

1

Introduction: Evolution and the Foundations of Biology

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

- LIFE
- **Biology** is the scientific study of life
 - Biologists ask questions such as
 - How does a single cell develop into an organism? → cell Bio
 - How does the human mind work? → neurology
 - How do different forms of life in a forest interact? → ecology

Concept 1.1: The study 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:
- LIFE IS ORGANIZED
- Organization - Global (Biosphere) - Ecosystems - Community - populations
 - molecular - cells - TISSUES - ORGANS - ORGANISMS
 - Information - Cellular communication (muscle, nervous, Epithelial, Connective)
 - Energy and Matter - SUN (light energy) → photosynthesis → FOOD (chemical energy)
 - Interactions
 - Evolution → ecology

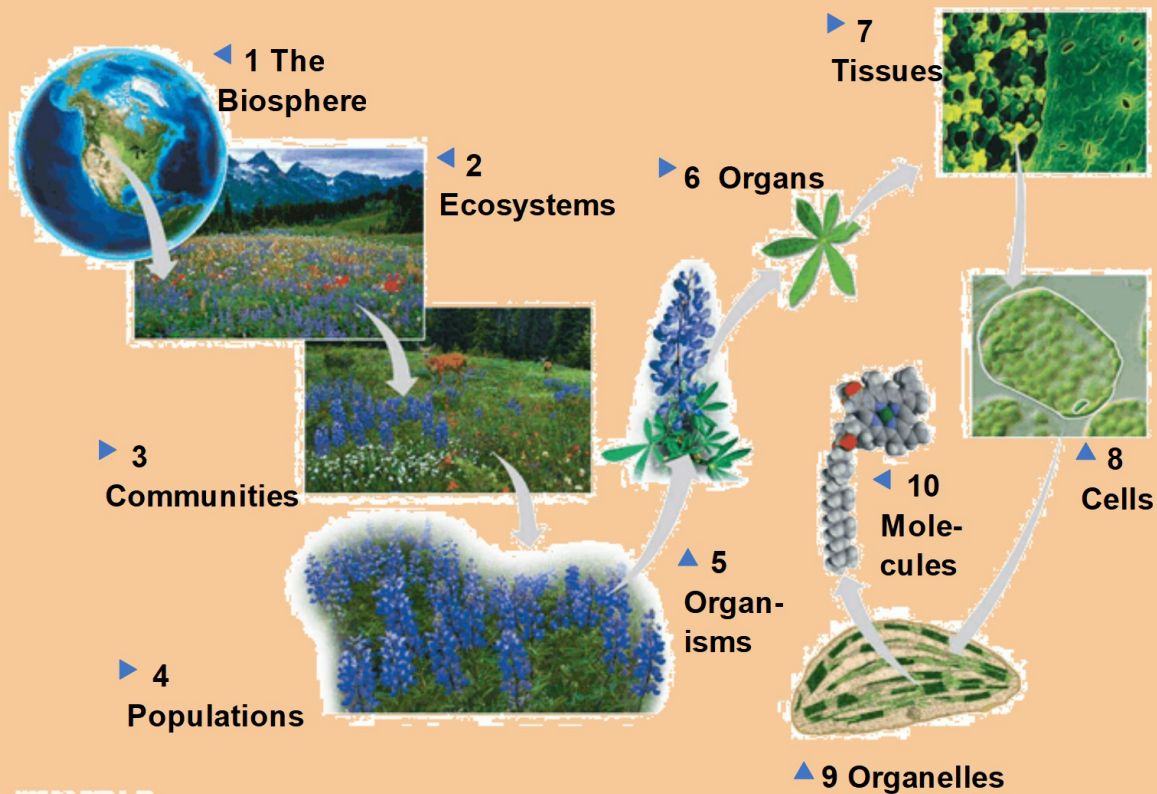
Theme: New Properties Emerge at Successive Levels of Biological Organization

- 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

DNA, PRO
C
U
P

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Figure 1.3



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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

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- Biologists today complement 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 do networks of genes in our cells function to generate our 24-hour cycle of wakefulness and sleep?
 - How does increasing CO₂ alter the biosphere?

↓ - CH₄ - H₂O
Greenhouse gas methane
↑ temp

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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

Body temp.

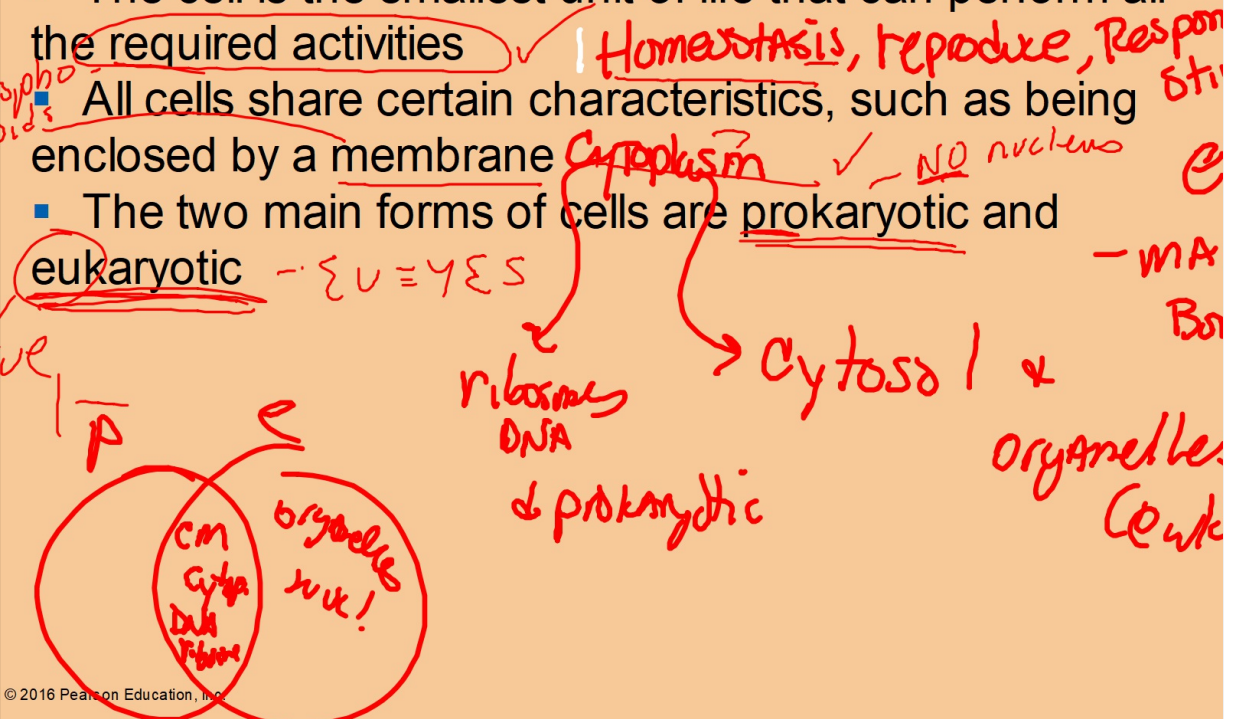
ENZYMES - specific

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



multicellular & single celled

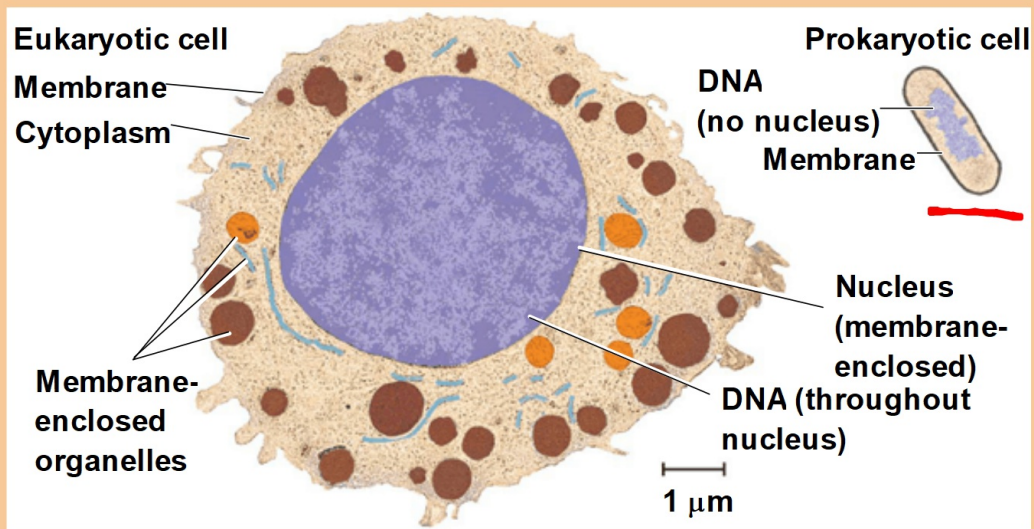
→ PLANTS, ANIMALS, FUNGUS, PROTISTS

- 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

→ BACTERIA (Eubacteria & Archaeobacteria)

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Figure 1.4



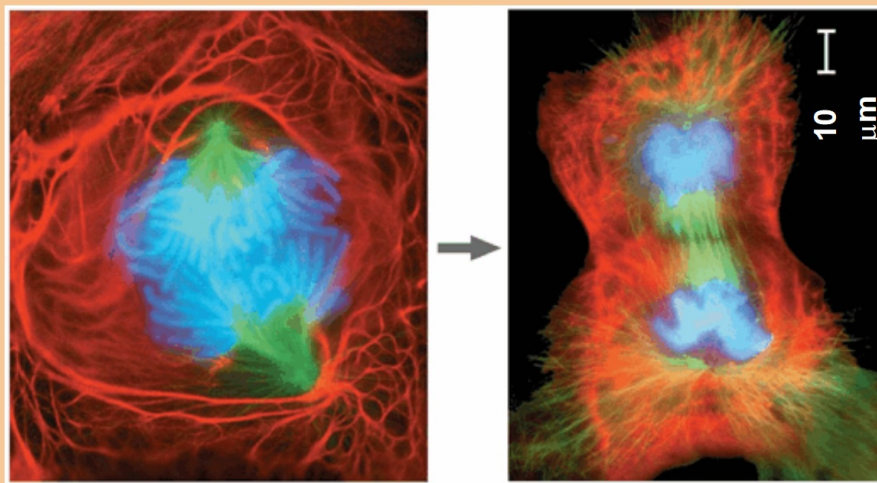
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Theme: Life's Processes Involve the Expression and Transmission of Genetic Information

- Chromosomes contain most of a cell's genetic material in the form of DNA (deoxyribonucleic acid)

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Figure 1.5



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DNA, the Genetic Material

Human Genome $\sim 25,000$

DNA
DNA

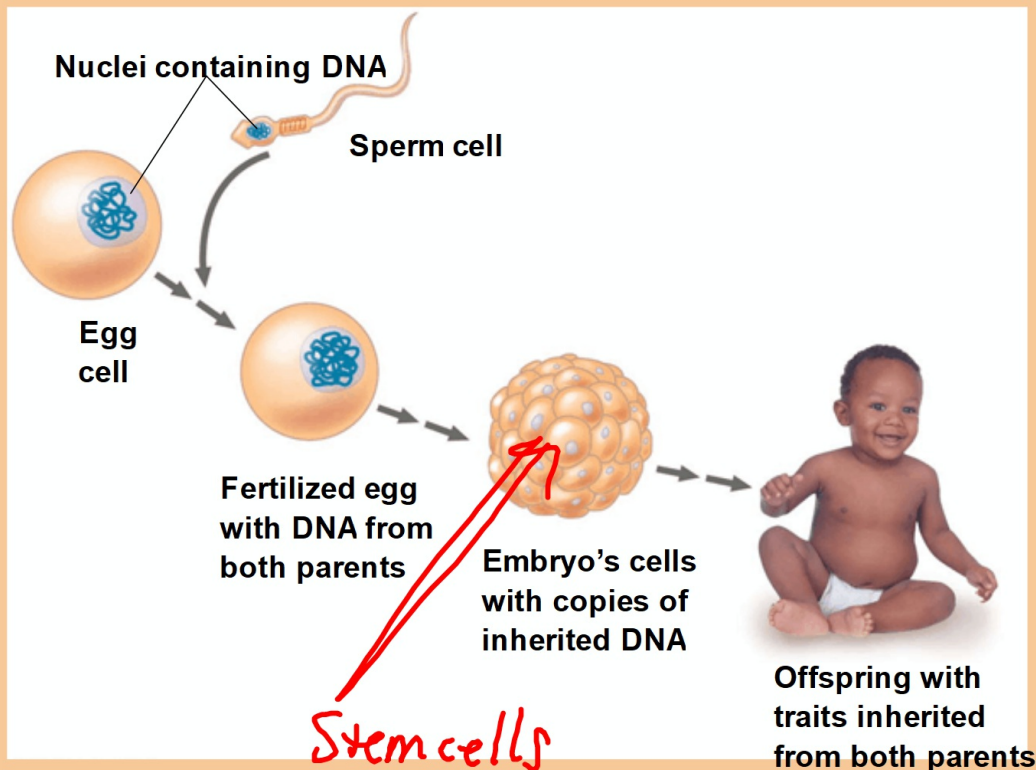
DNA
DNA

- 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

Not all DNA is genes (only $\sim 3\%$)
other 97% ? \rightarrow Body Plan Design
 \rightarrow Switches (turn genes on)
 \rightarrow Timer genes

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Figure 1.6

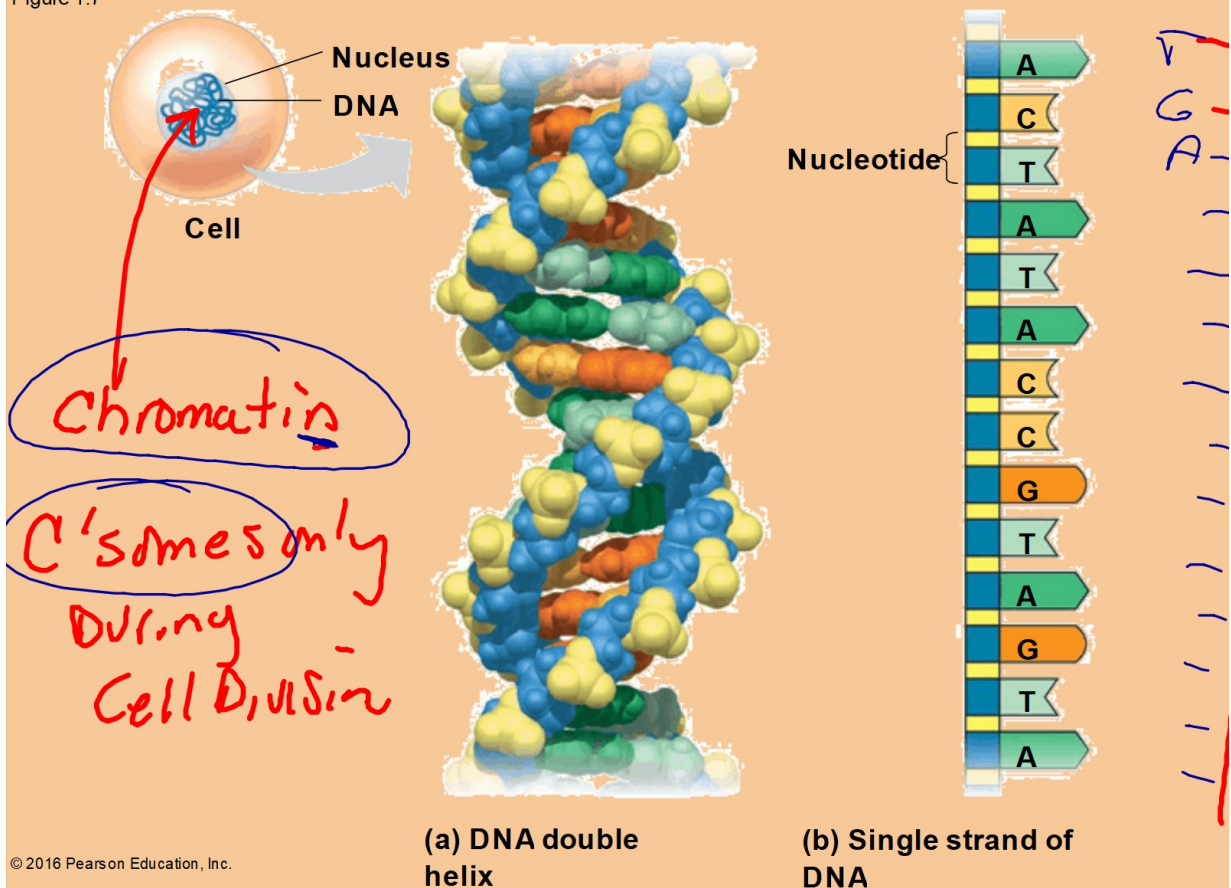


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- A DNA molecule is made of two long chains (strands) arranged in a double helix
- Each link of a chain is one of four kinds of chemical building blocks called nucleotides, abbreviated A, T, C, and G

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Figure 1.7



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(a) DNA double helix

(b) Single strand of DNA

Structural **Fibrous Proteins** (Keratin, Collagen) *globular - enzyme - hemoglobin*

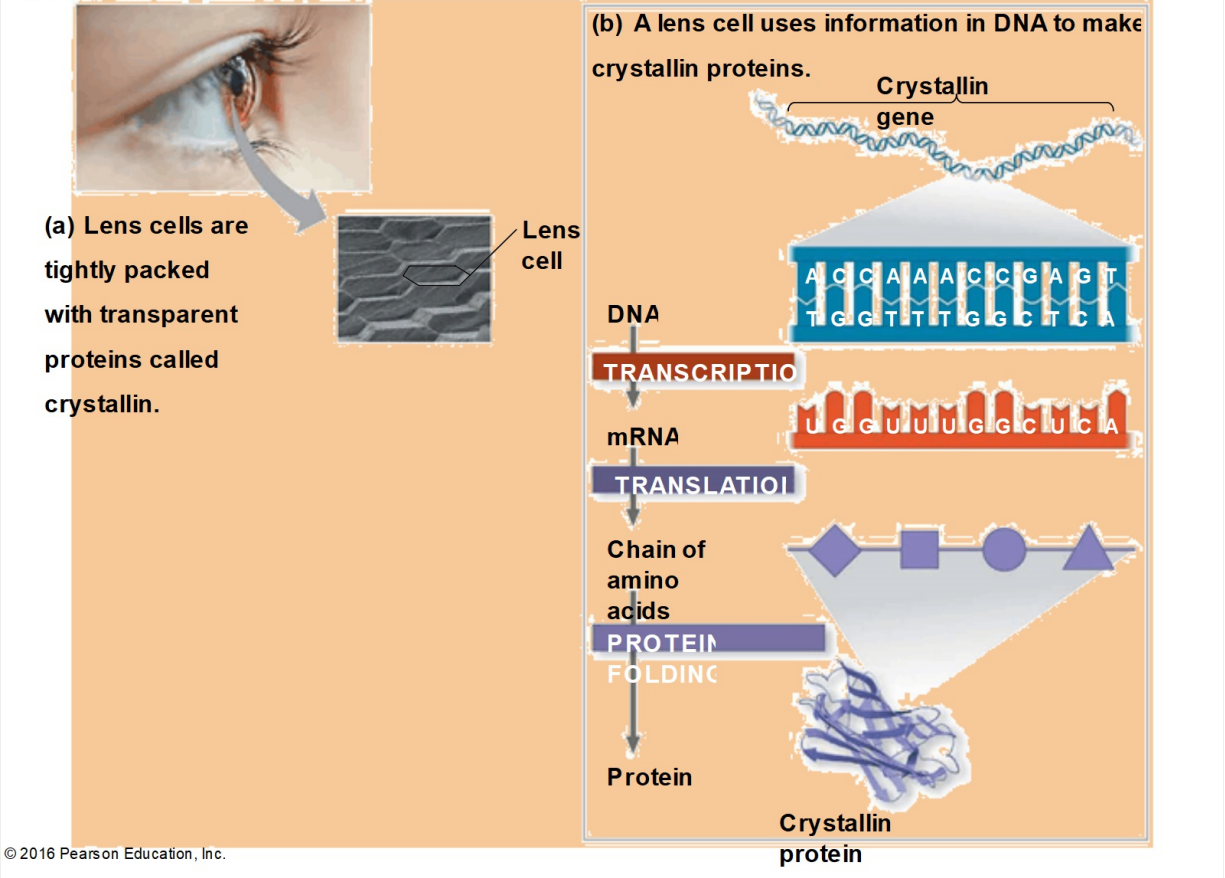
- DNA provides blueprints for making proteins, the major players in building and maintaining a cell
- Genes control protein production indirectly, using RNA as an intermediary
- **Gene expression** is the process of converting information from gene to cellular product

Sugar RIBOSE
A, U, C, G
Single

DNA → RNA → Protein
→ TRAIT

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Figure 1.8



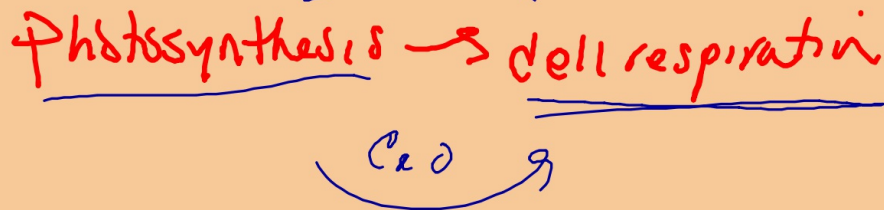
Genomics: Large-Scale Analysis of DNA Sequences

- An organism's **genome** is its entire set of genetic instructions
- **Genomics** is the study of sets of genes within and between species
- **Proteomics** refers to the study of sets of proteins and their properties
- The entire set of proteins expressed by a cell or group of cells is called a **proteome**

- “**High-throughput**” technology refers to tools that can analyze biological samples 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 *Light, chemical, heat, mechanical*
- Plants and other photosynthetic organisms convert the energy of sunlight into the chemical energy of sugars O_2
- This chemical energy of these producers is then passed to consumers that feed on the producers



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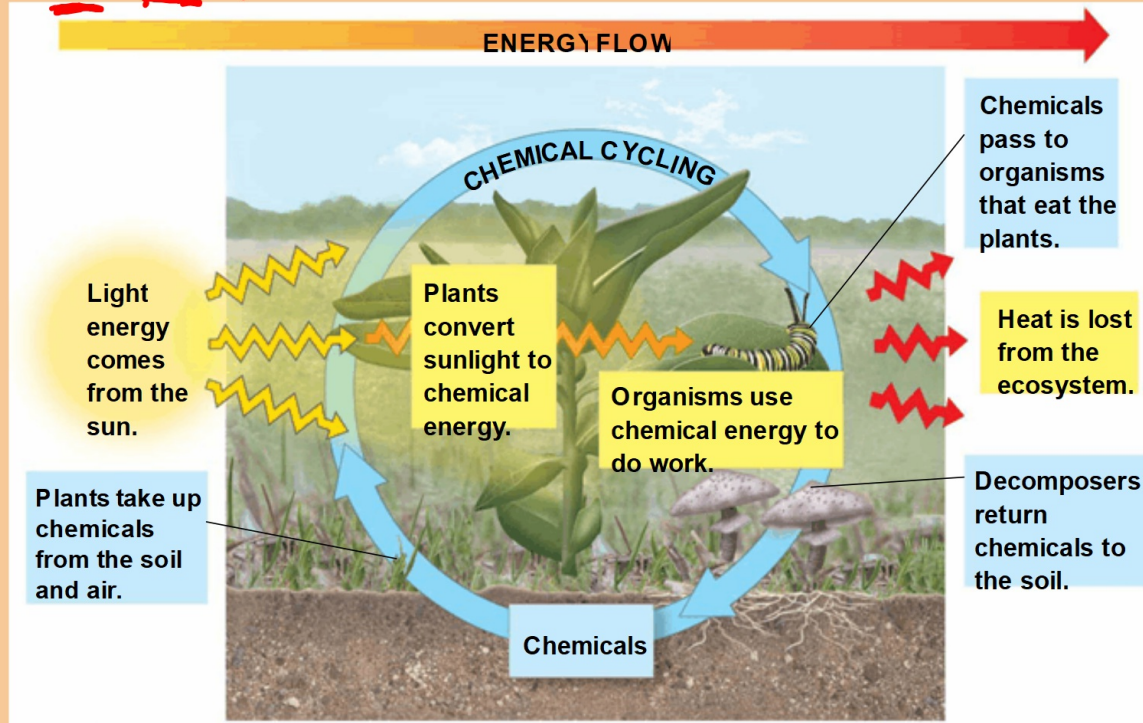
- Energy flows through an ecosystem, generally entering as light and exiting as heat
- Chemical elements are recycled within an ecosystem

C, H, O, N

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Figure 1.9

C, O, N



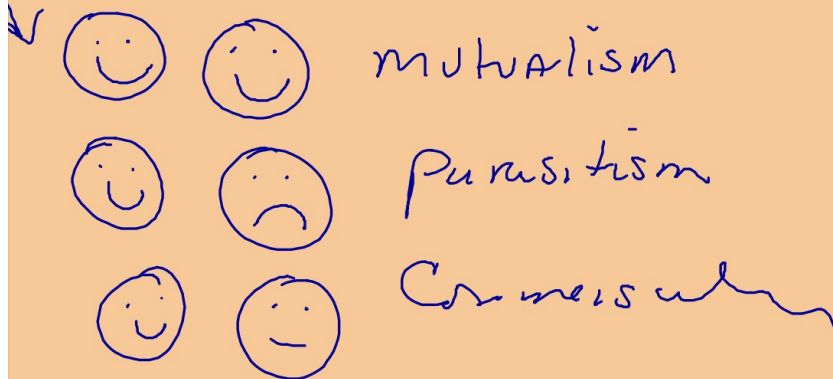
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Theme: Organisms Interact with Other Organisms and the Physical Environment (Ecology)

- Every organism interacts with other organisms and with physical factors in its environment
- Both organisms and their environments are affected by the interactions between them
 - For example, a plant 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

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- Interactions between organisms include those that benefit both organisms and those in which both organisms are harmed **Symbioses**
- Interactions affect individual organisms and the way that populations evolve over time



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- Scientists calculate that the CO₂ that human activities have added to the atmosphere has increased the average temperature of the planet by 1°C since 1900
- **Climate change** is a directional change in global climate that lasts three decades or more
- Climate change has already affected organisms and their habitats all over the planet

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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

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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

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Classifying the Diversity of Life

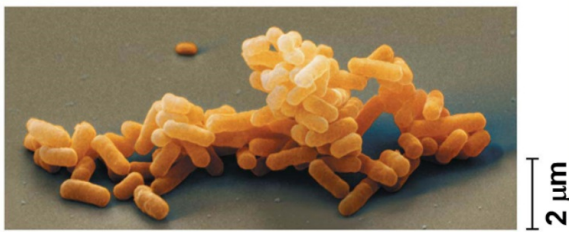
- Humans group diverse items according to their similarities and relationships to each other
- Careful analysis of form and function has been used to classify life-forms
- New methods of assessing species relationships, especially comparisons of DNA sequences, have led to a reevaluation of larger groupings

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- Biologists currently divide the kingdoms of life into three domains: Bacteria, Archaea, and Eukarya

- 3 Domains **Bacteria** and **Archaea** are prokaryotes
unicellular

(a) Domain Bacteria



(b) Domain Archaea

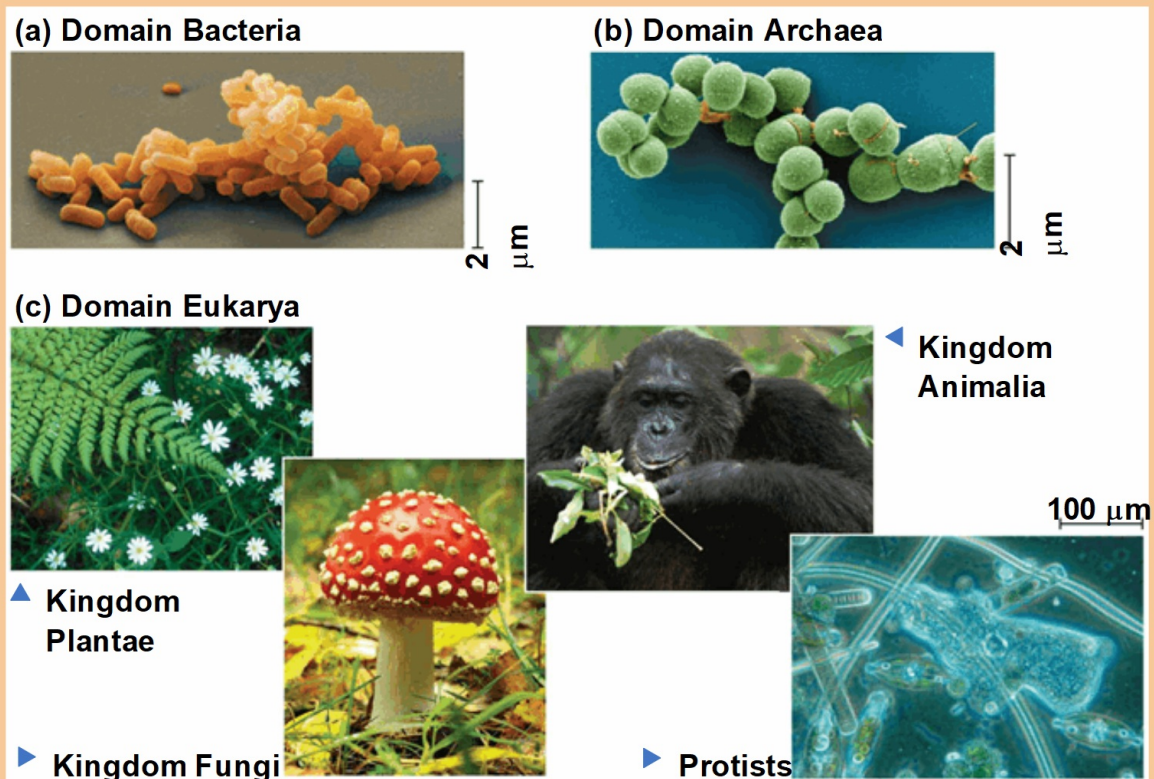


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- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes three multicellular kingdoms: **Plantae**, **Fungi**, and **Animalia**
 - ✓ Plants produce their own food by photosynthesis
 - ✓ Fungi absorb nutrients (*Decomposers*)
 - ✓ Animals ingest their food → *other organisms*

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Figure 1.12



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

Charles Darwin and the Theory of Natural Selection

- Charles Darwin published *On the Origin of Species by Means of Natural Selection* in 1859
- Darwin made two main points
 - Species showed evidence of “descent with modification” from common ancestors
 - Natural selection is the mechanism behind “descent with modification”
- Darwin’s theory captured the duality of unity and diversity

Figure 1.15

▼ American flamingo



▼ European robin



▼ Gentoo penguin



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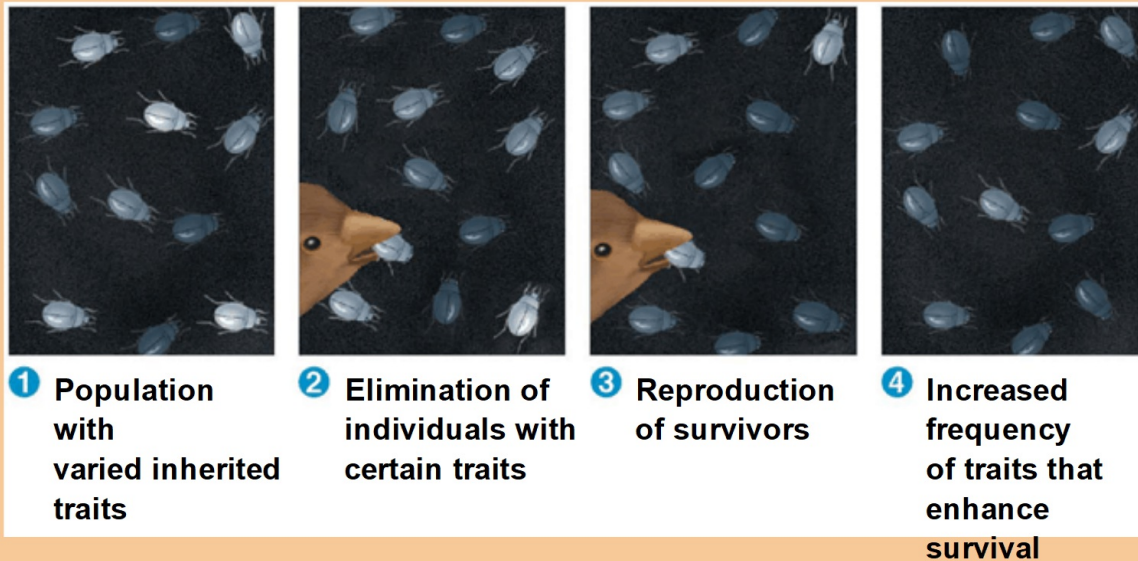
- Darwin observed that
 - Individuals in a population vary in their traits, many of which are heritable
 - More offspring are produced than survive, and competition is inevitable
 - Species generally suit their environment

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- 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**

Figure 1.16-s4



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The Tree of Life

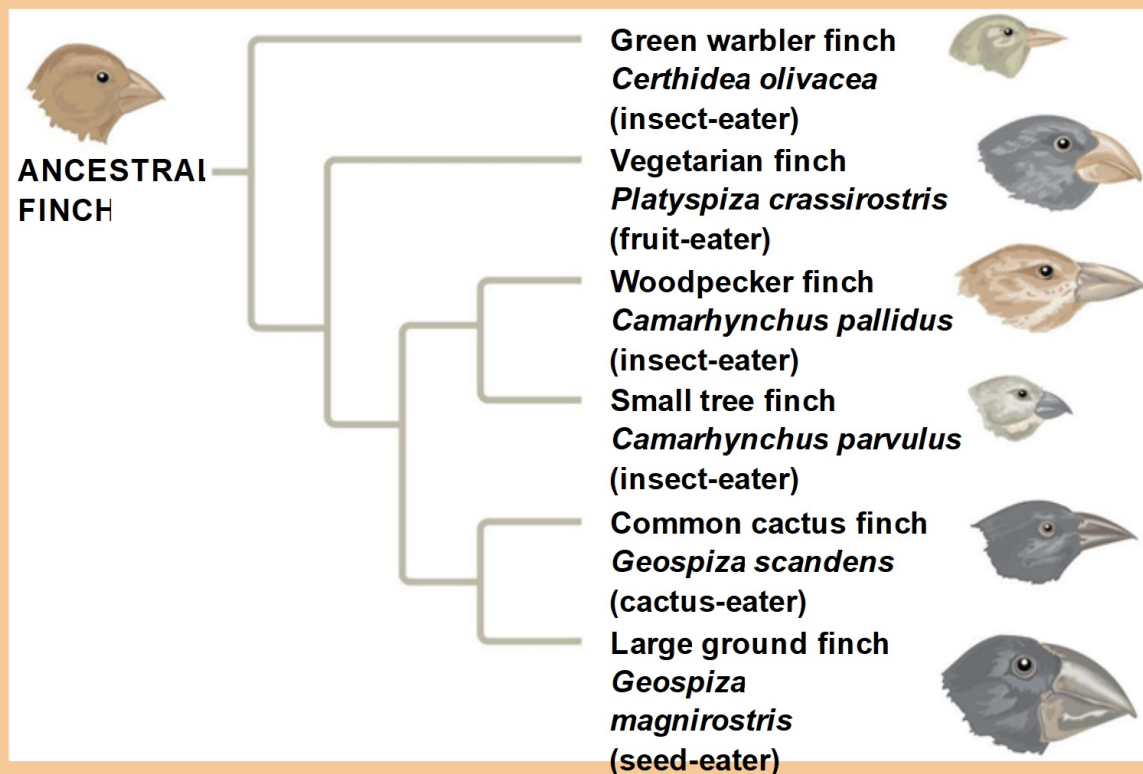
- The forelimb of a human, foreleg of a horse, flipper of a whale, and wing of a bat all share a common skeletal architecture (*Homologous Structures*)
- The shared anatomy of mammalian limbs reflects inheritance of a limb structure from a common ancestor
- The diversity of mammalian limbs results from modification by natural selection over millions of years

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- Darwin proposed that natural selection could cause an ancestral species to give rise to two or more descendent species
 - For example, the finch species of the Galápagos Islands are descended from a common ancestor
- Evolutionary relationships are often illustrated with treelike diagrams that show ancestors and their descendants

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Figure 1.17



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

- 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

must be testable

Exploration and Discovery

- Biology begins with careful observations
- Biologists describe natural structures and processes
- By reading about and understanding past studies, scientists can build on the foundations of existing knowledge

Gathering and Analyzing Data

- 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

- **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

An **experiment** is a scientific test, often carried out under controlled conditions

- The initial observations may lead to multiple hypotheses to be tested
- For example
 - Observation: Your desk lamp doesn't work
 - Question: Why doesn't your lamp work?
 - Hypothesis 1: The bulb is burnt out
 - Hypothesis 2: The lamp is broken
- Both these hypotheses are testable

Deductive Reasoning

- **Deductive reasoning** extrapolates from general premises to specific predictions
- The hypothesis is then tested experimentally

- 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

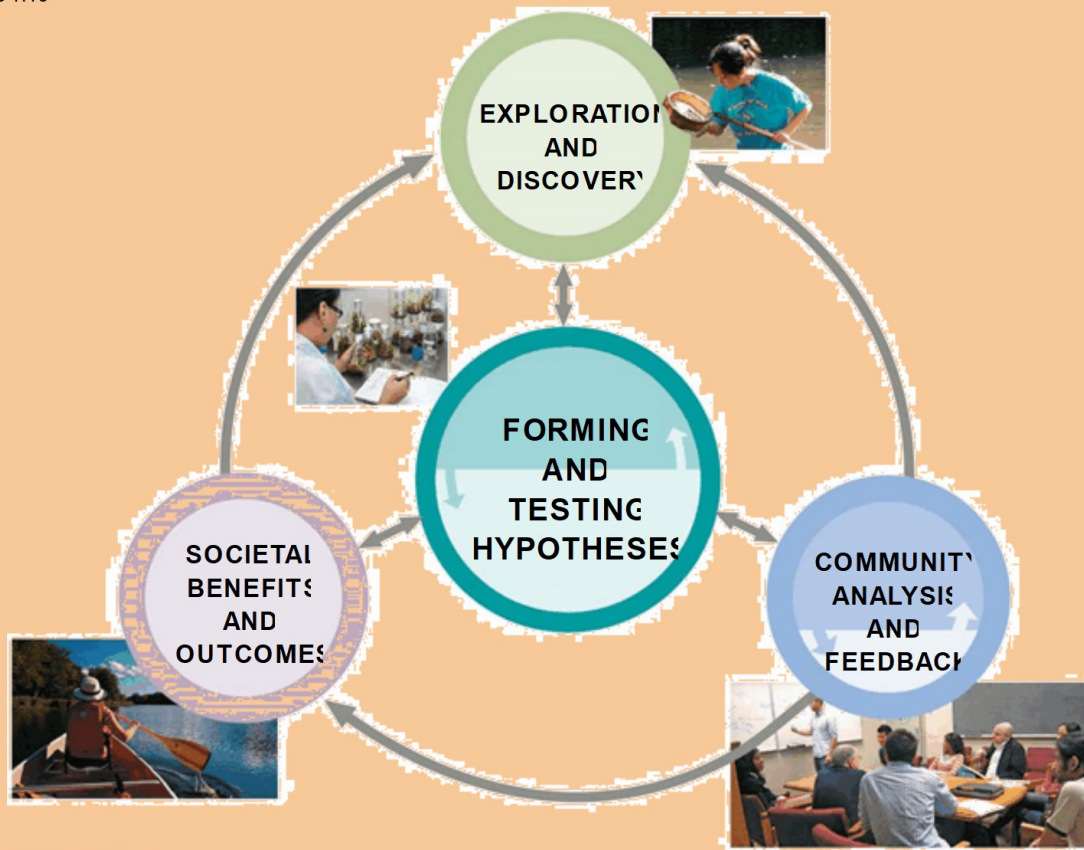
Questions That Can and Cannot Be Addressed by Science

- A hypothesis must be testable and falsifiable
 - For example, hypotheses involving supernatural explanations cannot be tested
- Such explanations are outside the bounds of science

The Flexibility of the Scientific Process

- Very few scientific studies adhere rigidly to the sequence of steps typically used to describe the scientific method

Figure 1.19



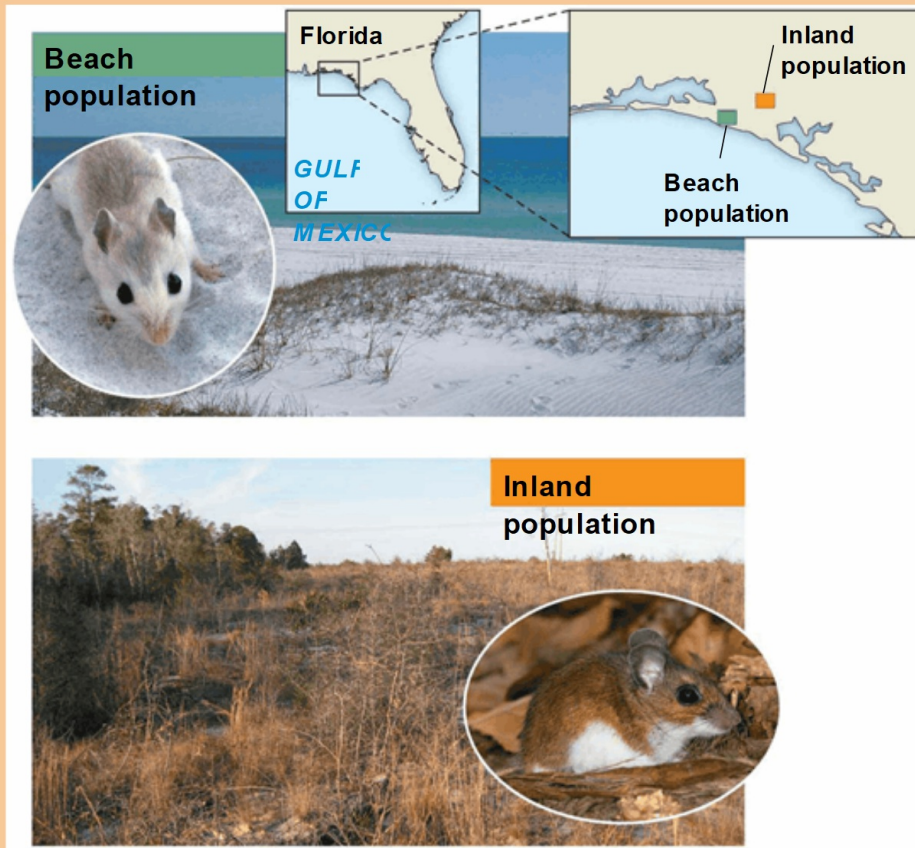
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A Case Study in Scientific Inquiry: Investigating Coat Coloration in Mouse Populations

- Color patterns in animals vary widely in nature, even among members of the same species
- 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?

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Figure 1.20



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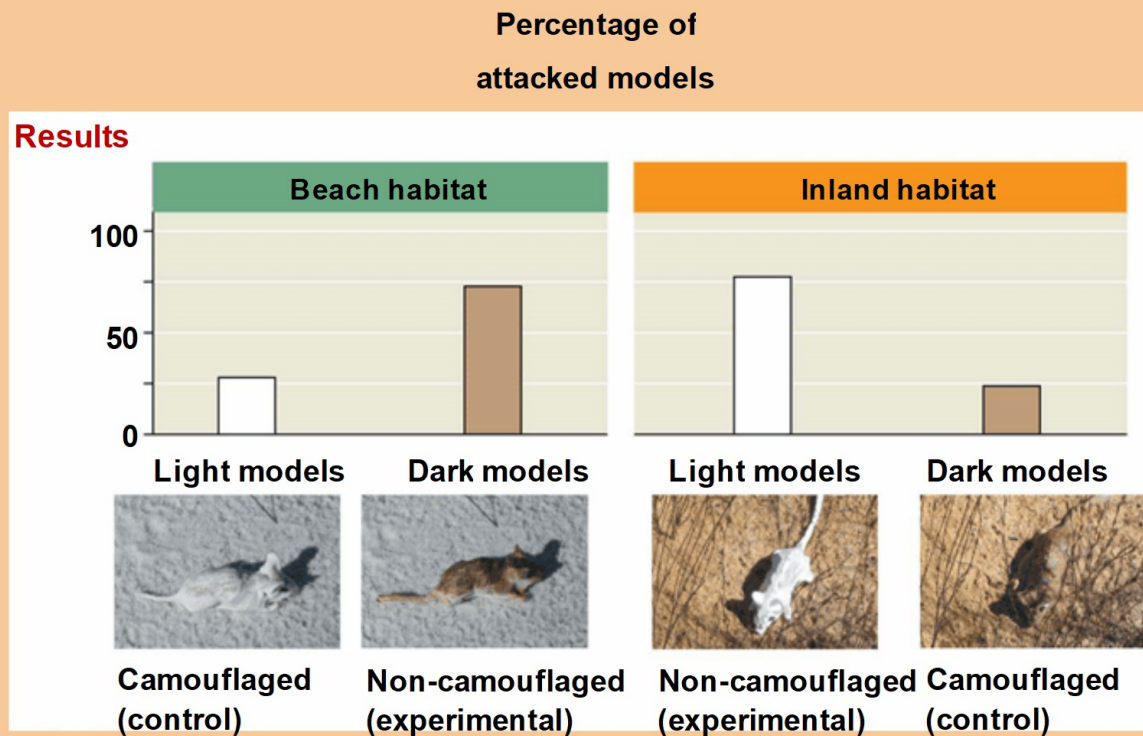
- The natural predators of the mice are all visual hunters
- Francis Bertody Sumner hypothesized that the color patterns in the mice had evolved as adaptations that camouflage the mice to protect them from predation
- Recently Hopi Hoekstra and a group of her students tested the predictions of this hypothesis

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- Prediction: Mice with coloration that does not match the habitat should suffer heavier predation than the native, well-matched mice
- The group built many 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

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Figure 1.21



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Experimental Variables and Controls

- A **controlled experiment** compares an experimental group (the non-camouflaged mice) with a control group (the camouflaged mice)
 - The factor that is manipulated and the effect of the factor on the system are both experimental **variables**
 - The factor manipulated by the researchers—color—is called the **independent variable**
 - The effect of the manipulated factor—amount of predation—is called the **dependent variable**

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- Researchers usually control unwanted variables not by eliminating them, but by canceling them out using control groups

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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

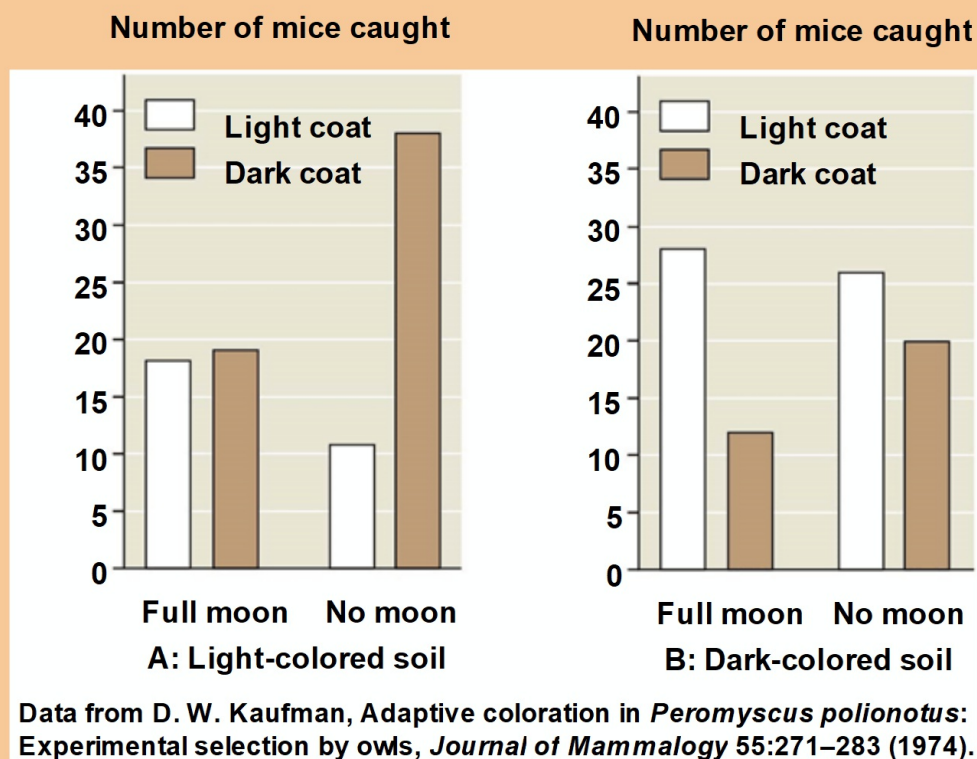
Science as a Social Process

- Anyone who becomes a scientist benefits from the rich storehouse of discoveries by others who have come before
 - Most scientists work in teams
 - Scientists working in the same research field often check one another's claims by attempting to confirm observations or repeat experiments

- 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

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