Overview: Inquiring About the World of Life

- **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 a single cell develops into an organism
  - How the human mind works
  - How living things interact in communities
• Life defies a simple, one-sentence definition
• Life is recognized by what living things do
- Order
- Evolutionary adaptation
- Response to the environment
- Regulation
- Energy processing
- Reproduction
- Growth and development
Concept 1.1: Themes connect the concepts of biology

- Biology consists of more than memorizing factual details
- Themes help to organize biological information
Evolution, the Overarching Theme of Biology

• Evolution makes sense of everything we know about living organisms

• Organisms living on Earth are modified descendents of common ancestors
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
The Power and Limitations of Reductionism

• Reductionism is the reduction of complex systems to simpler components that are more manageable to study
  – For example, the molecular structure of DNA

• Often for the sake of simplicity and understanding, biologists and other scientists generalize in order to facilitate understanding.
Theme: Organisms interact with their environments, exchanging matter and energy

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

- The dynamics of an ecosystem include two major processes:
  - Cycling of nutrients, in which materials acquired by plants eventually return to the soil
  - The flow of energy from sunlight to producers to consumers
Fig. 1-5

Ecosystem

Cycling of chemical nutrients

Producers (plants and other photosynthetic organisms)

Chemical energy

Consumers (such as animals)

Sunlight

Heat

Heat
Energy Conversion

- Work requires a source of energy
- Energy can be stored in different forms, for example, light, chemical, kinetic, or thermal
- The energy exchange between an organism and its environment often involves energy transformations
- 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
(a) Wings

(b) Bones

Infoldings of membrane

Mitochondrion

(c) Neurons

(d) Mitochondria
**Theme: Cells are an organism’s basic units 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

- The ability of cells to divide is the basis of all reproduction, growth, and repair of multicellular organisms
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.

Bacteria and Archaea are prokaryotic; plants, animals, fungi, and all other forms of life are eukaryotic.
Eukaryotic cell

- Membrane
- Cytoplasm
- Nucleus (contains DNA)
- Organelles

Prokaryotic cell

DNA (no nucleus)

1 µm
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
DNA Structure and Function

- Each chromosome has one long DNA molecule with hundreds or thousands of genes.
- DNA is inherited by offspring from their parents.
- DNA controls the development and maintenance of organisms.
• Genes control protein production indirectly

• DNA is transcribed into RNA then translated into a protein

• An organism’s genome is its entire set of genetic instructions
• Advances in systems biology at the cellular and molecular level depend 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 – *exs.* childbirth – oxytocin speeds up contractions, blood clotting
(a) Negative feedback

Excess D blocks a step

Negative feedback −

Enzyme 1

Enzyme 2

Enzyme 3

A

B

C

D
Excess Z stimulates a step

(b) Positive feedback
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
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.

(All Species Inventory)
Grouping Species: The Basic Idea

• Taxonomy is the branch of biology that names and classifies species into groups of increasing breadth

• Domains, followed by kingdoms, are the broadest units of classification
Ursus americanus (American black bear)
The Three Domains of Life

• The three-domain system is currently used, and replaces the old five-kingdom system

• **Domain Bacteria** and **domain Archaea** comprise the prokaryotes

• **Domain Eukarya** includes all eukaryotic organisms
Fig. 1-15

(a) DOMAIN BACTERIA

(b) DOMAIN ARCHAEA

(c) DOMAIN EUKARYA

Protists

Kingdom Fungi

Kingdom Plantae

Kingdom Animalia
• The domain Eukarya includes three multicellular kingdoms:
  – Plantae
  – Fungi
  – Animalia

• Other eukaryotic organisms were formerly grouped into a kingdom called Protista, though these are now often grouped into many separate kingdoms
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
Fig. 1-16

Cilia of *Paramecium*

Cross section of a cilium, as viewed with an electron microscope

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Charles Darwin and the Theory of Natural Selection

- Fossils and other evidence document the evolution of life on Earth over billions of years.

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 have traits that vary
  – Many of these traits are heritable (passed from parents to offspring)
  – More offspring are produced than survive
  – 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 natural environment “selects” for beneficial traits
1 Population with varied inherited traits.
2 Elimination of individuals with certain traits.
3 Reproduction of survivors.
4 Increasing frequency of traits that enhance survival and reproductive success.
The Tree of Life

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

• Fossils provide additional evidence of anatomical unity from descent with modification
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.

Evolutionary relationships are often illustrated with tree-like diagrams that show ancestors and their descendents.
Fig. 1-22

COMMON ANCESTOR

Warbler finches

Insect-eaters

Seed-eaters

Bud-eaters

Insect-eaters

Seed-eaters

Tree finches

Insect-eaters

Cactus-flower-eaters

Ground finches

Seed-eaters

Warbler finches

Insect-eaters

Seed-eaters

Green warbler finch
Certhidea olivacea

Gray warbler finch
Certhidea fusca

Sharp-beaked ground finch
Geospiza difficilis

Vegetarian finch
Platyspiza crassirostris

Mangrove finch
Cactospiza heliobates

Woodpecker finch
Cactospiza pallida

Medium tree finch
Camarhynchus pauper

Large tree finch
Camarhynchus psittacula

Small tree finch
Camarhynchus parvulus

Large cactus ground finch
Geospiza conirostris

Cactus ground finch
Geospiza scandens

Small ground finch
Geospiza fuliginosa

Medium ground finch
Geospiza fortis

Large ground finch
Geospiza magnirostris
1. Briefly describe the unifying themes that characterize the biological sciences

2. Distinguish among the three domains of life, and the eukaryotic kingdoms

3. Distinguish between the following pairs of terms: discovery science and hypothesis-based science, quantitative and qualitative data, inductive and deductive reasoning, science and technology