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Introduction:
Evolution and the Foundations of Biology

Lecture Presentations by
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Overview: Inquiring About Life

- An organism’s adaptations to its environment are the result of evolution
  - For example, a beach mouse’s light, dappled fur acts as camouflage, allowing the mouse to blend into its surroundings
  - Inland mice of the same species are darker in color, matching their surroundings
- **Evolution** is the process of change that has transformed life on Earth
Biology is the scientific study of life

Biologists ask questions such as

- How does a single cell develop into an organism?
- How does the human mind work?
- How do different forms of life in a forest interact?
Concept 1.1: Studying the diverse forms of life reveals common themes

- To organize and make sense of all the information encountered in biology, focus on a few big ideas
- These unifying themes help to organize biological information
Theme: New Properties Emerge at Successive Levels of Biological Organization

- Life can be studied at different levels, from molecules to the entire living planet
- The study of life can be divided into different levels of biological organization
- In reductionism, complex systems are reduced to simpler components to make them more manageable to study
Emergent Properties

- **Emergent properties** result from the arrangement and interaction of parts within a system.

- Emergent properties characterize nonbiological entities as well.
  - For example, a functioning bicycle emerges only when all of the necessary parts connect in the correct way.
Biologists today combine reductionism with **systems biology**, the exploration of a biological system by analyzing the interactions among its parts.

The systems approach poses questions such as:

- How does a drug for blood pressure affect other organs?
- How does increasing CO$_2$ alter the biosphere?
Structure and Function

- At each level of the biological hierarchy we find a correlation between structure and function.
- Analyzing a biological structure can give clues about what it does and how it works.
The Cell: An Organism’s Basic Unit of Structure and Function

- The cell is the smallest unit of life that can perform all the required activities
- All cells share certain characteristics, such as being enclosed by a membrane
- The two main forms of cells are prokaryotic and eukaryotic
A eukaryotic cell contains membrane-enclosed organelles, including a DNA-containing nucleus.

Some organelles, such as the chloroplast, are limited only to certain cell types, that is, those that carry out photosynthesis.

Prokaryotic cells lack a nucleus or other membrane-bound organelles and are generally smaller than eukaryotic cells.
Figure 1.5

Eukaryotic cell

- Membrane
- Cytoplasm
- Membrane-enclosed organelles
- Nucleus (membrane-enclosed)
- DNA (throughout nucleus)

Prokaryotic cell

- Membrane
- DNA (no nucleus)

1 µm
Figure 1.5a

Eukaryotic cell

Membrane

Cytoplasm

Membrane-enclosed organelles

Nucleus (membrane-enclosed)

DNA (throughout nucleus)

1 μm
Prokaryotic cell

DNA
(no nucleus)

Membrane

1 μm
Theme: Life’s Processes Involve the Expression and Transmission of Genetic Information

- Chromosomes contain most of a cell’s genetic material in the form of **DNA** (deoxyribonucleic acid)
DNA Structure and Function

- A DNA molecule holds hundreds or thousands of genes, each a stretch of DNA along the chromosome.
- **Genes** are the units of inheritance that transmit information from parents to offspring.
- As cells grow and divide, the genetic information encoded by DNA directs their development.
Figure 1.7

Nucleus with DNA

Sperm cell

Egg cell

Fertilization

Fertilized egg with DNA from both parents

Embryo’s cells with copies of inherited DNA

Offspring with traits inherited from both parents
A DNA molecule is made of two long chains (strands) arranged in a double helix.

Each link of a chain is one of four kinds of chemical building blocks called nucleotides and abbreviated A, T, C, and G.
Figure 1.8

(a) DNA double helix

(b) Single strand of DNA
DNA provides blueprints for making proteins, the major players in building and maintaining a cell

Genes control protein production indirectly, using RNA as an intermediary

**Gene expression** is the process of converting information from gene to cellular product
An organism’s **genome** is its entire set of genetic instructions

The human genome and the genomes of many other organisms have been sequenced using DNA-sequencing machines

**Genomics** is the study of sets of genes within and between species
“High-throughput” technology refers to tools that can analyze biological materials very rapidly.

**Bioinformatics** is the use of computational tools to store, organize, and analyze the huge volume of data.

Interdisciplinary research teams aim to learn how activities of all proteins and noncoding RNAs are coordinated in cells and whole organisms.
Theme: Life Requires the Transfer and Transformation of Energy and Matter

- Input of energy, mainly from the sun, and transformation of energy from one form to another make life possible.
- Plants and other photosynthetic organisms convert the energy of sunlight into the chemical energy of sugars.
- This chemical energy of these producers is then passed to consumers that feed on the producers.
- Energy flows through an ecosystem, generally entering as light and exiting as heat
- Chemical elements are recycled within an ecosystem
Figure 1.9

Energy flow

Chemical cycling

Chemical elements

Chemicals pass to organisms that eat plants.

Decomposers return chemicals to soil.

Light energy

Chemical energy

Heat
Theme: Organisms Interact with Other Organisms and the Physical Environment

- Every organism interacts with physical factors in its environment
- 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
Interactions between organisms include those that benefit both organisms and those in which both organisms are harmed.

Interactions affect individual organisms and the way that populations evolve over time.
Figure 1.10
Evolution, the Core Theme of Biology

- Evolution makes sense of everything we know about living organisms
- Evolution explains patterns of unity and diversity in living organisms
- Similar traits among organisms are explained by descent from common ancestors
- Differences among organisms are explained by the accumulation of heritable changes
Concept 1.2: The Core Theme: Evolution accounts for the unity and diversity of life

- The remarkably diverse forms of life on this planet arose by evolutionary processes
Classifying the Diversity of Life: The Three Domains of Life

- Humans group diverse items according to their similarities and relationships to each other.
- Careful analysis of form and function has been used to classify life-forms.
- Recently, new methods of assessing species relationships, especially comparisons of DNA sequences, have led to a reevaluation of larger groupings.
Biologists currently divide the kingdoms of life into three domains: Bacteria, Archaea, and Eukarya.

- Domains **Bacteria** and **Archaea** are prokaryotes.
- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes three multicellular kingdoms: Plantae, Fungi, and Animalia
  - Plants produce their own food by photosynthesis
  - Fungi absorb nutrients
  - Animals ingest their food
Unity in the Diversity of Life

- A striking unity underlies the diversity of life
- For example, DNA is the universal genetic language common to all organisms
- Similarities between organisms are evident at all levels of the biological hierarchy
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 captured 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
In other words, the environment “selects” for the propagation of beneficial traits

Darwin called this process **natural selection**
Population with varied inherited traits

Elimination of individuals with certain traits

Reproduction of survivors

Increasing frequency of traits that enhance survival
The Tree of Life

- The forelimb of a human, foreleg of a horse, flipper of a whale, and wing of a bat all share a common skeletal architecture.

- The shared anatomy of mammalian limbs reflects inheritance of a limb structure from a common ancestor.

- The diversity of mammalian limbs results from modification by natural selection over millions of years.
Darwin proposed that natural selection could cause an ancestral species to give rise to two or more descendent species

- For example, the finch species of the Galápagos Islands are descended from a common ancestor

- Evolutionary relationships are often illustrated with treelike diagrams that show ancestors and their descendants
Figure 1.16

COMMON ANCESTOR

Insect-eater

Green warbler finch
*Certhidea olivacea*

Vegetarian finch
*Platyspiza crassirostris*

Woodpecker finch
*Cactospiza pallida*

Small tree finch
*Camarhynchus parvulus*

Cactus ground finch
*Geospiza scandens*

Seed-eater

Large ground finch
*Geospiza magnirostris*
Concept 1.3: Biological inquiry entails forming and testing hypotheses based on observations of nature

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

- Biologists describe natural structures and processes
- Recorded observations are called **data**
Data fall into two categories

- Qualitative data, or descriptions rather than measurements
  - For example, Jane Goodall’s observations of chimpanzee behavior
- Quantitative data, or recorded measurements, which are sometimes organized into tables and graphs
Figure 1.17
- **Inductive reasoning** draws conclusions through the logical process of induction

- Through induction, generalizations are drawn from a large number of observations
  - For example, “all organisms are made of cells” was based on two centuries of microscopic observations
Forming and Testing Hypotheses

- In science, a **hypothesis** is a rational accounting for a set of observations, guided by inductive reasoning.
- It is an explanation on trial.
- A scientific hypothesis leads to predictions that can be tested with additional observations or an experiment.
Deductive Reasoning

- **Deductive reasoning** extrapolates from general premises to specific predictions
- The hypothesis is then tested experimentally
The initial observations may lead to multiple hypotheses to be tested

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
A hypothesis can never be conclusively proven to be true because we can never test all the alternatives.

Hypotheses gain credibility by surviving multiple attempts at falsification, while alternative hypotheses are eliminated by testing.
Questions That Can and Cannot Be Addressed by Science

- A hypothesis must be testable and falsifiable
  - For example, hypotheses involving supernatural explanations cannot be tested
- Such explanations are outside the bounds of science
A Case Study in Scientific Inquiry: Investigating Coat Coloration in Mouse Populations

- Color patterns in animals vary widely in nature
- Two mouse populations that reside in different habitats have different coat colors
- What accounts for the “match” between the coat colors of the mice and the color of the sand or soil in their habitats?
Members of the same species living inland are darker in color.

Beach mice have light tan, dappled coats.
The natural predators of the mice are all visual hunters.

Francis Bertody Sumner hypothesized that the color patterns in the mice had evolved as adaptations that camouflage the mice to protect them from predation.

Recently Hopi Hoekstra and a group of her students tested the predictions of this hypothesis.
Prediction: Mice with coloration that does not match the habitat should suffer heavier predation than the native, well-matched mice.

The group built many silicone models of mice that resembled either beach or inland mice and placed equal numbers of models randomly in both habitats.

The results showed that the camouflaged models suffered much lower rates of predation than the mismatched ones.
Results

Camouflaged (control)

Non-camouflaged (experimental)

Predation rate

Light models  Dark models

Beach habitats

Light models  Dark models

Inland habitats

Camouflaged (control)

Non-camouflaged (experimental)
A controlled experiment compares an experimental group (the non-camouflaged mice) with a control group (the camouflaged mice).

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.
Theories in Science

- In the context of science, a **theory** is
  - Broader in scope than a hypothesis
  - General enough to lead to new testable hypotheses
  - Supported by a large body of evidence in comparison to a hypothesis
Science as a Social Process: Community and Diversity

- Anyone who becomes a scientist benefits from the rich storehouse of discoveries by others who have come before
- Most scientists work in teams
- Science is rarely perfectly objective but is continuously evaluated through expectation that observations and experiments are repeatable and hypotheses are falsifiable
The relationship between science and society is clearer when technology is considered.

The goal of technology is to apply scientific knowledge for some specific purpose.

Science and technology are interdependent.
Figure 1 UN01

A: Light-colored soil
- Full moon: 35 mice caught
- No moon: 10 mice caught

B: Dark-colored soil
- Full moon: 20 mice caught
- No moon: 15 mice caught
Population of organisms

- Hereditary variations
- Overproduction of offspring and competition

Environmental factors

Differences in reproductive success of individuals

Evolution of adaptations in the population