

BIO101: Cellular basis of life

Course Outline

- Diversity of Life forms and the evolution of body plans. Properties of life. Darwins voyage and the theory of natural selection- an introduction.
- **Molecules of Life:** pH and Buffers in Biology. Chemistry of water. The chemistry of carbon. Proteins. Functions of proteins. Amino acids as building blocks of proteins. How proteins fold and unfold. Nucleic acids as information molecules. DNA and RNA Carbohydrates. Simple sugars, polysaccharides. Lipids and Vitamins
- **Origin of Life:** Origin of cells. Cell Theory What is life? Theories about the origin of life. The Miller-Urey experiment. Theories about the origin of cells
- **Cell structure and cell processes:** Prokaryotic cells and eukaryotic cells Organelles of eukaryotic cell: Nucleus, endoplasmic reticulum, Golgi apparatus, vesicles, peroxisomes, hydrogenosomes, Organelles that contain DNA. The evolution of eukaryotic organelles
- **Membranes as fluid layers of lipid:** The phospholipids bilayer. The fluid mosaic model. Model Membranes Membrane proteins. Passive transport across membranes: Diffusion, facilitated diffusion, Osmosis. Active transport
- **Cell-cell interactions:** Receptor proteins and signaling between cells. Types of cell signaling. Intracellular receptors Cell-surface receptors. Second messengers to transmit signals. Cell-surface proteins mediate cell-cell interactions. Intercellular adhesion. Tight junctions. Anchoring junctions. Communicating junctions.
- **Energy and metabolism:** The law of thermodynamics in living things. Free energy. Activation energy. Enzymes as biological catalysts. Mechanisms of enzyme action. Enzymes take many forms-multienzyme complexes, Ribozymes and Abzymes Factors affecting enzyme action. ATP as the energy currency of life. Metabolism as the chemical life of a cell.
- **How cells harvest energy:** Chemical energy to drive metabolism. Energy-rich intermediates. Mitochondria. Harvesting energy by extracting electrons. The chemiosmotic hypothesis. Summarizing aerobic respiration. Regulating aerobic respiration. Catabolism of proteins and fats as a source of energy. Fermentation. Metabolism of food without oxygen Chloroplasts-photosynthetic electron transport, Calvin cycle.

Recommended Reading

- D. Sadava, W. K. Purves, G. H. Orians, and H. C. Heller, *Life: the science of biology*, 8th Edn., Sinauer Assoc. & Freeman & Co. (2008).
- N. A. Campbell, J. B. Reece, R. B. Jackson, M. L. Cain, L. A. Urry, S. A. Wasserman, P. V. Minorsky, *Biology*, 8th Edn. Benjamin-Cummings Pub Co. (2007).

Evaluation

- Mid Sem -**40-50** marks
- Quizzes/assignments-**10** marks (date not announced)
- End Sem-**40-50** Marks
- Total-**100-110**
- Relative grading **A,B,C,D** and **F**

Introduction: Themes in the Study of Life

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

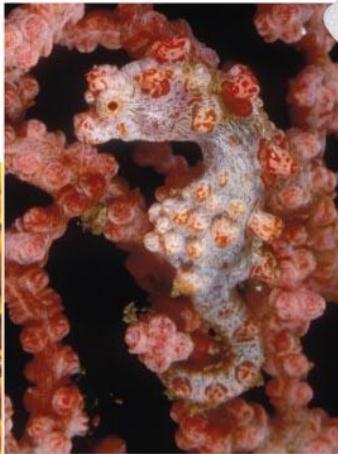




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- Life defies a simple, one-sentence definition
 - Life is recognized by what living things do

▼Order



▲ 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

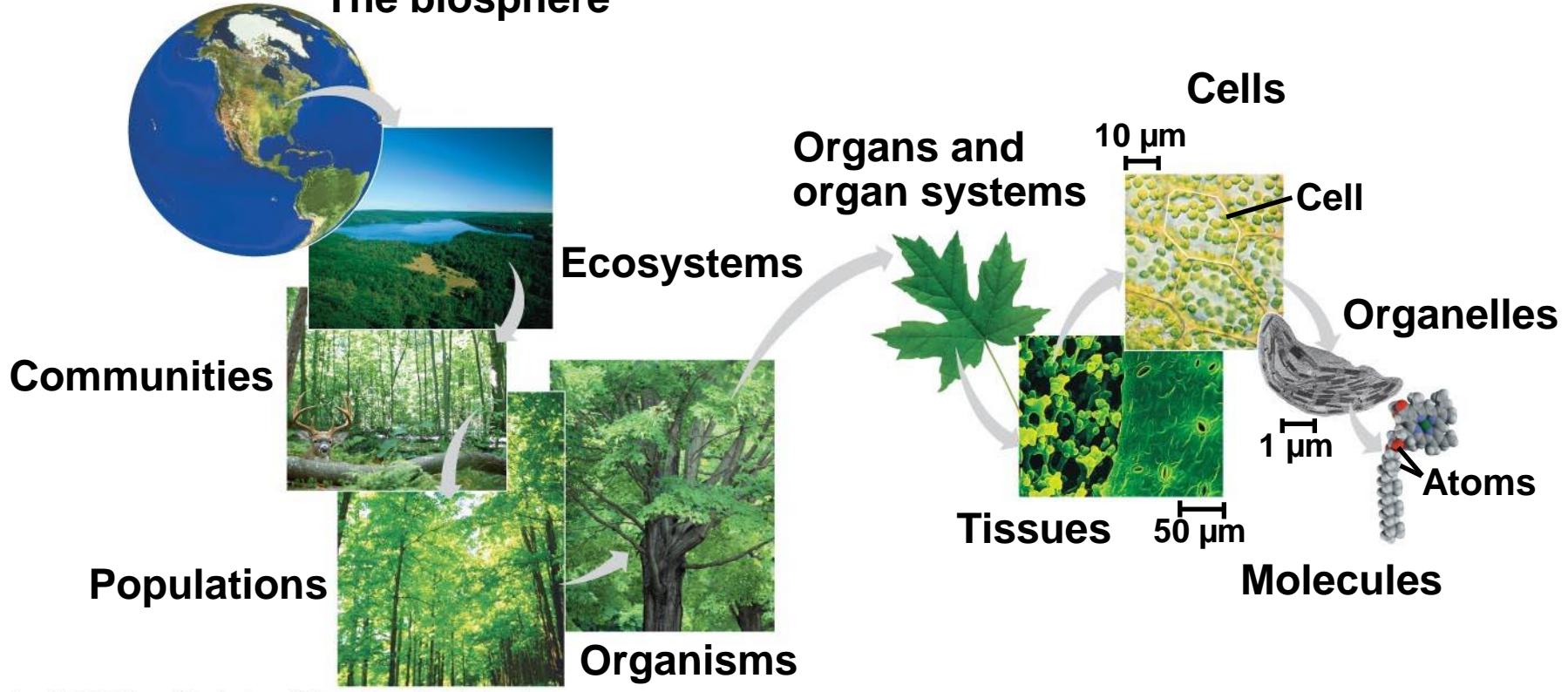
Evolution, the Overarching Theme of Biology

- Evolution makes sense of everything we know about living organisms
- Organisms living on Earth are modified descendants 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 biosphere



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The biosphere

Communities



Populations



Ecosystems



Organisms



Organs and organ systems



Cells

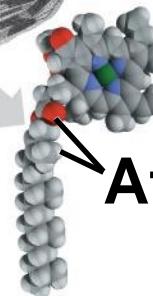
10 μm



Cell

Organelles

1 μm



Atoms

Molecules

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

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
- An understanding of biology balances reductionism with the study of emergent properties
 - For example, new understanding comes from studying the interactions of DNA with other molecules

Systems Biology

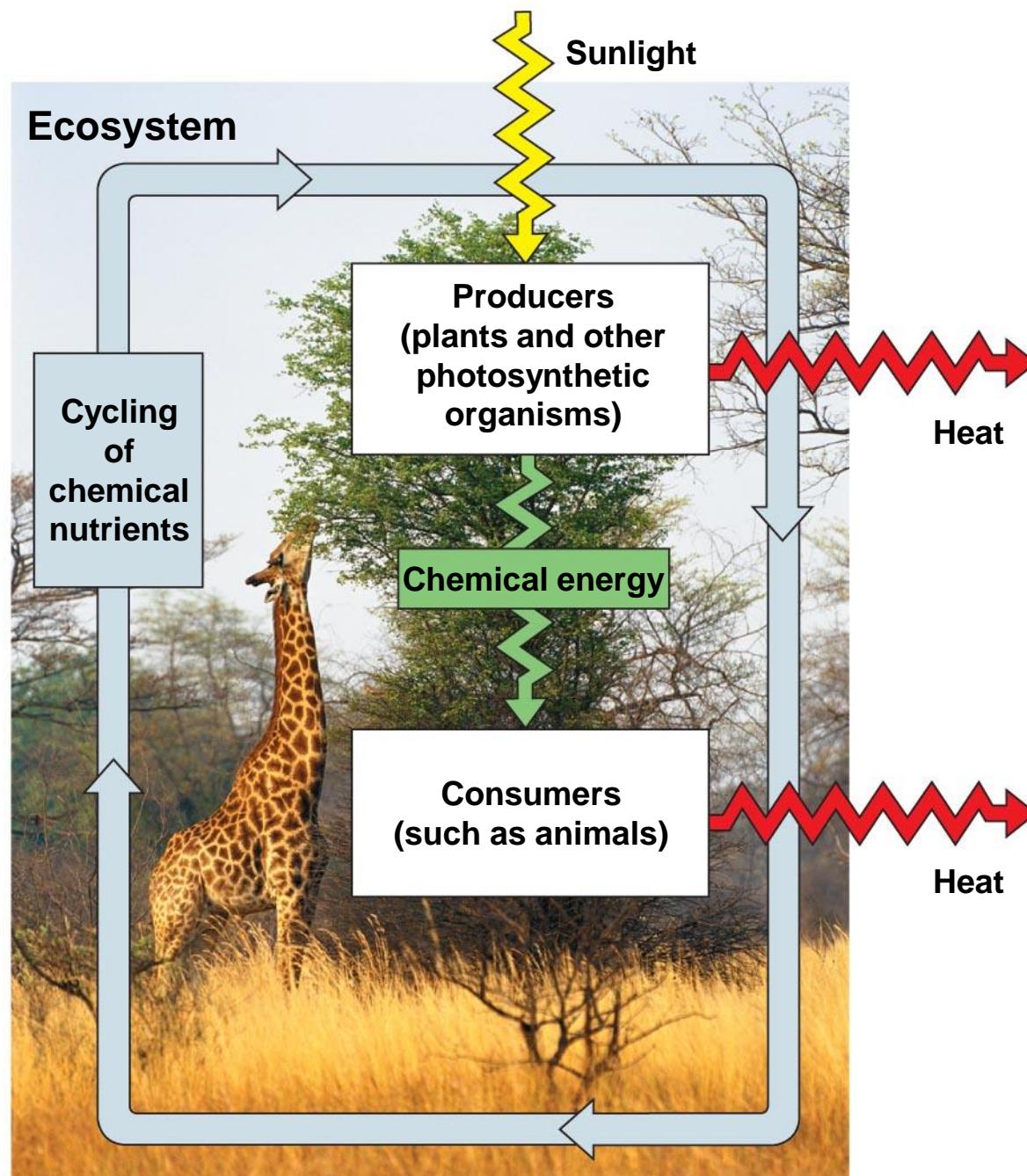
- A system is a combination of components that function together
- **Systems biology** constructs models for the dynamic behavior of whole biological systems
- The systems approach poses questions such as:
 - How does a drug for blood pressure affect other organs?
 - How does increasing CO₂ alter the biosphere?

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



Energy Conversion

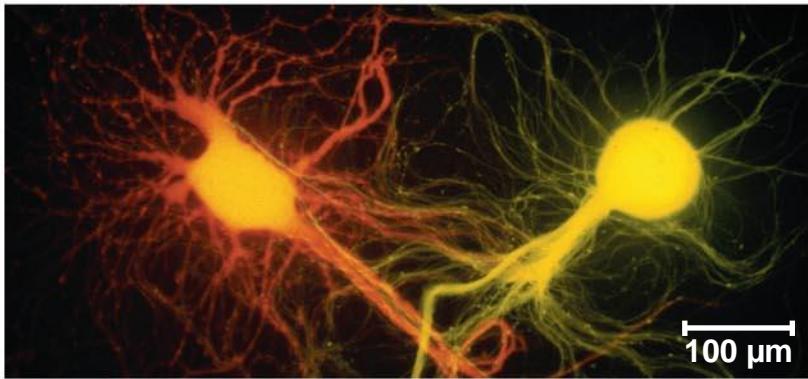
- Work requires a source of energy
- Energy can be stored in different forms, for example, light, chemical, kinetic, or thermal
- The energy exchange between an organism and its environment often involves energy transformations
- Energy flows *through* an ecosystem, usually entering as light and exiting 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

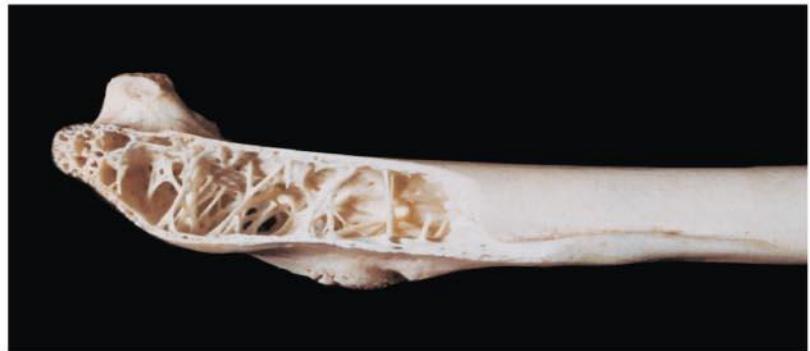


(a) Wings

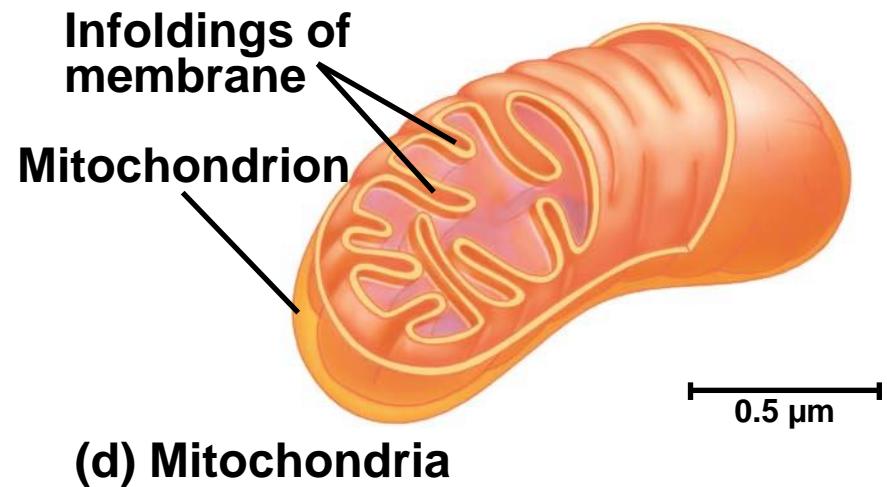


(c) Neurons

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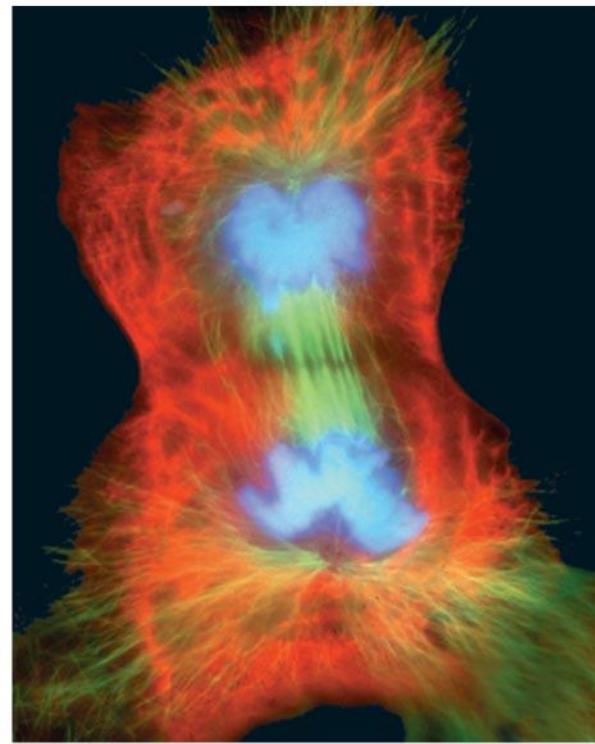
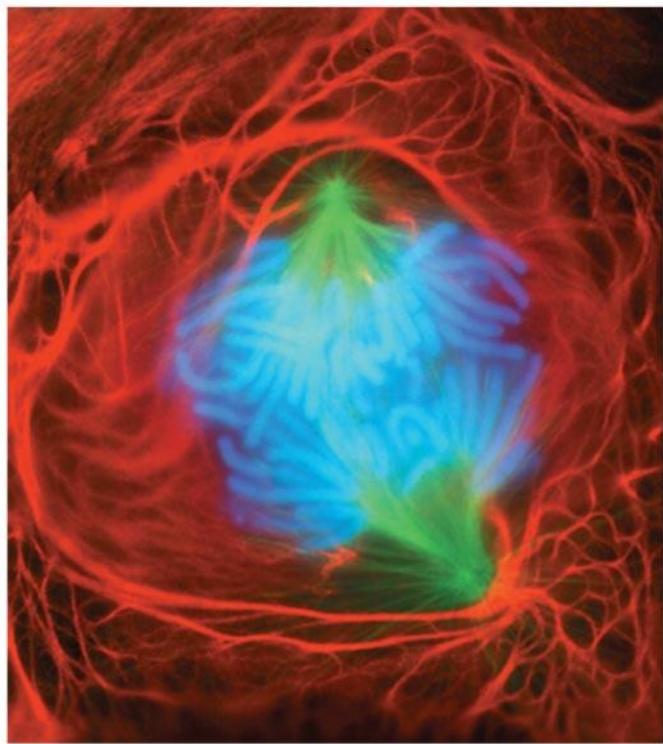
(b) Bones



(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



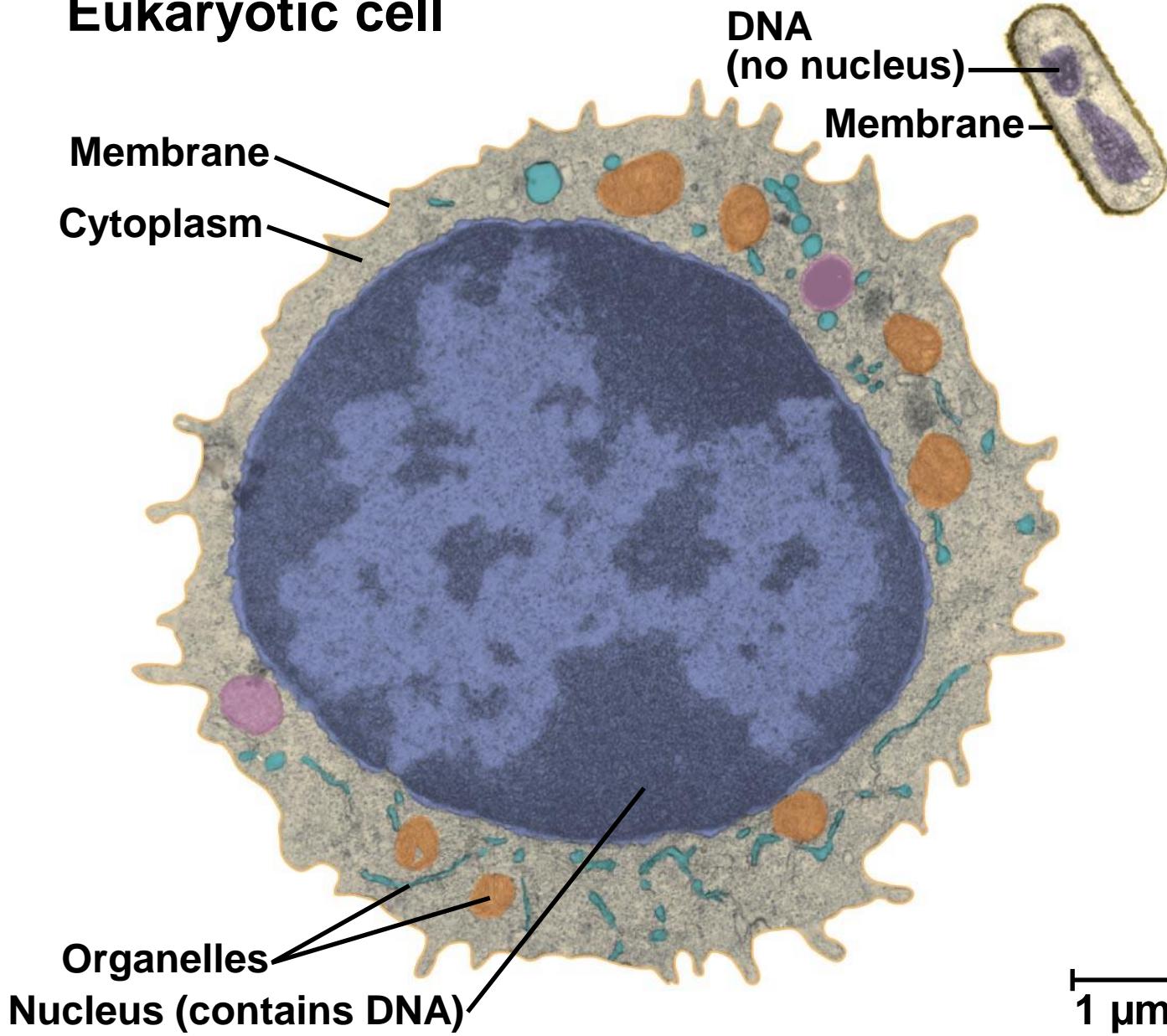
25 μm

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- 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

Prokaryotic cell

Eukaryotic cell

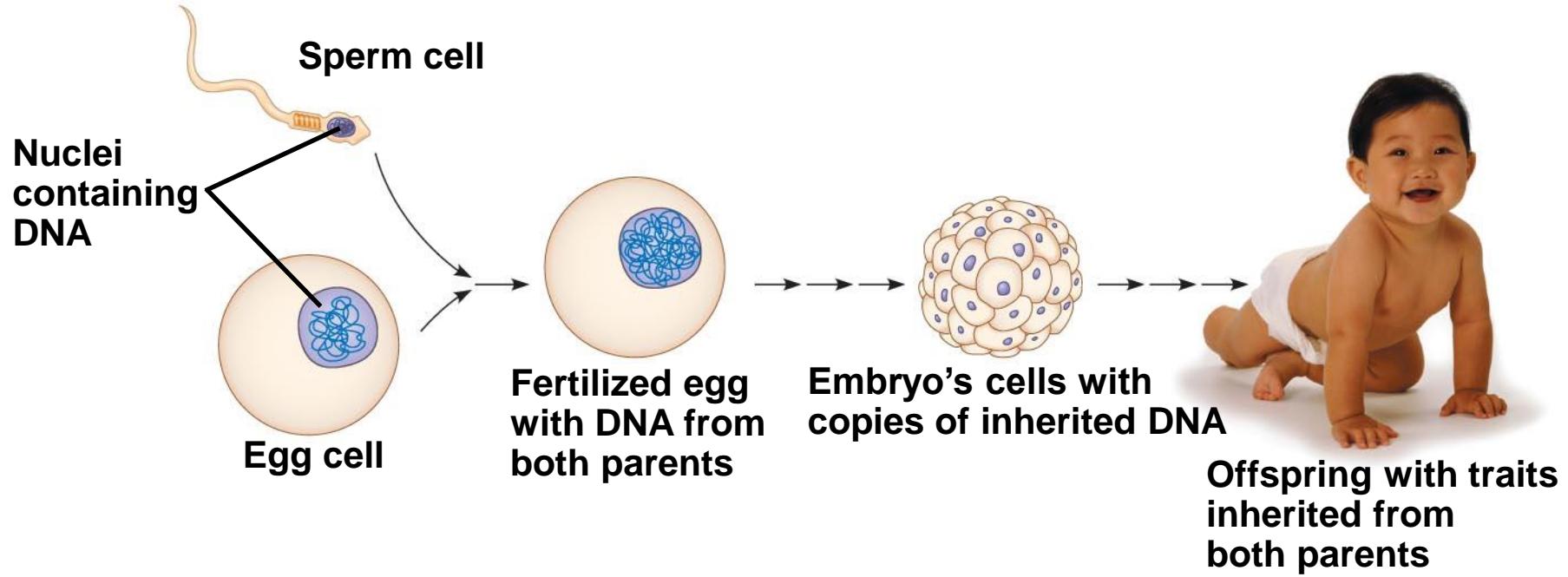


Theme: The continuity of life is based on heritable information in the form of DNA

- 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

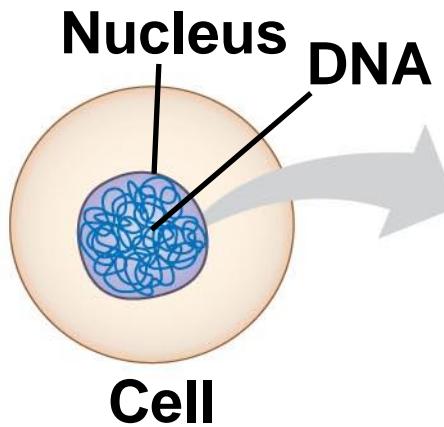
DNA Structure and Function

- 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



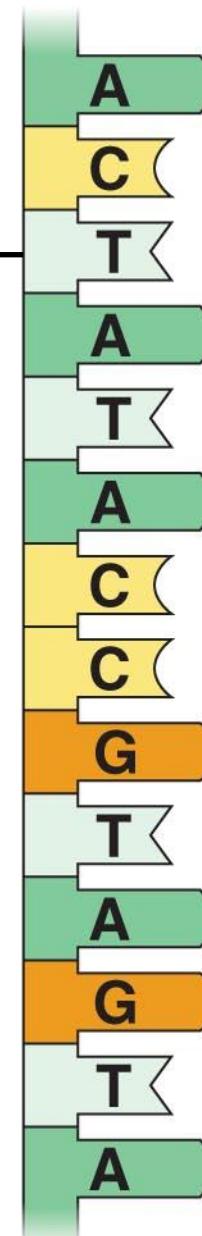
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- Each DNA molecule is made up of two long chains arranged in a double helix
 - Each link of a chain is one of four kinds of chemical building blocks called nucleotides



(a) DNA double helix

Nucleotide



(b) Single strand of DNA

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- 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

Systems Biology at the Levels of Cells and Molecules

- The human genome and those of many other organisms have been sequenced using DNA-sequencing machines
- Knowledge of a cell's genes and proteins can be integrated using a systems approach

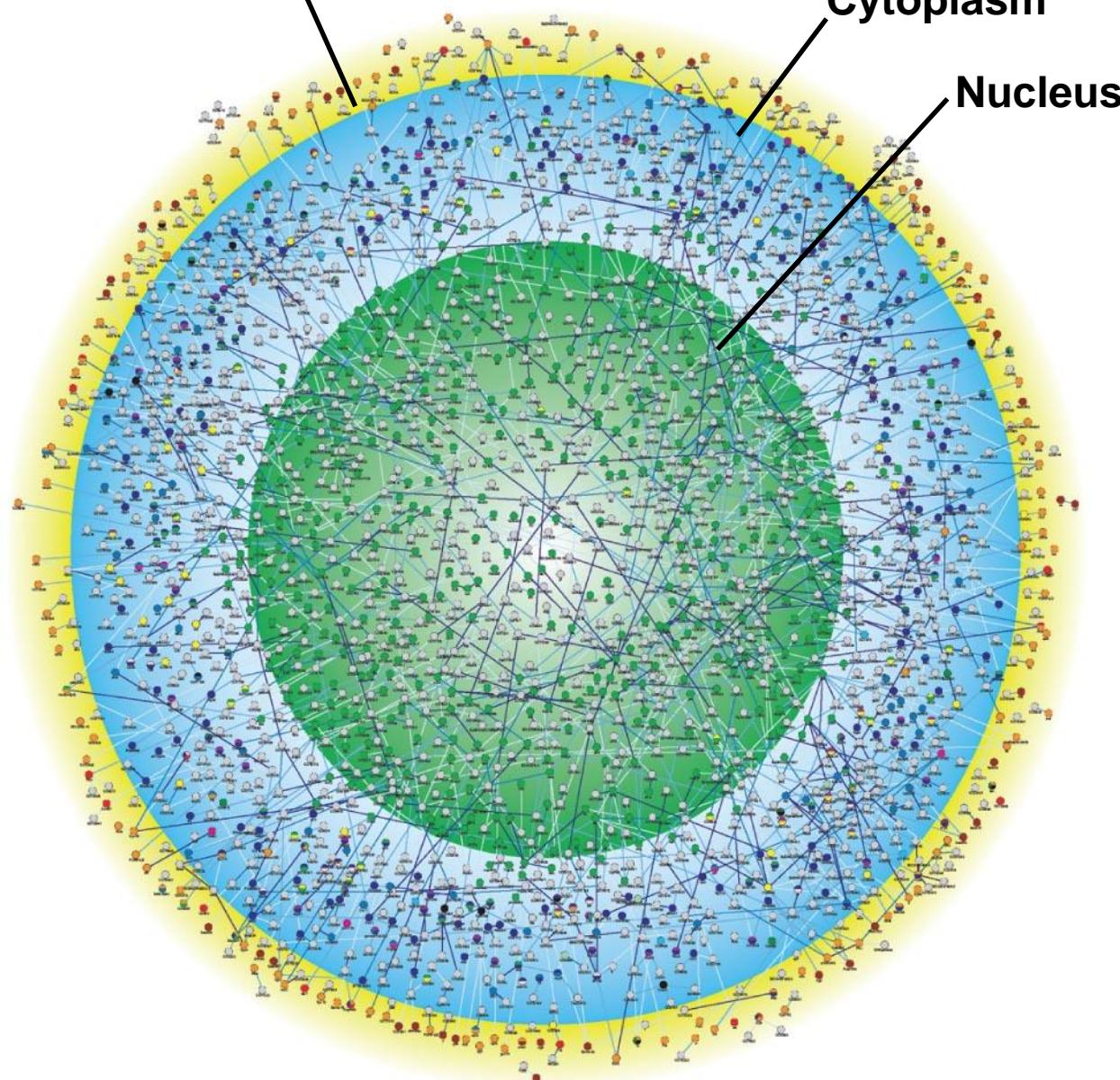


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**Outer membrane
and cell surface**

Cytoplasm

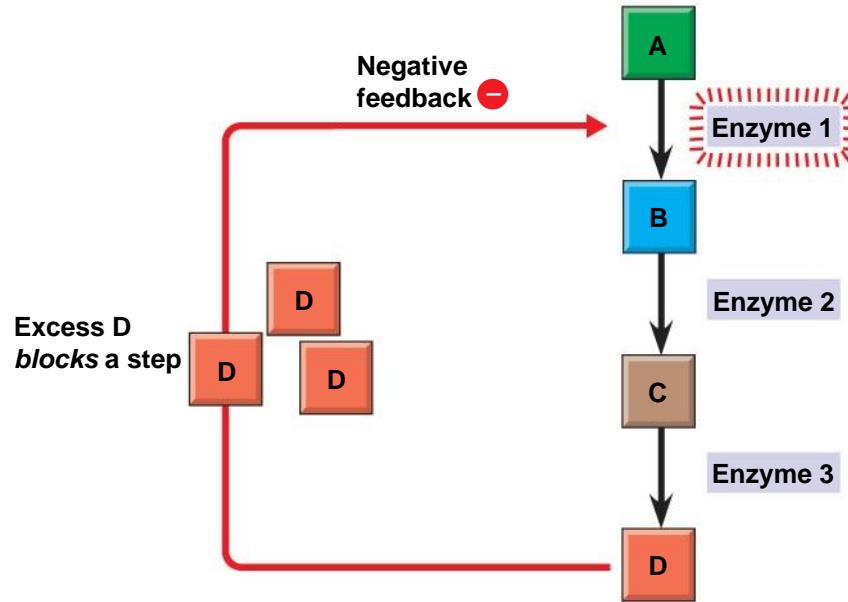
Nucleus



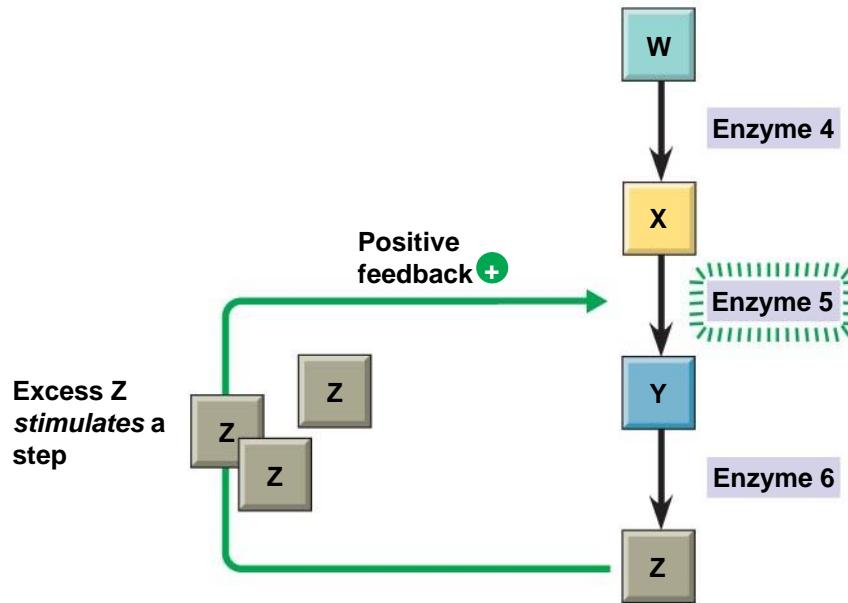
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- Advances in systems biology at the cellular and molecular level depend on
 - “High-throughput” technology, which yields enormous amounts of data
 - **Bioinformatics**, which is the use of computational tools to process a large volume of data
 - Interdisciplinary research teams

Theme: Feedback mechanisms regulate biological systems

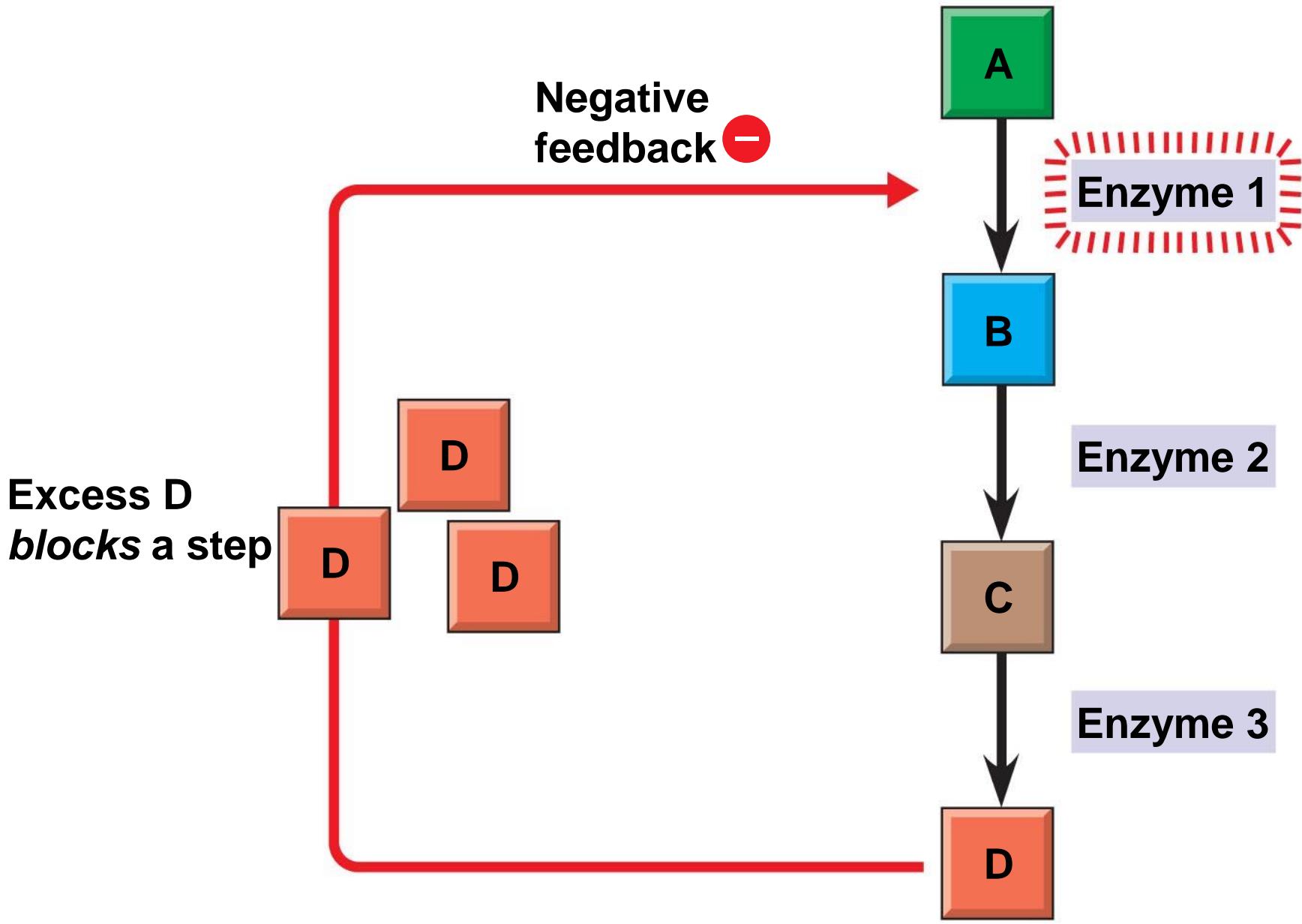
- Feedback mechanisms allow biological processes to self-regulate
- **Negative feedback** means that as more of a product accumulates, the process that creates it *slows* and *less* of the product is produced
- **Positive feedback** means that as more of a product accumulates, the process that creates it *speeds up* and *more* of the product is produced



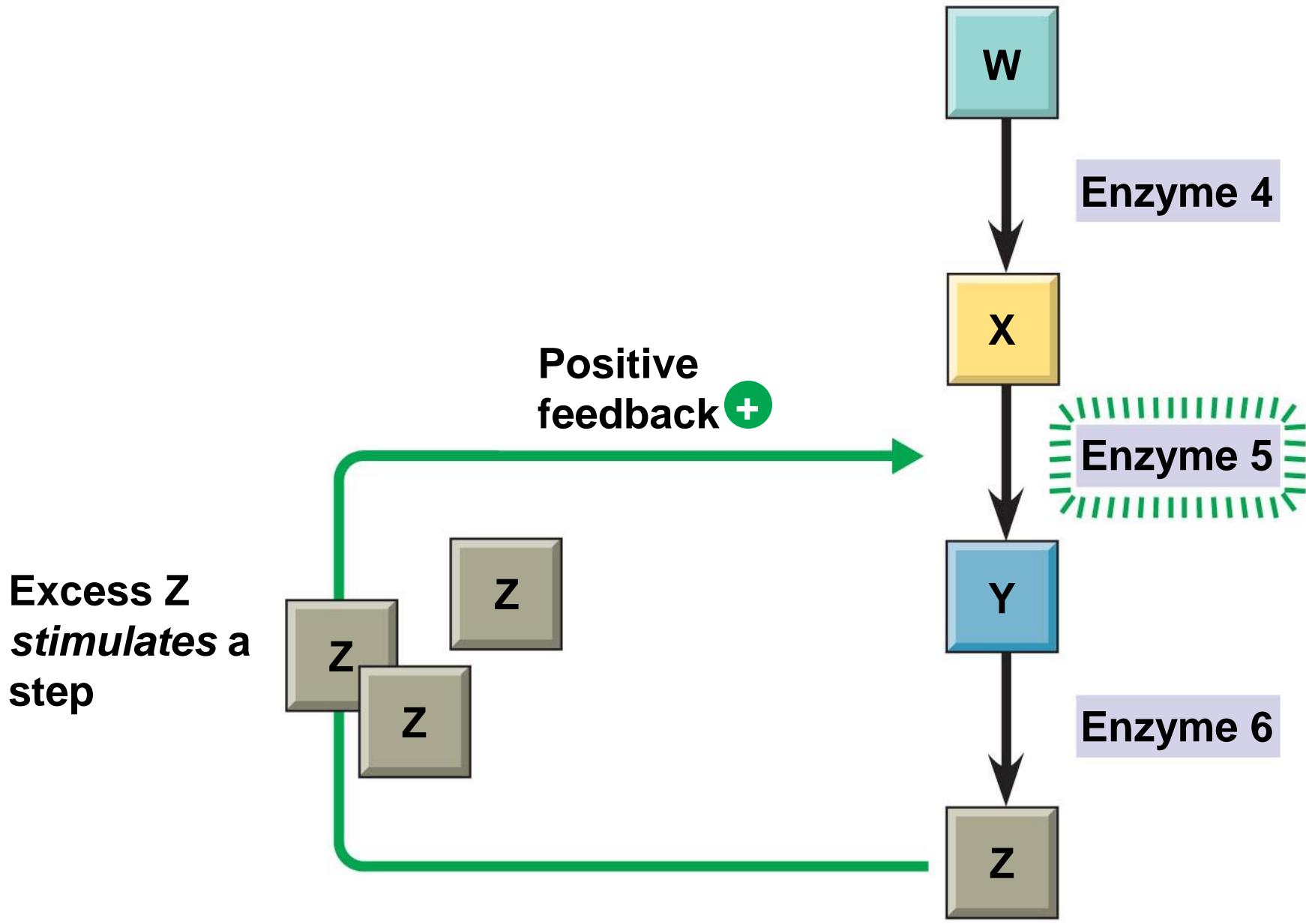
(a) Negative feedback



(b) Positive feedback



(a) Negative feedback



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

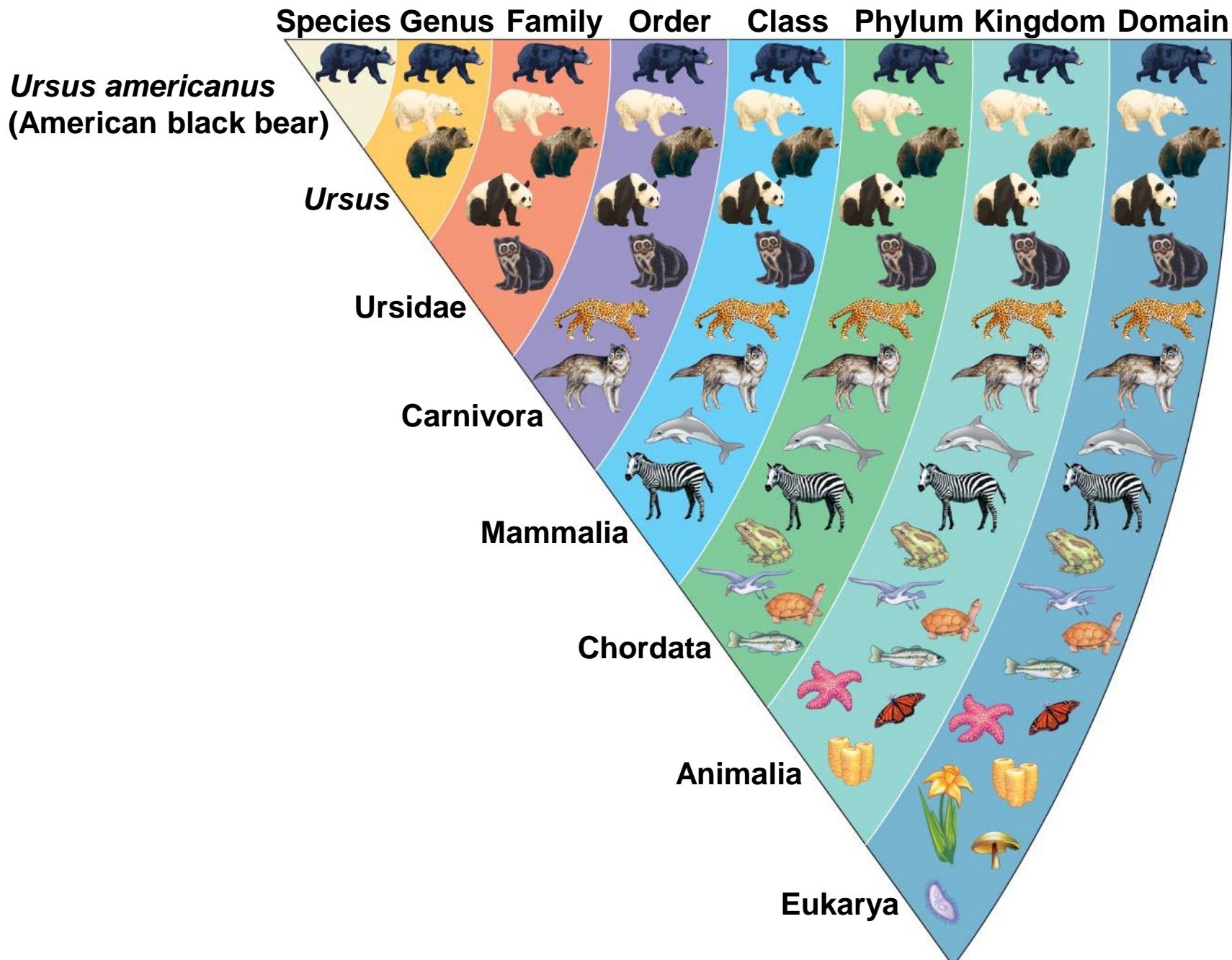
- “Nothing in biology makes sense except in the light of evolution”—Theodosius Dobzhansky
- Evolution unifies biology at different scales of size throughout the history of life on Earth

Organizing the Diversity of Life

- 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

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



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

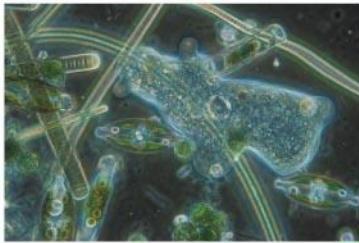
(a) DOMAIN BACTERIA



(b) DOMAIN ARCHAEA



(c) DOMAIN EUKARYA



Protists



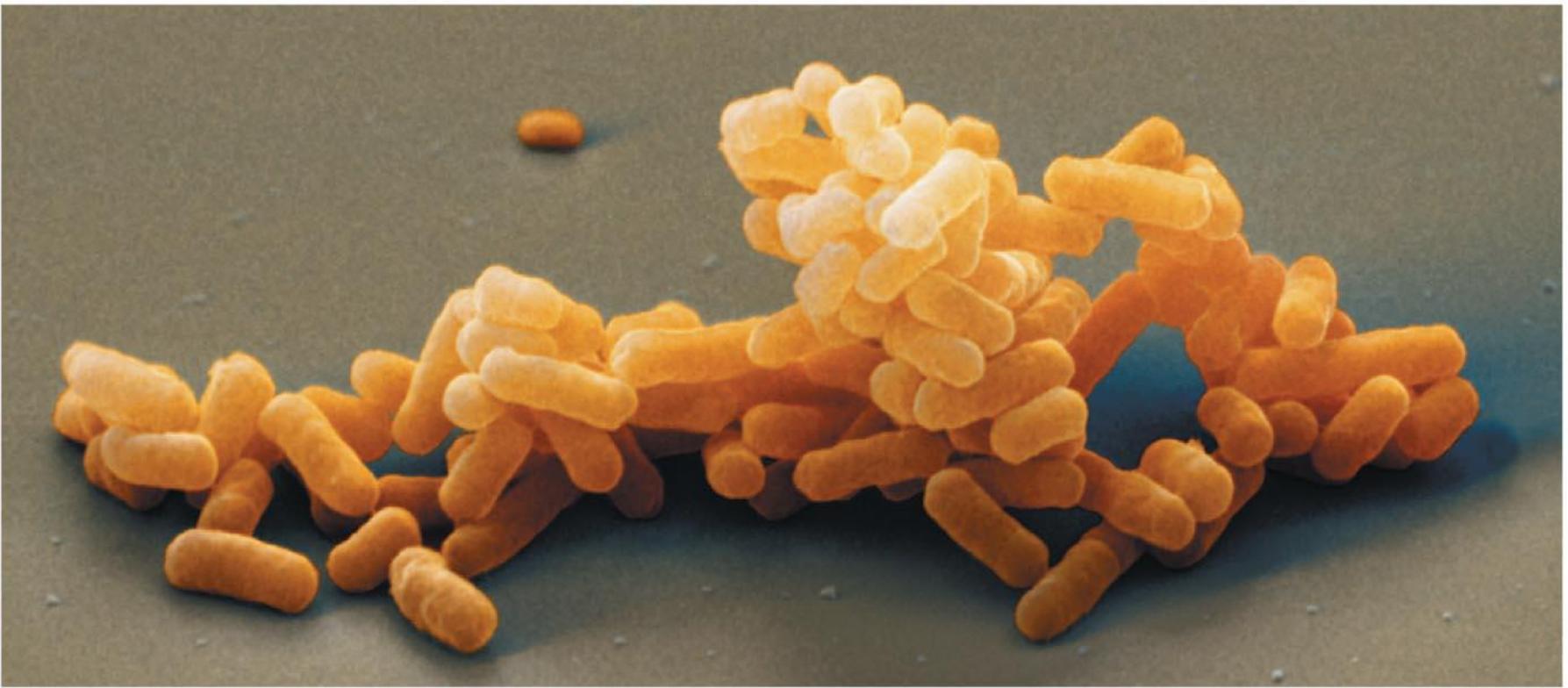
Kingdom Fungi



Kingdom Plantae



Kingdom Animalia



(a) DOMAIN BACTERIA

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(b) DOMAIN ARCHAEA

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- 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



Protists



Kingdom Fungi



Kingdom Plantae



Kingdom Animalia

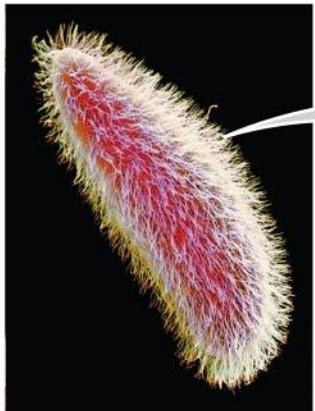
(c) DOMAIN EUKARYA

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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
 - Unity is evident in many features of cell structure

15 μm



Cilia of
Paramecium

5 μm



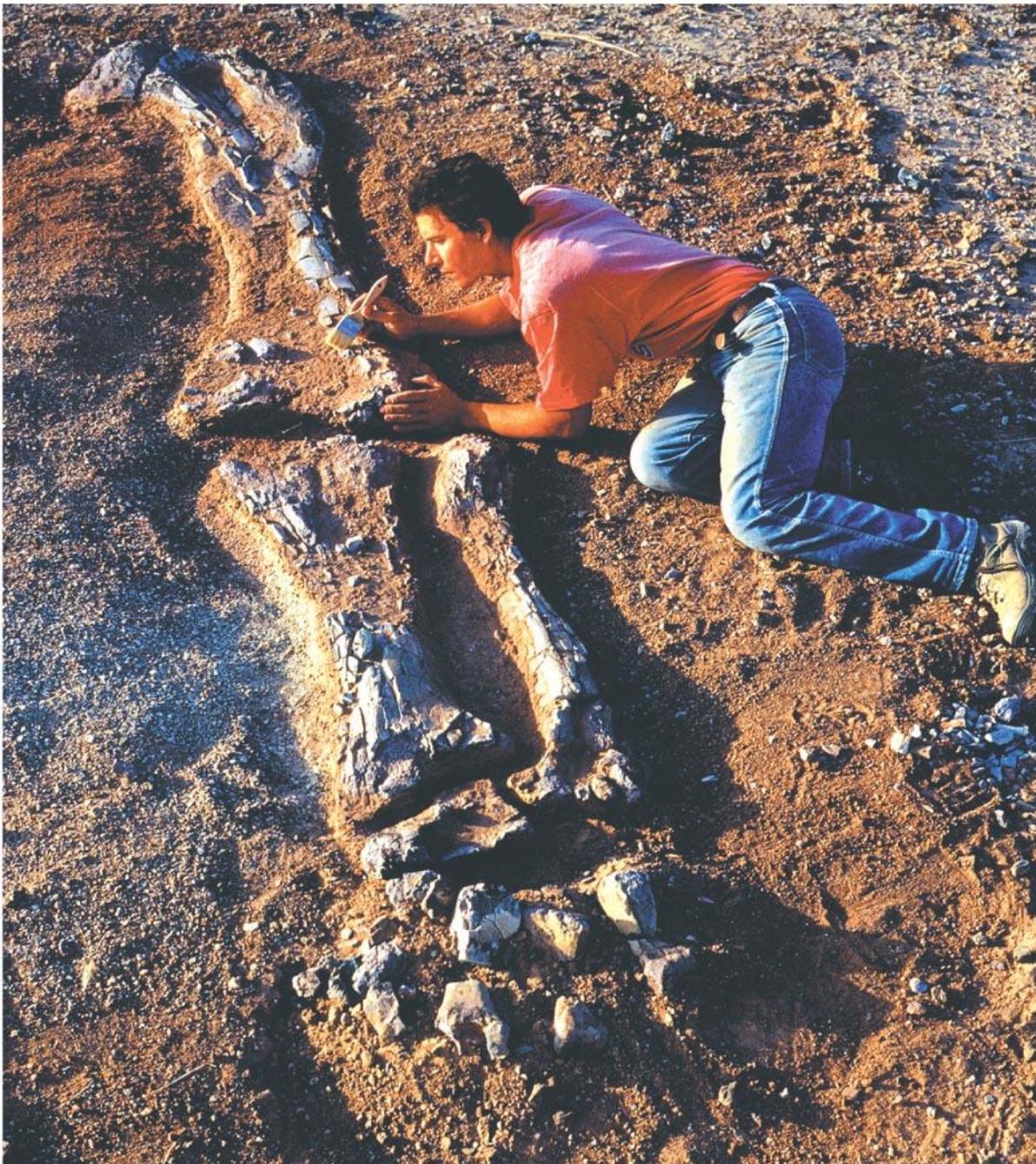
Cilia of
windpipe
cells

0.1 μm

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

Charles Darwin and the Theory of Natural Selection

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



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- 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 explained the duality of unity and diversity
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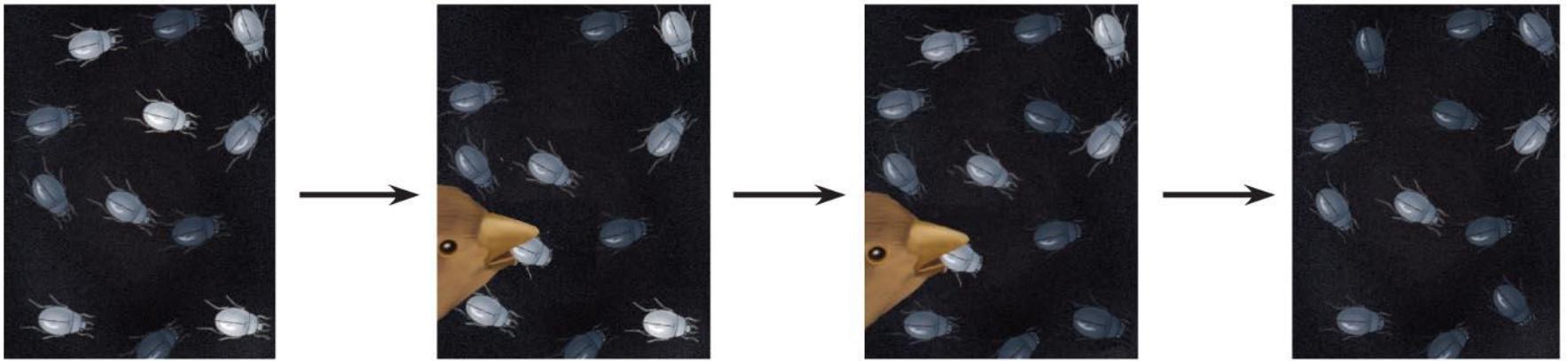
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- Darwin observed that:
 - Individuals in a population have traits that vary
 - Many of these traits are heritable (passed from parents to offspring)
 - More offspring are produced than survive
 - Competition is inevitable
 - Species generally suit 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.

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- Natural selection is often evident in adaptations of organisms to their way of life and environment
 - Bat wings are an example of adaptation

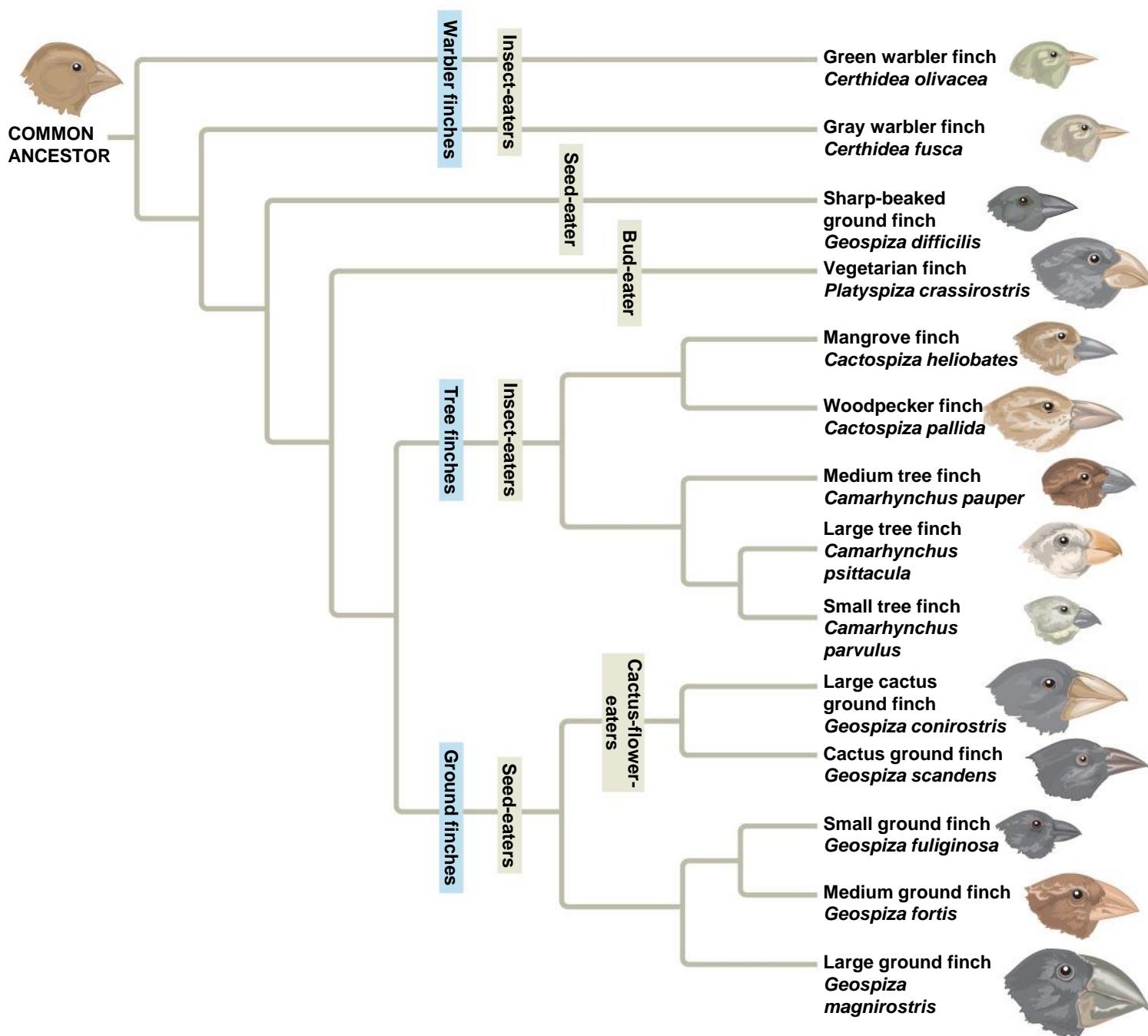


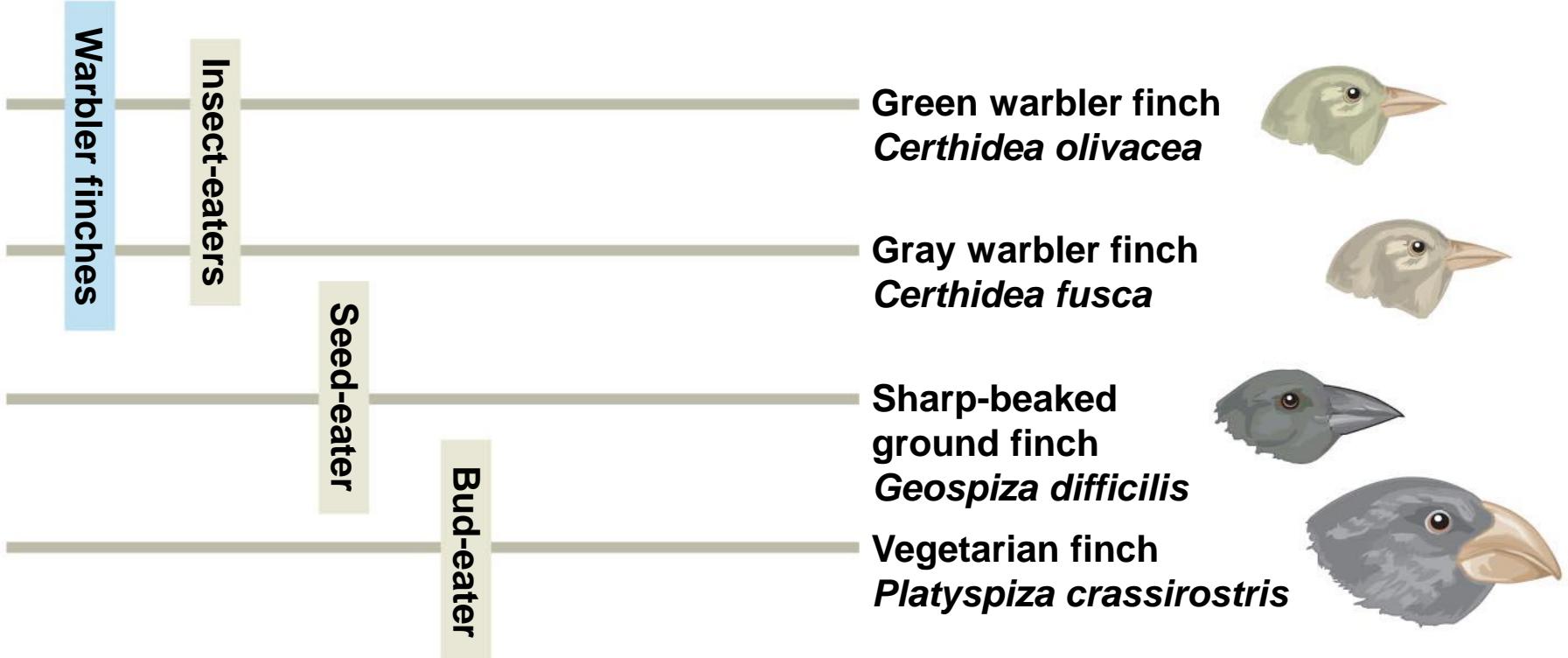
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The Tree of Life

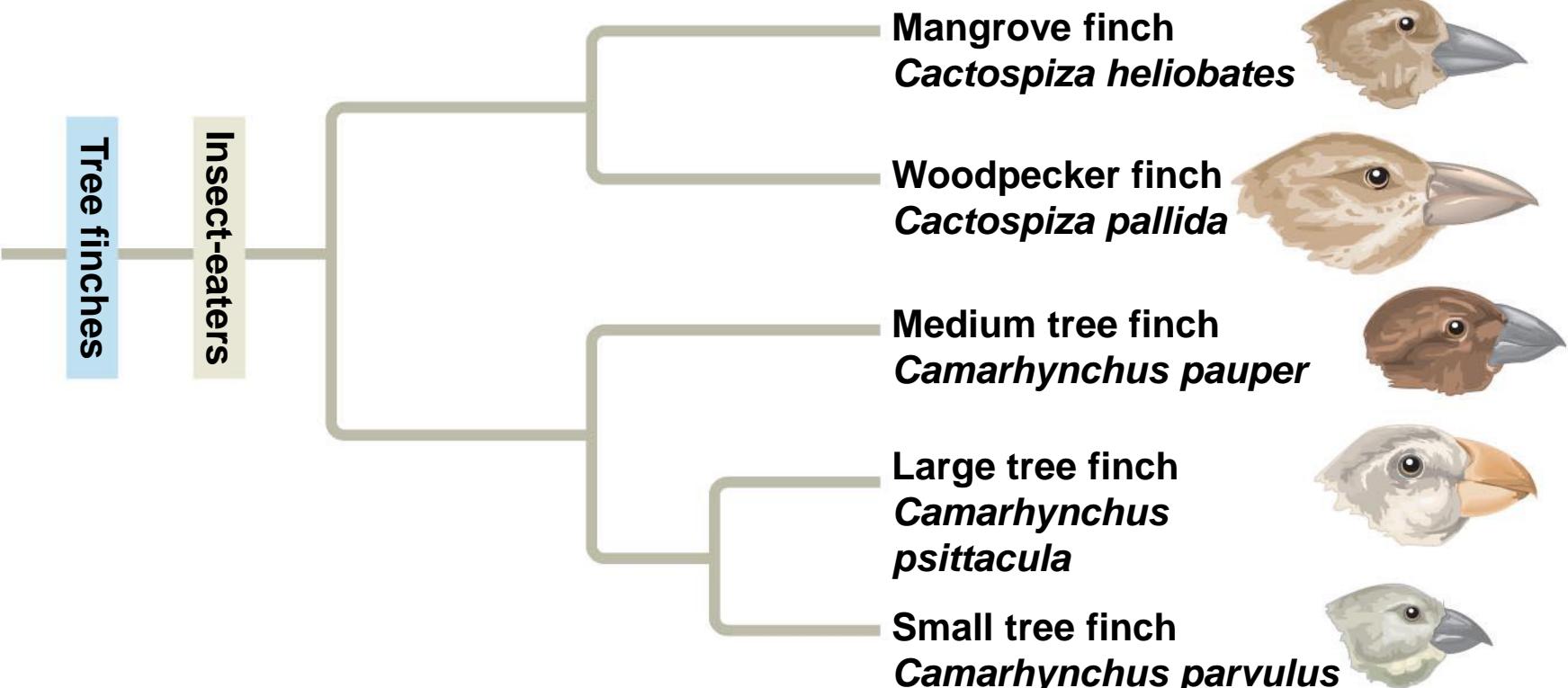
- “Unity in diversity” arises from “descent with modification”
 - For example, the forelimb of the bat, human, horse and the whale flipper all share a common skeletal architecture
- Fossils provide additional evidence of anatomical unity from descent with modification

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- Darwin proposed that natural selection could cause an ancestral species to give rise to two or more descendant species
 - For example, the finch species of the Galápagos Islands
 - Evolutionary relationships are often illustrated with tree-like diagrams that show ancestors and their descendants

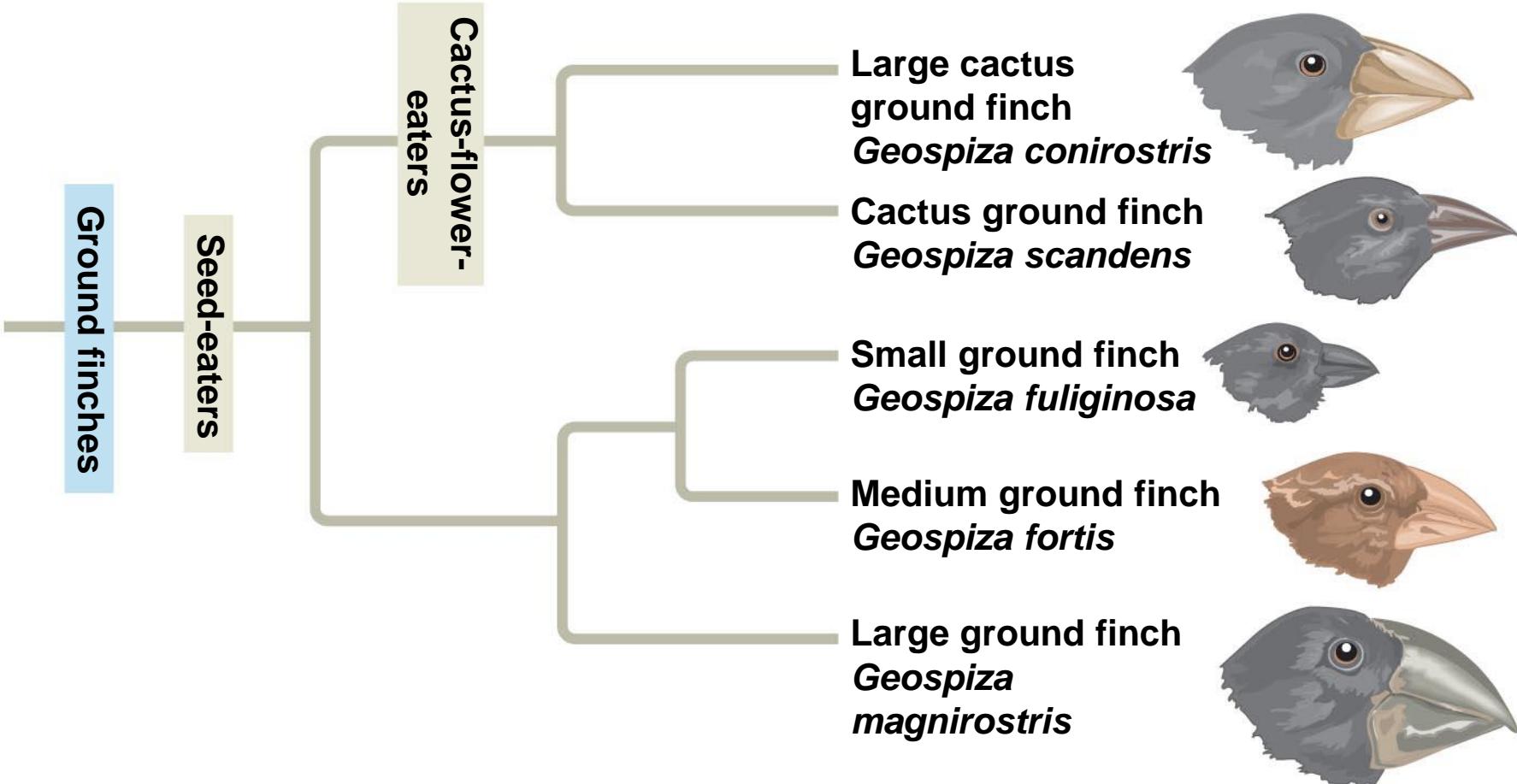




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Concept 1.3: Scientists use two main forms of inquiry in their study of nature

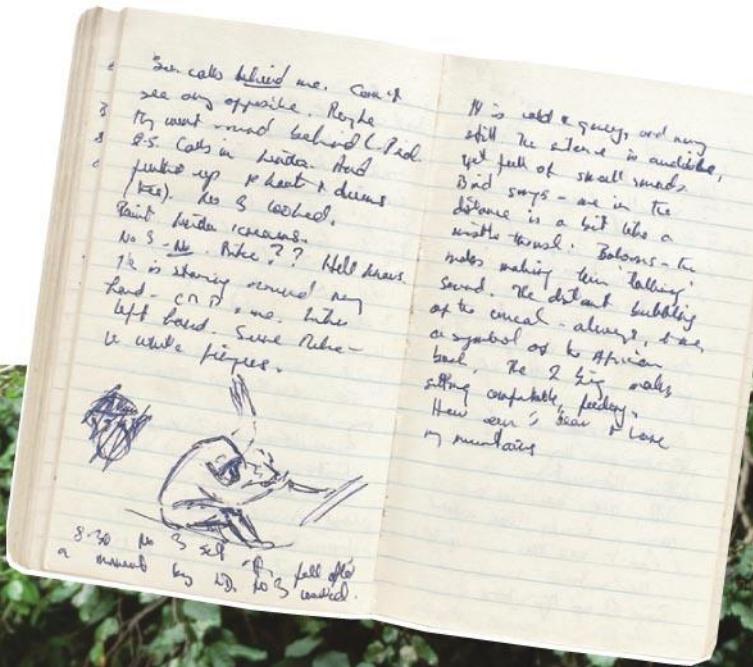
- The word *Science* is derived from Latin and means “to know”
- **Inquiry** is the search for information and explanation
- There are two main types of scientific inquiry: discovery science and hypothesis-based science

Discovery Science

- **Discovery science** describes natural structures and processes
- This approach is based on observation and the analysis of data

Types of Data

- **Data** are recorded observations or items of information
- Data fall into two categories
 - *Qualitative*, or descriptions rather than measurements
 - *Quantitative*, or recorded measurements, which are sometimes organized into tables and graphs



Induction in Discovery Science

- **Inductive reasoning** draws conclusions through the logical process of induction
- Repeat specific observations can lead to important generalizations
 - For example, “the sun always rises in the east”

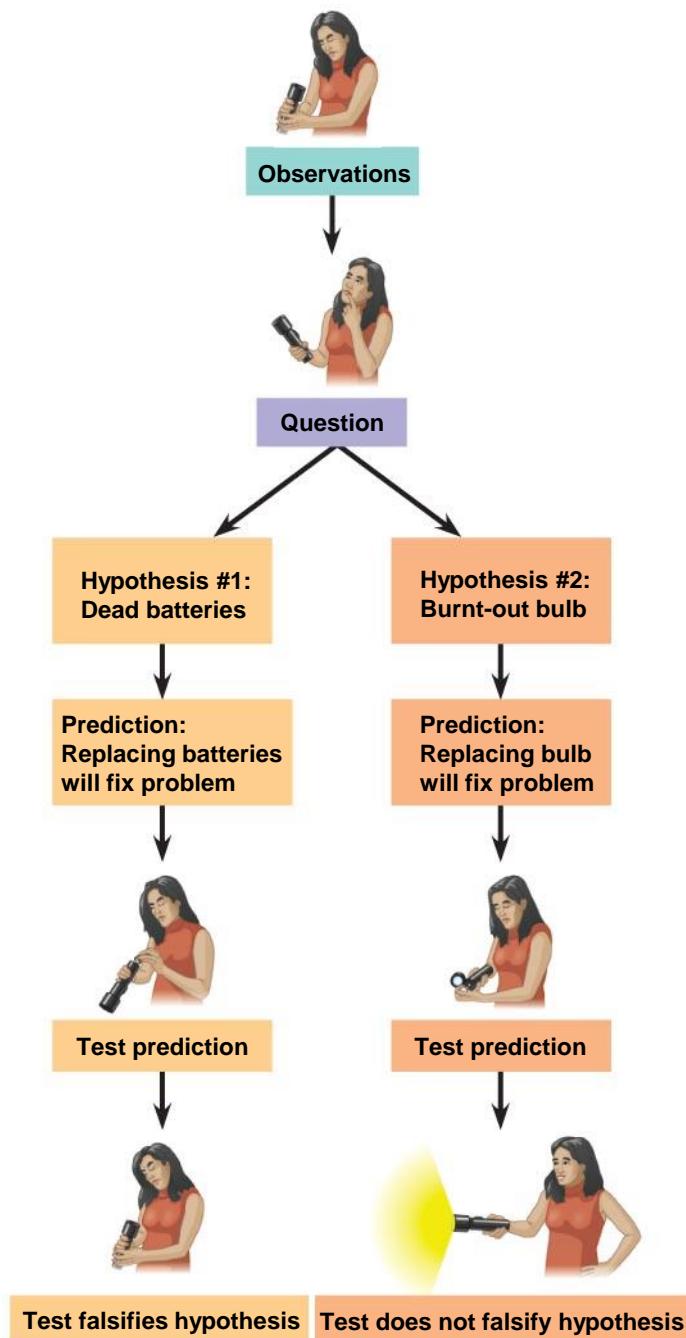
Hypothesis-Based Science

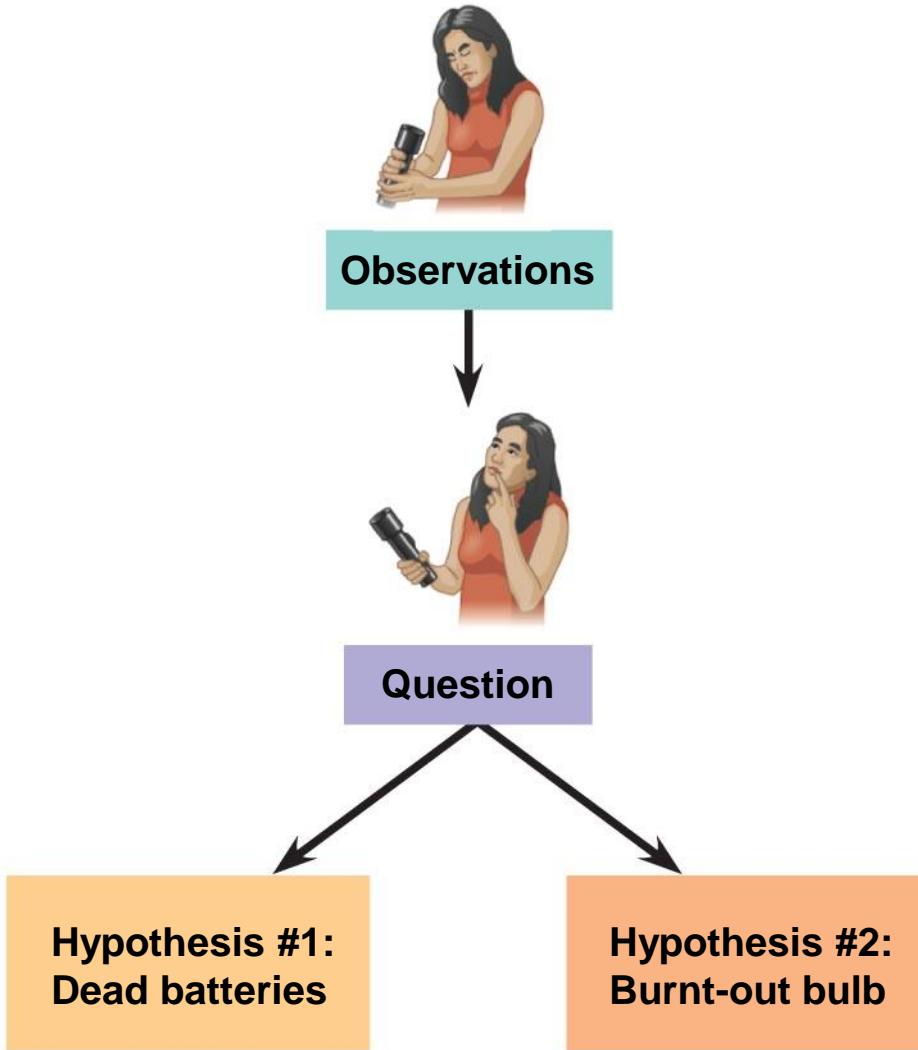
- Observations can lead us to ask questions and propose hypothetical explanations called **hypotheses**

The Role of Hypotheses in Inquiry

- A **hypothesis** is a tentative answer to a well-framed question
- A scientific hypothesis leads to predictions that can be tested by observation or experimentation

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- 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





**Hypothesis #1:
Dead batteries**



**Prediction:
Replacing batteries
will fix problem**



Test prediction



**Hypothesis #2:
Burnt-out bulb**



**Prediction:
Replacing bulb
will fix problem**



Test prediction



Test falsifies hypothesis

Test does not falsify hypothesis

Deduction: The “If...Then” Logic of Hypothesis Based Science

- **Deductive reasoning** uses general premises to make specific predictions
- For example, *if* organisms are made of cells (premise 1), and humans are organisms (premise 2), *then* humans are composed of cells (deductive prediction)

A Closer Look at Hypotheses in Scientific Inquiry

- A hypothesis must be *testable* and *falsifiable*
- Hypothesis-based science often makes use of two or more alternative hypotheses
- Failure to falsify a hypothesis does not *prove* that hypothesis
 - For example, you replace your flashlight bulb, and it now works; this supports the hypothesis that your bulb was burnt out, but does not prove it (perhaps the first bulb was inserted incorrectly)

The Myth of the Scientific Method

- The *scientific method* is an idealized process of inquiry
- Hypothesis-based science is based on the “textbook” scientific method but rarely follows all the ordered steps
- Discovery science has made important contributions with very little dependence on the so-called scientific method

A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations

- Many poisonous species are brightly colored, which warns potential predators
- Mimics are harmless species that closely resemble poisonous species
- Henry Bates hypothesized that this mimicry evolved in harmless species as an evolutionary adaptation that reduces their chances of being eaten

- This hypothesis was tested with the poisonous eastern coral snake and its mimic the nonpoisonous scarlet kingsnake
- Both species live in the Carolinas, but the kingsnake is also found in regions without poisonous coral snakes
- If predators inherit an avoidance of the coral snake's coloration, then the colorful kingsnake will be attacked less often in the regions where coral snakes are present

Scarlet kingsnake (nonpoisonous)



Key

- Range of scarlet kingsnake only
- Overlapping ranges of scarlet kingsnake and eastern coral snake



Scarlet kingsnake (nonpoisonous)



Eastern coral snake (poisonous)

Field Experiments with Artificial Snakes

- To test this mimicry hypothesis, researchers made hundreds of artificial snakes:
 - An experimental group resembling kingsnakes
 - A control group resembling plain brown snakes
- Equal numbers of both types were placed at field sites, including areas without poisonous coral snakes



(a) Artificial kingsnake



(b) Brown artificial snake that has been attacked



(a) Artificial kingsnake

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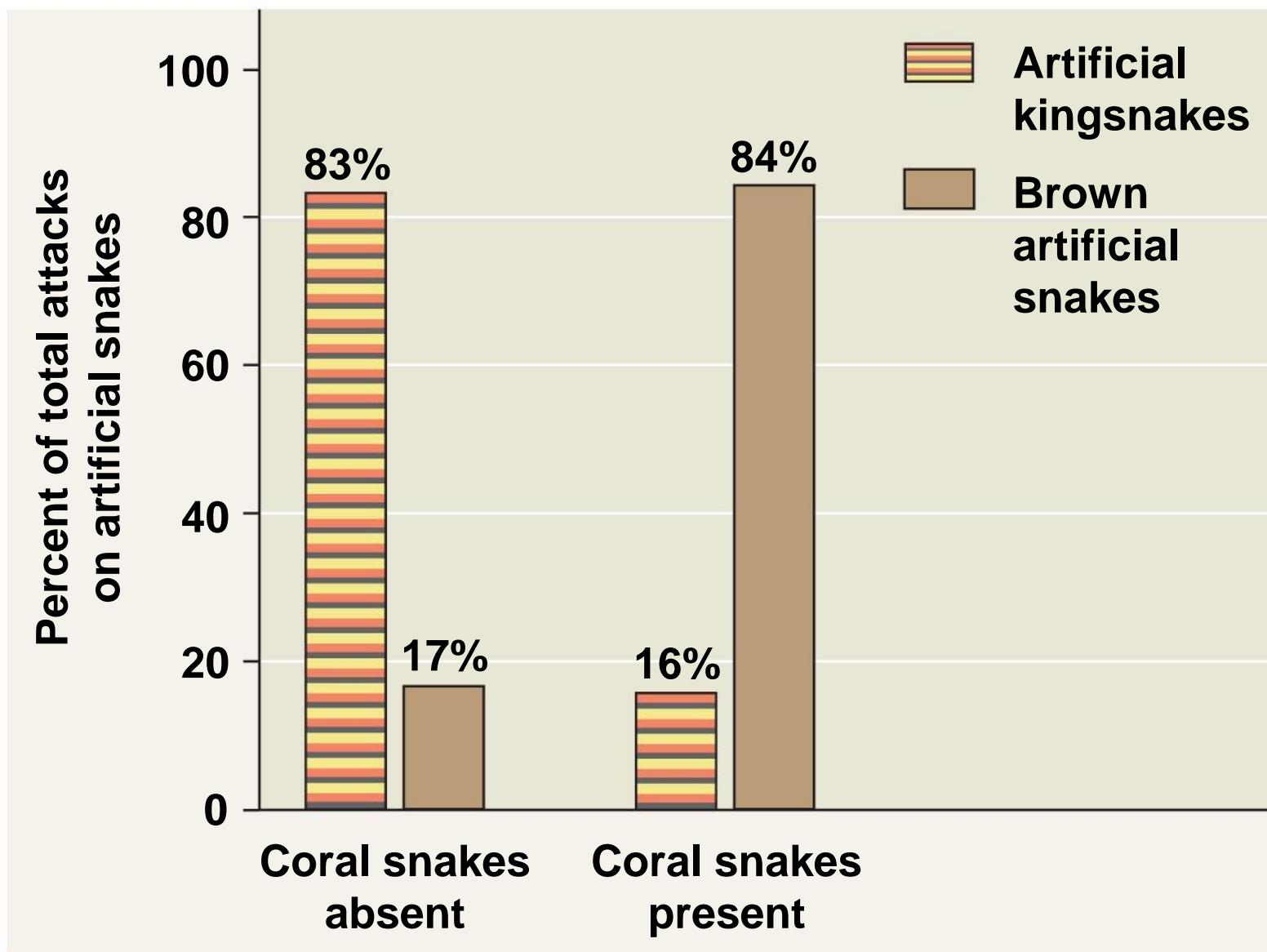


(b) Brown artificial snake that has been attacked

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- After four weeks, the scientists retrieved the artificial snakes and counted bite or claw marks
 - The data fit the predictions of the mimicry hypothesis: the ringed snakes were attacked less frequently in the geographic region where coral snakes were found

RESULTS



Designing Controlled Experiments

- A **controlled experiment** compares an experimental group (the artificial kingsnakes) with a control group (the artificial brown snakes)
- Ideally, only the variable of interest (the color pattern of the artificial snakes) 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

Limitations of Science

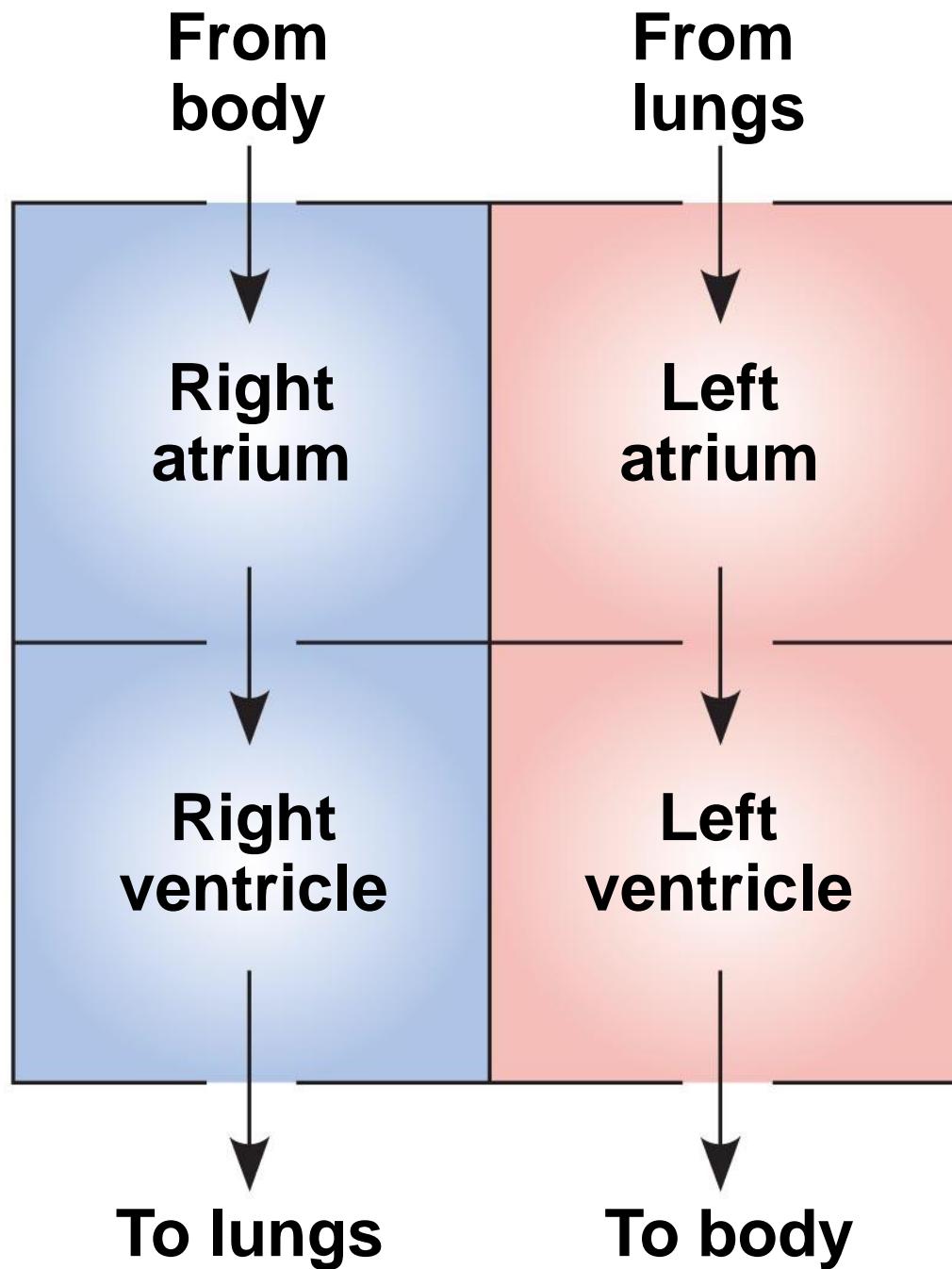
- In science, observations and experimental results must be repeatable
- Science cannot support or falsify supernatural explanations, which are outside the bounds of science

Theories in Science

- In the context of science, a **theory** is:
 - Broader in scope than a hypothesis
 - General, and can lead to new testable hypotheses
 - Supported by a large body of evidence in comparison to a hypothesis

Model Building in Science

- **Models** are representations of natural phenomena and can take the form of:
 - Diagrams
 - Three-dimensional objects
 - Computer programs
 - Mathematical equations



The Culture of Science

- Most scientists work in teams, which often include graduate and undergraduate students
- Good communication is important in order to share results through seminars, publications, and websites

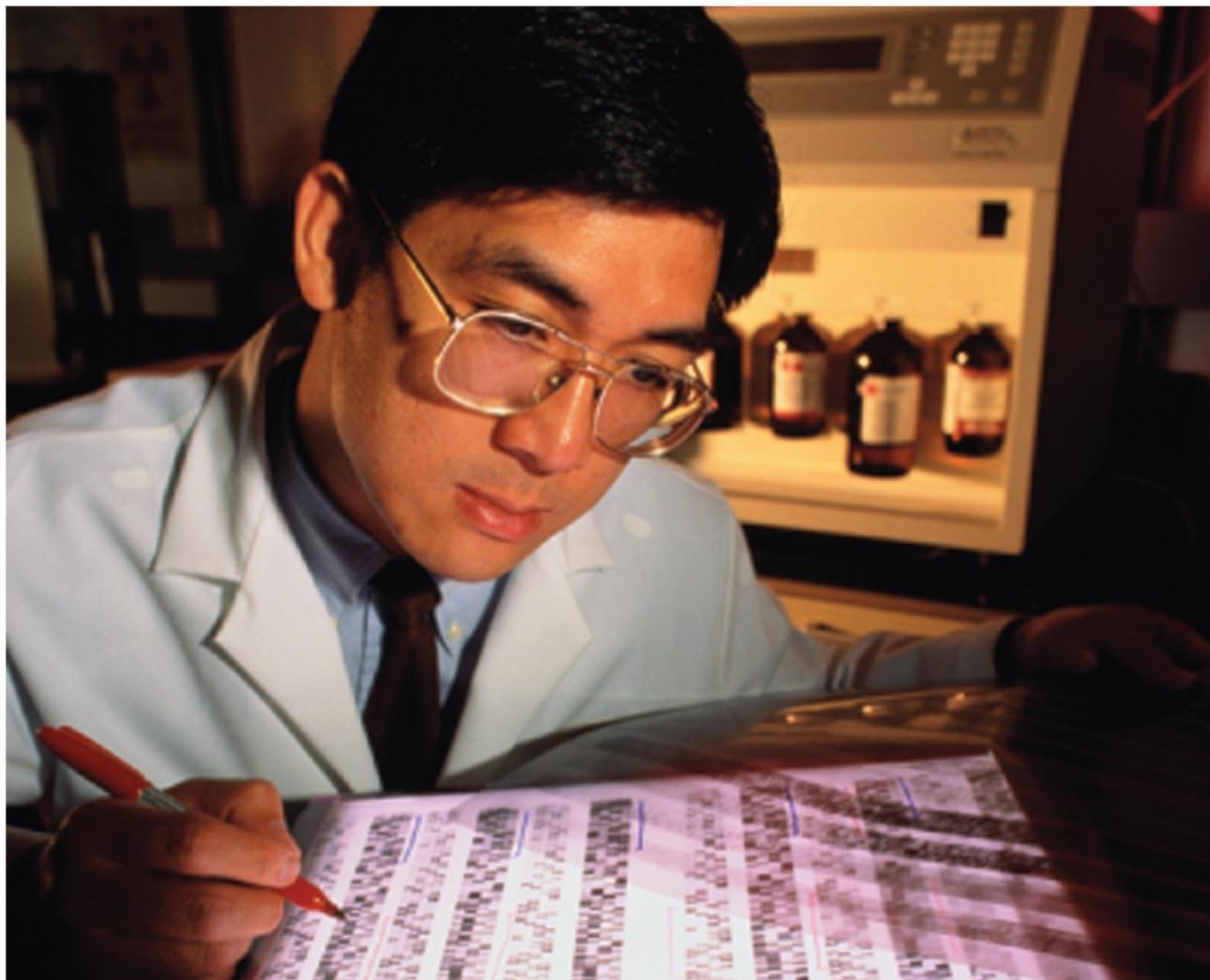


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Science, Technology, and Society

- The goal of science is to understand natural phenomena
- The goal of **technology** is to *apply* scientific knowledge for some specific purpose
- Science and technology are interdependent
- Biology is marked by “discoveries,” while technology is marked by “inventions”

- The combination of science and technology has dramatic effects on society
 - For example, the discovery of DNA by James Watson and Francis Crick allowed for advances in DNA technology such as testing for hereditary diseases
- Ethical issues can arise from new technology, but have as much to do with politics, economics, and cultural values as with science and technology



You should now be able to:

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