia, distinguished partly by their modes of nutrition.
  - Most plants produce their own sugars and other food molecules by photosynthesis.
  - Most fungi absorb dissolved nutrients from their surroundings. Many fungi decompose dead organisms and organic wastes (such as leaf litter and animal feces) and absorb nutrients from these sources.
  - Animals obtain food by ingesting other organisms.
- Neither animals, plants, nor fungi are as numerous or diverse as the single-celled eukaryotes we call protists.

- Once placed in a single kingdom, biologists now realize that protists do not form a single natural group of species.
- Some protist groups are more closely related to multicellular eukaryotes such as animals and fungi than they are to each other.
- The recent taxonomic trend has been to split the protists into several groups.

- Underlying the diversity of life is a striking unity, especially at the molecular and cellular levels of organization.
  - The universal genetic language of DNA unites prokaryotes and eukaryotes.
  - Among the eukaryotes, unity is evident in many details of cell structure.
- How do scientists account for life's dual nature of unity and diversity?
  - The process of evolution explains both the similarities and differences among living things.
- The history of life is the saga of a changing Earth, billions of years old, inhabited by an evolving cast of living forms.
- Charles Robert Darwin brought evolution into focus in 1859 when he presented two main points in one of the most important and influential books ever written, *On the Origin of Species by Means of Natural Selection.*
- Darwin's first point was that contemporary species arose from a succession of ancestors through "descent with modification."
  - This phrase 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 a proposed mechanism for descent with modification: natural selection.
- Darwin started with three observations from nature.
  - Individuals in a population of any species vary in many heritable traits.
  - A population can potentially produce far more offspring than the environment can support; therefore, competition is inevitable.
  - Species generally are suited to, or adapted to, their environments.
- Darwin made inferences from these observations to arrive at his theory of evolution.
  - Individuals with inherited traits that are best suited to the local environment will produce more healthy, fertile offspring than less well-suited individuals.
  - Over many generations, heritable traits that enhance survival and reproductive success will tend to increase in frequency among a population's individuals.
  - Evolution occurs as the unequal reproductive success of individuals ultimately leads to adaptation to their environment, as long as the environment remains unchanged.
- Darwin called this mechanism of evolutionary adaptation **natural selection** because the natural environment "selects" for the propagation of certain traits among naturally occurring variant traits in the population.
- The unity of mammalian limb anatomy reflects inheritance of that structure from a common ancestor—the "prototype" mammal from which all other mammals descended.
  - The diversity of mammalian forelimbs results from modification by natural selection operating over millions of generations in different environmental contexts.
  - Fossils and other evidence corroborate anatomical unity in supporting this view of mammalian descent from a common ancestor.

- 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 West Indies.
  - Each species adapted to exploit different food sources on different islands.
- Researchers use anatomical and geographic data and more recently DNA sequence comparisons to sort out the relationships among the finch species.
  - 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 relatively recent common ancestor.
  - Finches share a more distant ancestor with all other birds.
  - The common ancestor of all vertebrates is even more ancient.
- If life is traced back far enough, all living things have a common ancestor.
  - All of life is connected through its long evolutionary history.

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

- The word *science* is derived from a Latin verb meaning "to know."
- **Science** is a way of knowing—an approach to understanding the natural world.
- At the heart of science is **inquiry**, asking questions about nature and focusing on specific questions that can be answered.
- As scientists, biologists attempt to understand how natural phenomena work using a process of inquiry that includes making observations, forming logical hypotheses, and testing them.
  - The process is necessarily repetitive: in testing a hypothesis, more observations are made that may force outright rejection of the hypothesis or revision and further testing.
  - This process allows biologists to get closer to their best estimation of the laws governing nature.

Scientists plan careful observations.

- Biologists describe natural structures and processes as accurately as possible through careful observation and analysis of data.
  - The observations are often valuable in their own right.
  - For example, a series of detailed observations have built our understanding of cell structure, and are currently expanding our databases of genomes of diverse species.
- Recorded observations are called **data**, items of information on which scientific inquiry is based.
- *Data* can be qualitative or quantitative.
  - *Qualitative data* may be in the form of recorded descriptions.
  - For example, Jane Goodall has spent decades recording qualitative data in the form of her observations of chimpanzee behavior during field research in Tanzania.
  - Jane Goodal has also collected volumes of *quantitative data,* which are generally recorded as measurements.

Observations can lead to important conclusions based on inductive reasoning.

- Through **induction**, scientists derive generalizations based on a large number of specific observations.
- Observations and inductive reasoning stimulate scientists to seek natural causes and explanations for those observations.
- In science, inquiry usually involves proposing and testing of hypotheses.
  - In science, a **hypothesis** is a tentative answer to a well-framed question.
  - It is usually a rational accounting for a set of observations, based on the available data and guided by inductive reasoning.
  - A scientific hypothesis leads to predictions that can be tested by recording additional observations or by performing experiments.

A type of logic called deduction is built into hypothesis-based science.

- In **deductive reasoning**, logic flows from the general to the specific.
  - From general premises, scientists extrapolate to a specific result that should be expected if the premises are true.
- In hypothesis-based science, deduction usually takes the form of predictions about what scientists should expect if a particular hypothesis is correct.
  - Scientists test the hypothesis by performing the experiment to see whether or not the results are as predicted.
  - Deductive logic takes the form *"If… then…"*
- 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, because it is impossible to test *all* alternative hypotheses.
  - A hypothesis gains support by surviving various tests that could falsify it; testing falsifies alternative hypotheses.
- Not all hypotheses meet the criteria of science.
  - Because science requires natural explanations for natural phenomena, it can neither support nor falsify hypotheses that angels, ghosts, or spirits, whether benevolent or evil, cause storms, rainbows, illnesses, and cures.
  - Such supernatural explanations are simply outside the bounds of science, as are religious matters, which are issues of personal faith.

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.

- We will consider a case study of scientific research that begins with a set of observations and inductive generalizations.
- Many poisonous animals have warning coloration that signals danger to potential predators.
  - Imposter species mimic poisonous species, although they are harmless.
  - 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 of the University of North Carolina, together with undergraduate William Harcombe, designed a set of field experiments to test Bates' mimicry hypothesis.
- In North and South Carolina, a venomous snake called the eastern coral snake has warning coloration: alternating rings of red, yellow (or white), and black coloration.
  - Predators avoid coral snakes.
  - It is unlikely that predators learn to avoid coral snakes because 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 kingsnake mimics the ringed coloration of the coral snake.
- Both kingsnakes and coral snake live in North and South Carolina, but the kingsnake's range also extends into areas that have no coral snakes.
- The geographic distribution of these two species allowed the Pfennigs and Harcombe to test a key prediction of the mimicry hypothesis.
  - Mimicry should protect the kingsnake from predators, but *only* in regions where coral snakes live.
  - Predators in areas with no coral snakes should attack kingsnakes more frequently than predators 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 white ring pattern of kingsnakes.
  - The *control group* had plain brown coloring.
- Equal numbers of both types of artificial snakes were placed at field sites, including areas without coral snakes.
- After four weeks, the scientists retrieved the fake snakes and counted bite or claw marks made by foxes, coyotes, raccoons, and black bears.
- The data fit the predictions of the mimicry hypothesis: The ringed snakes were attacked by predators less frequently than the brown snakes *only* in 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 kingsnakes) is compared with a control group (brown artificial 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 artificial brown snakes allowed the scientists to rule out such variables as predator density and temperature as possible determinants of the number of predator attacks.

- A common misconception is that the term *controlled experiment* means that scientists control the experimental environment to keep everything constant except the one variable being tested.
    - Researchers usually “control” unwanted variables, not by *eliminating* them, but by *canceling* their effects using control groups.
- Another hallmark of science is that the observations and experimental results must be repeatable.
- Observations that can’t be verified may be interesting or even entertaining, but they cannot count as evidence in scientific inquiry.
    - The scientists who investigated snake mimicry in the Carolinas obtained similar data when they repeated their experiments with different species of coral snakes and kingsnakes in Arizona.
    - *You* should be able to obtain similar results if you were to repeat the snake experiments.
- The everyday use of the term *theory* implies an untested speculation; *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.
    - For example, the theory of biological diversity that lumped bacteria and archaea together as a kingdom of prokaryotes was abandoned when new methods for comparing cells and molecules allowed testing of hypothetical relationships between organisms based on the theory.
- If there is “truth” in science, it is conditional, based on the preponderance of available evidence.

Concept 1.4 Science benefits from a cooperative approach and diverse viewpoints

- Science is an intensely social activity.
    - Most scientists work in teams, which often include graduate and undergraduate students.
    - To succeed in science, it helps to be a good communicator.
    - Research results have no impact until shared with a community of peers through seminars, publications, and websites.
- Both cooperation and competition characterize scientific culture.
- Scientists attempt to confirm each other’s observations and may repeat experiments.
    - If experimental results are unable to be repeated by scientific colleagues, this may reflect some underlying weakness in the original claim, which will then have to be revised.
- In a sense, science polices itself.
    - Integrity and adherence to honesty and high professional standards when reporting results are central to the scientific endeavor.
    - After all, the validity of experimental data is key to designing further lines of inquiry.

- Scientists may be very competitive when focusing on the same research question.
  - Some scientists enjoy the challenge of being first with an important discovery or key experiment, while others derive more satisfaction from cooperating with fellow scientists working on the same problem.
- Scientists also cooperate by sharing data about **model organisms**—organisms that are easy to grow in the lab and lend themselves to the study of particular questions.
  - Because all organisms are evolutionarily related, lessons learned from a model organism are often applicable to a much wider group.
  - For example, genetic studies of the fruit fly *Drosophila melanogaster* have taught us a lot about how genes work in other species, including humans.
  - Some other popular model organisms are the mustard plant *Arabidopsis thaliana*, the soil worm *Caenorhabditis elegans*, the zebrafish *Danio rerio*, the mouse *Mus musculus*, and the bacterium *Escherichia coli*.
- 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 natural laws, not human interpretations of nature.
  - The reality of science is somewhere in between.
  - The cultural milieu affects scientific fashion, but the need to replicate observations and hypothesis testing distinguishes science from other fields.

Both science and technology are functions of society.

- Although both science and technology employ similar inquiry patterns, their basic goals differ.
  - The goal of science is to understand natural phenomena.
  - In contrast, **technology** *applies* scientific knowledge for some specific purpose.
- Biologists and other scientists often speak of "discoveries," while engineers and other technologists more often speak of "inventions."
  - Scientists benefit from inventions as they put new technology to work in their research.
  - Science and technology are thus interdependent.
- The discovery of the structure of DNA by Watson and Crick sparked an explosion of scientific activity.
  - Many technologies of DNA engineering are transforming applied fields, including medicine, agriculture, and forensics.
- The direction that technology takes depends less on science than on the needs of humans and the values of society.
  - Debates about technology focus more on "*Should* we do it?" than on "*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.

Diverse viewpoints have value in science.

- Science gains much from embracing a diversity of backgrounds and viewpoints among its practitioners.
- Science in the U.S. and Europe has, until recently, been carried out primarily by men.

- Over the past 50 years, changing attitudes about career choices have increased the proportion of women in biology and some other sciences.
- The pace has been slow, and women and many racial and ethnic groups are still underrepresented in many scientific professions.