Biology Themes

ENV-103

Teachers

Prof. Ianina Altshuler MACE lab

Environmental Microbiology

Dr. Anna Carratala Ripolles

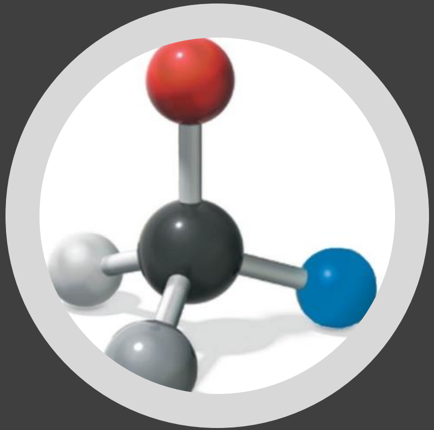
Aquatic Ecology of Microorganisms

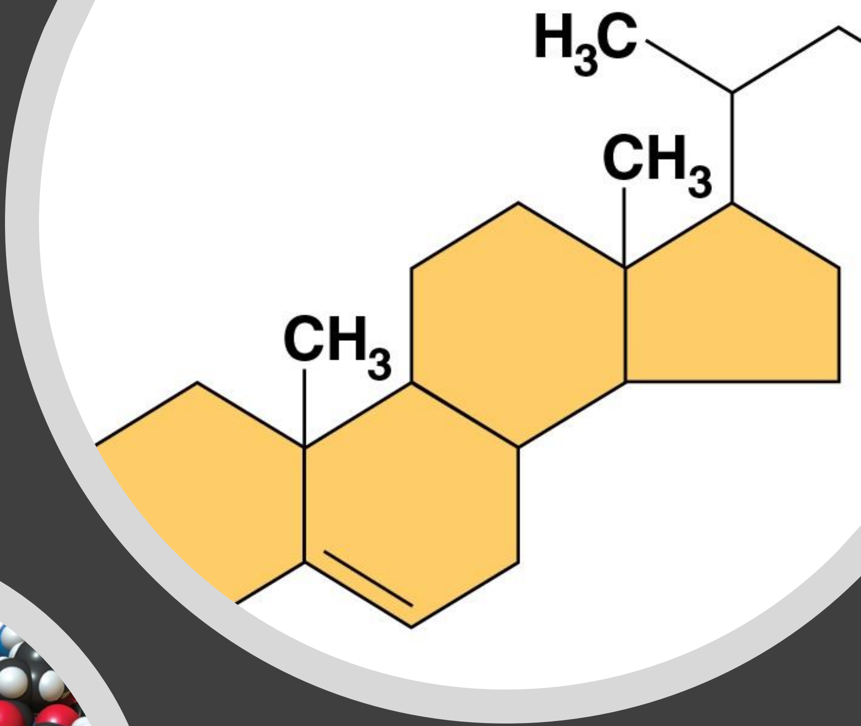
Lectures

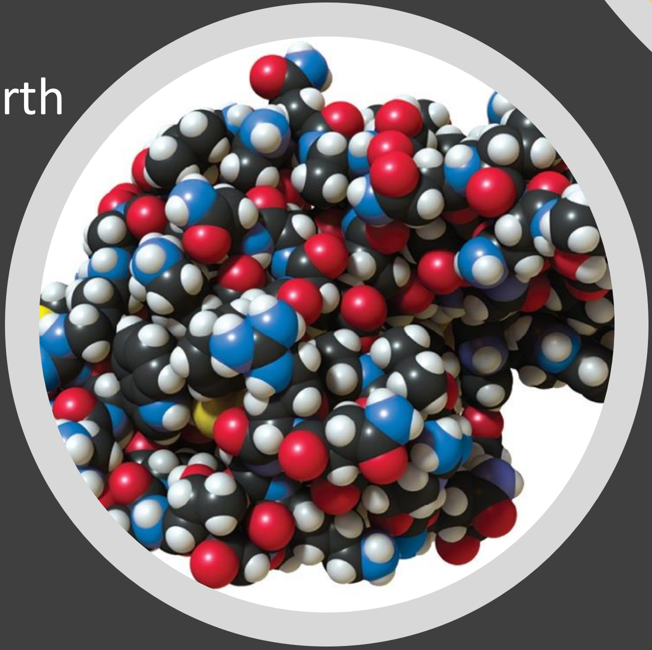
- Tuesdays: 10:00 - 12:00
- Wednesdays: 10:00 - 12:00

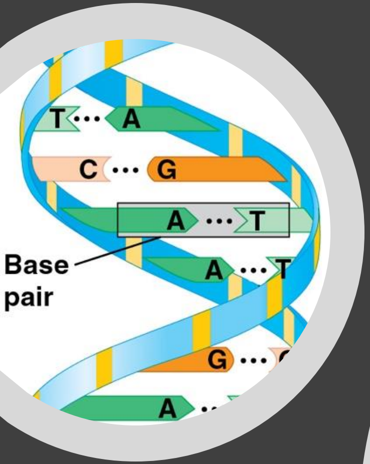
Course topics

- Themes of Biology
- Water, Carbon, Life
- Biomolecules
- Cellular structures and functions
- Cellular biochemistry
- Respiration and Metabolism
- Photosynthesis
- DNA and Genes
- Evolution
- Cell division
- History of life on Earth
- Biological diversity on Earth
- Ecology









Teaching Assistants

Grace

Anastasiia

Haohua

Nuri

Linus

Maël

Exercise Sessions

- Tuesdays 13:00 - 15:00
- Time to ask questions and clarify concepts
- Practice questions

Why Biology for Environmental Engineers?

Ancient dam at Peloponnese,
Greese

Why Biology for Environmental Engineers?

Fish biodiversity declines with dam development in the Lower Mekong Basin – Sor et al. 2023

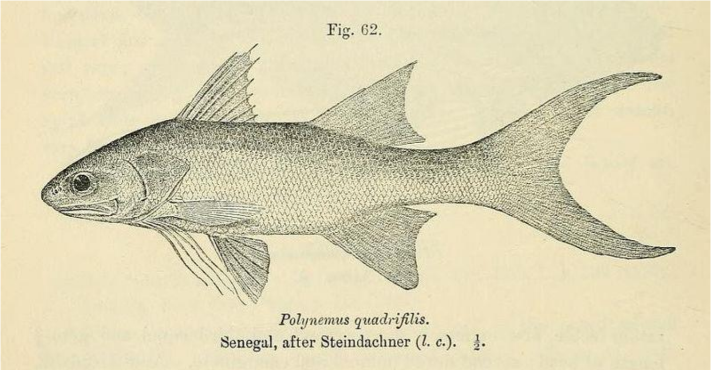
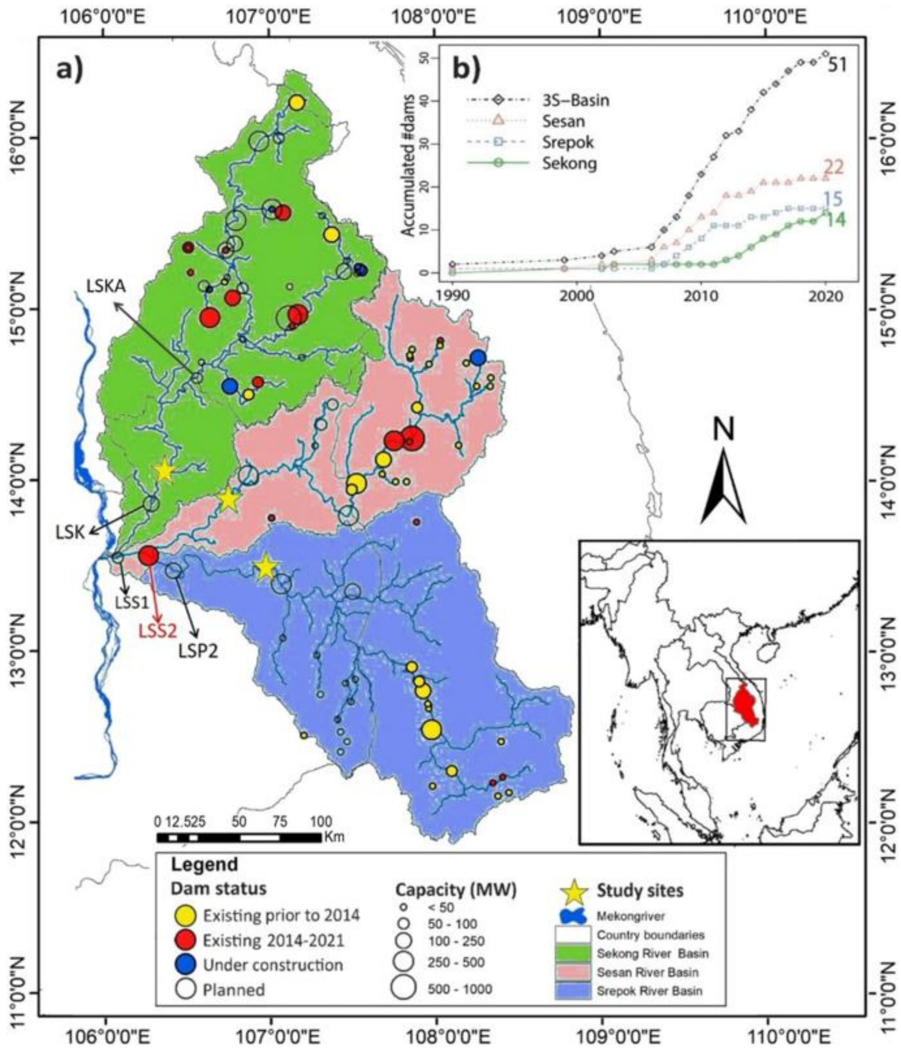


Fig. 62.

Polynemus quadrifilis.
Senegal, after Steindachner (*l. c.*). ½.



Why Biology for Environmental Engineers?

What happens when a mine closes?
Land reclamation?
Ecosystem remediation?

Industrial Microbiology

Wastewater Treatment: Microbes are used to clean wastewater.

Bioremediation: Microbes are used to clean contaminated environments.

Biofilms: Microbes grow on surfaces and can foul pipes and pipelines.

Biotechnology: Microbes can be genetically modified to produce high-value products such as pharmaceuticals and enzymes.

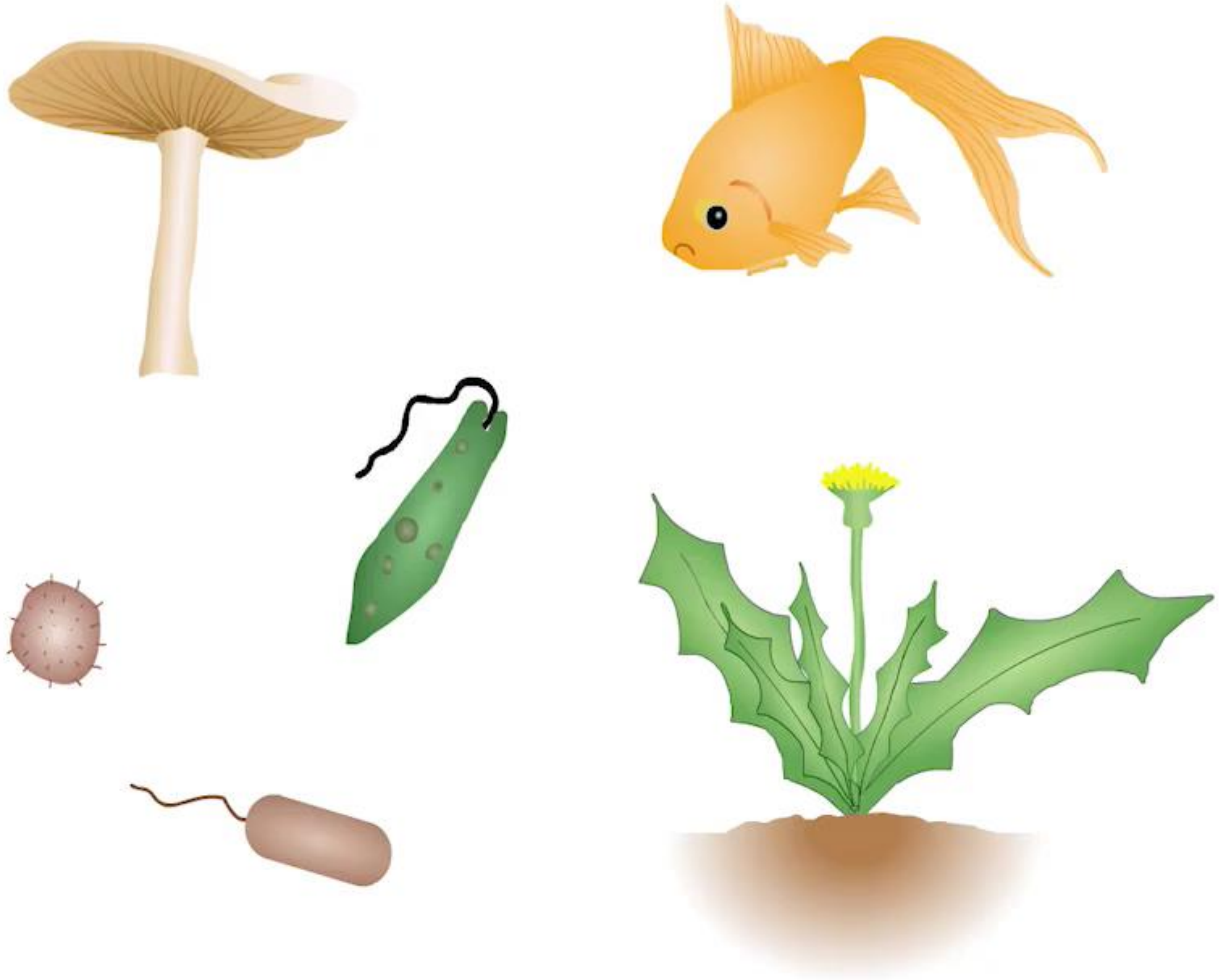
Fermentation: Microbes are used at industrial scale to make chemicals, solvents, enzymes, and pharmaceuticals.

Biofuels: Microbes are used to convert biomass into ethanol and wastes into natural gas (methane).

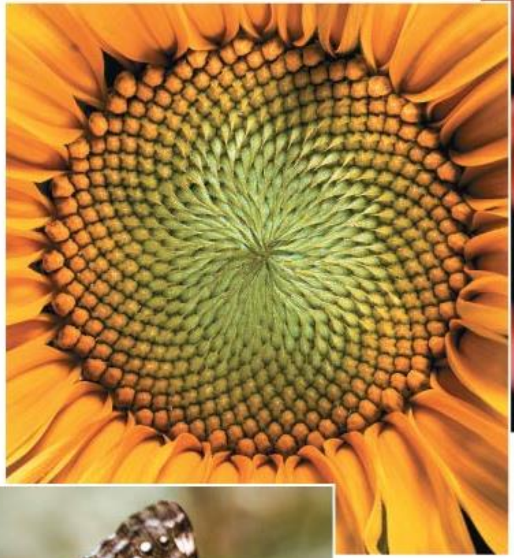
Inquiring About Life

- **Biology** is the scientific study of life
  - How does a single cell develop into an organism?
- Biology is an ongoing inquiry about the nature of life
- Life does not have a simple one-sentence definition
- Life is recognized by what living things do

Properties of Life



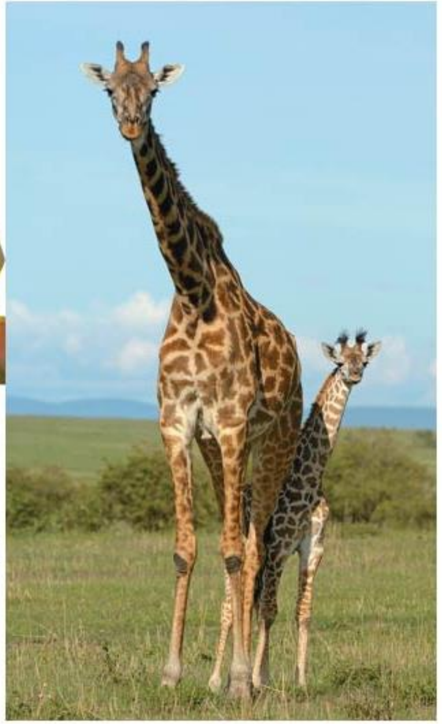
Order



Evolutionary adaptation

Regulation

Reproduction

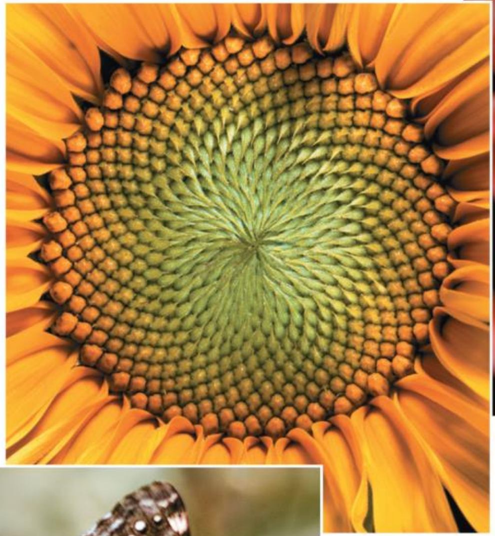


Energy processing

Growth and development

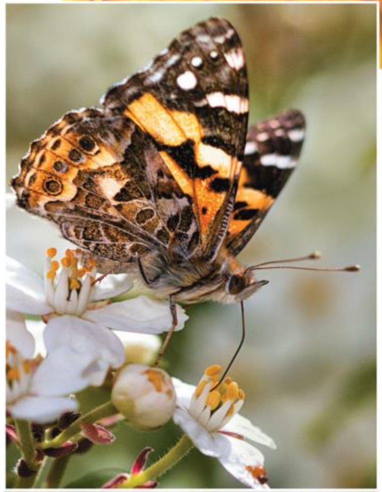
Response to the environment

▼ **Order.** This close-up of a sunflower illustrates the highly ordered structure that characterizes life.



▲ **Evolutionary adaptation.** The overall appearance of this pygmy sea horse camouflages the animal in its environment. Such adaptations evolve over countless generations by the reproductive success of those individuals with heritable traits that are best suited to their environments.

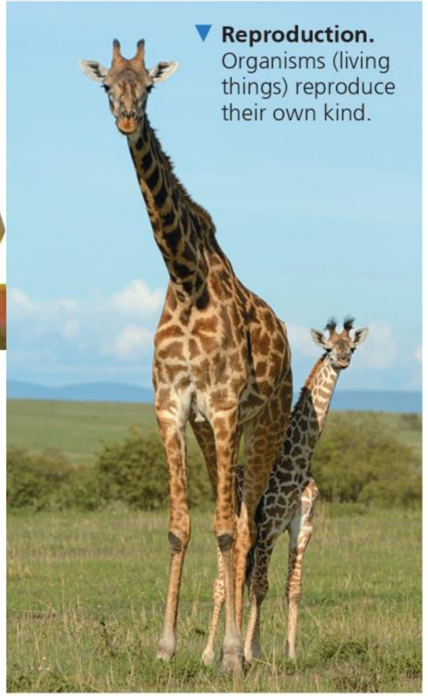
▲ **Regulation.** The regulation of blood flow through the blood vessels of this jackrabbit's ears helps maintain a constant body temperature by adjusting heat exchange with the surrounding air.



▲ **Energy processing.** This butterfly obtains fuel in the form of nectar from flowers. The butterfly will use chemical energy stored in its food to power flight and other work.

▲ **Growth and development.** Inherited information carried by genes controls the pattern of growth and development of organisms, such as this oak seedling.

▲ **Response to the environment.** The Venus flytrap on the left closed its trap rapidly in response to the environmental stimulus of a grasshopper landing on the open trap.

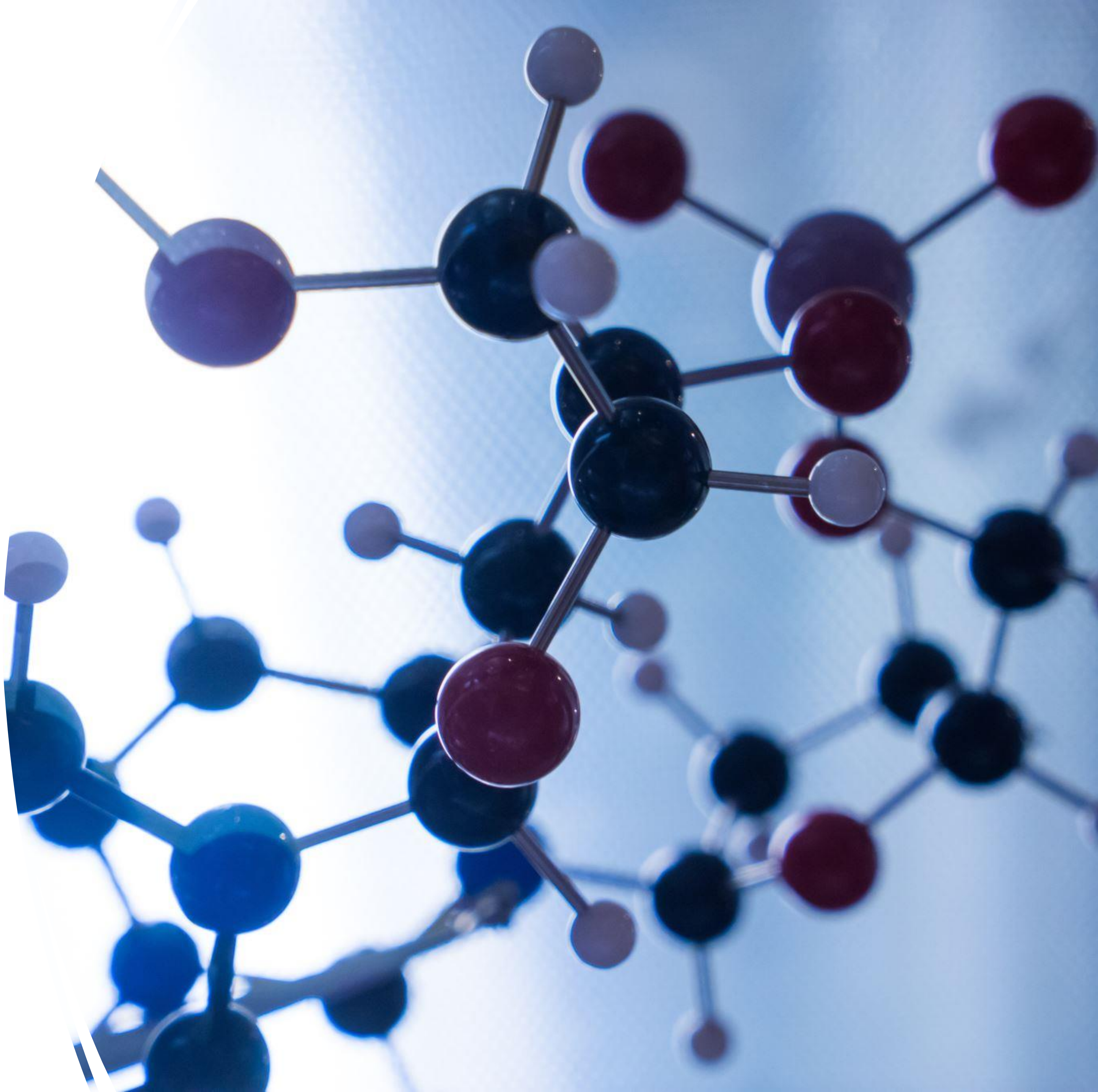


▼ **Reproduction.** Organisms (living things) reproduce their own kind.

The study of life reveals unifying themes

- Biology is a subject of enormous scope

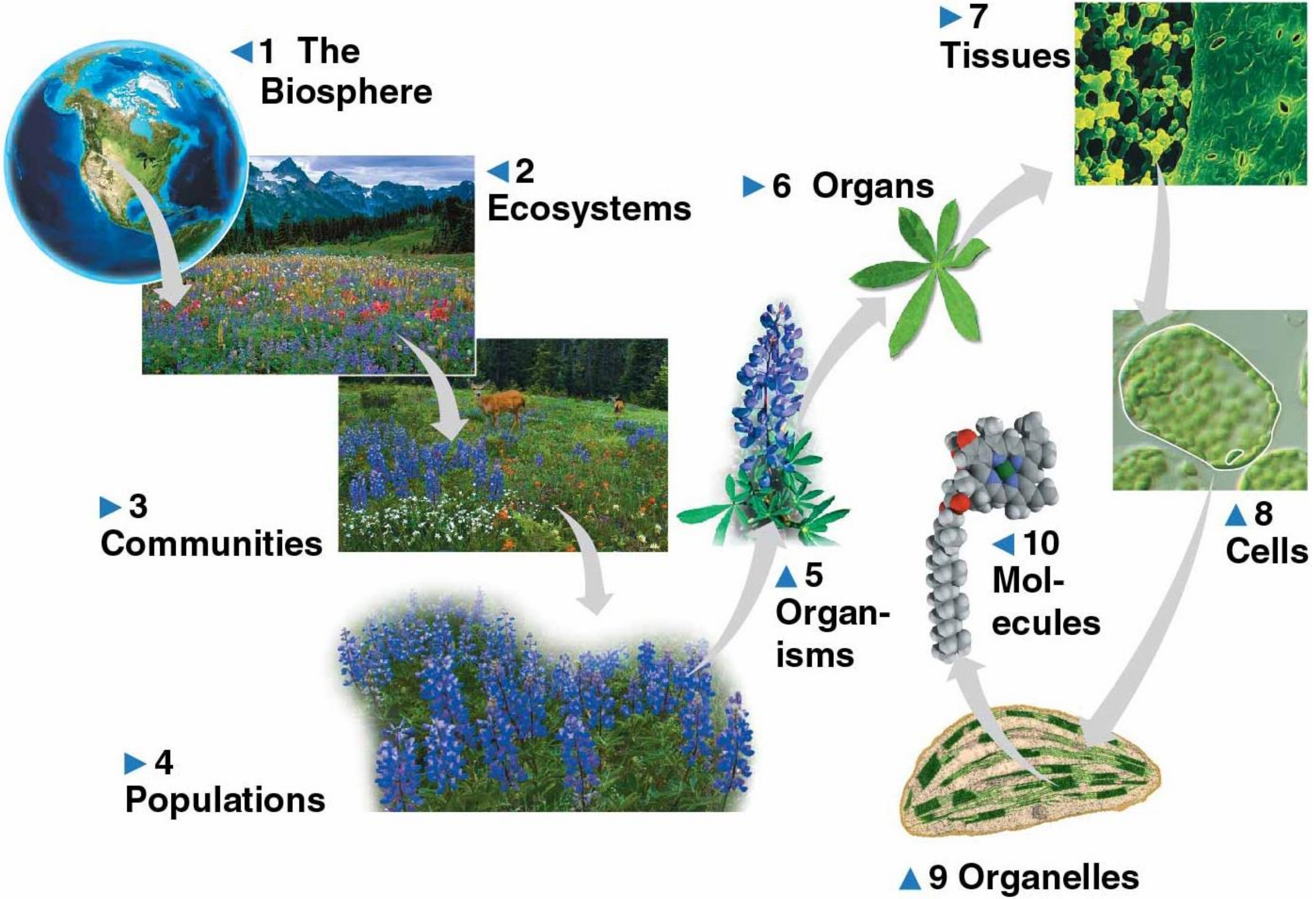
- There are five unifying themes:
  - Organization
  - Information
  - Energy and Matter
  - Interactions
  - Evolution



New Properties Emerge at Increasing Levels of Biological Organization

- Life can be studied at different levels, from molecules to the entire living planet

- This range can be divided into different levels of biological organization

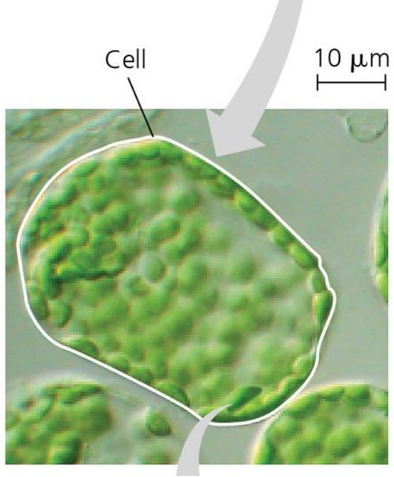

1 The Biosphere
2 Ecosystems
3 Communities
4 Populations
5 Organ- isms
6 Organs
7 Tissues
8 Cells
9 Organelles
10 Mol- ecules

◀1 The Biosphere

Even from space, we can see signs of Earth's life—in the mosaic of greens indicating forests, for example. We can also see the **biosphere**, which consists of all life on Earth and all the places where life exists: most regions of land, most bodies of water, the atmosphere to an altitude of several kilometers, and even sediments far below the ocean floor.

◀ 5 Organisms

Individual living things are called **organisms**. Each plant in the meadow is an organism, and so is each animal, fungus, and bacterium.

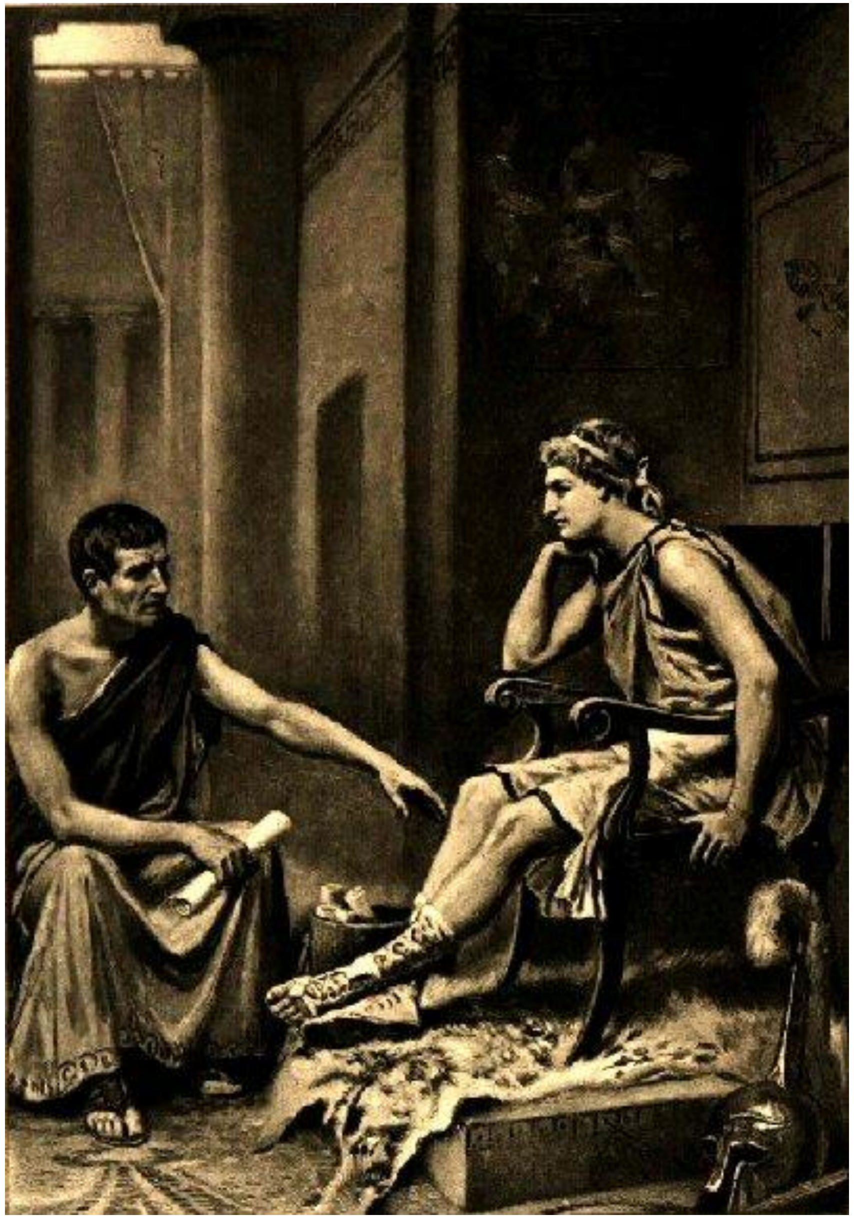


◀8 Cells

The **cell** is life's fundamental unit of structure and function. Some organisms consist of a single cell, which performs all the functions of life. Other organisms are multicellular and feature a division of labor among specialized cells. Here we see a magnified view of a cell in a leaf tissue. This cell is about 40 micrometers (µm) across—about 500 of them would reach across a small coin. Within these tiny cells are even smaller green structures called chloroplasts, which are responsible for photosynthesis.

Emergent Properties

- **Emergent properties** result from the arrangement and interaction of parts as complexity increases
- Emergent properties characterize non-biological entities as well
  - For example, a functioning bicycle emerges only when all of the necessary parts connect in the correct way



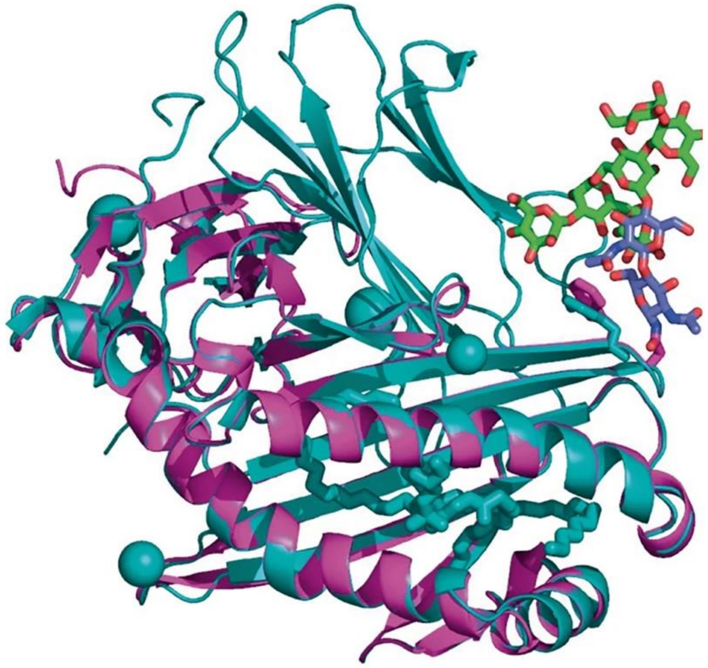
The whole is greater than the sum of the parts.
– attributed to Aristotle

Reductionist Approach

- The **reductionist approach** studies the isolated components of the living system
- To explore emergent properties, biologists complement reductionism with **systems biology**, analysis of the interactions among the parts of a biological system

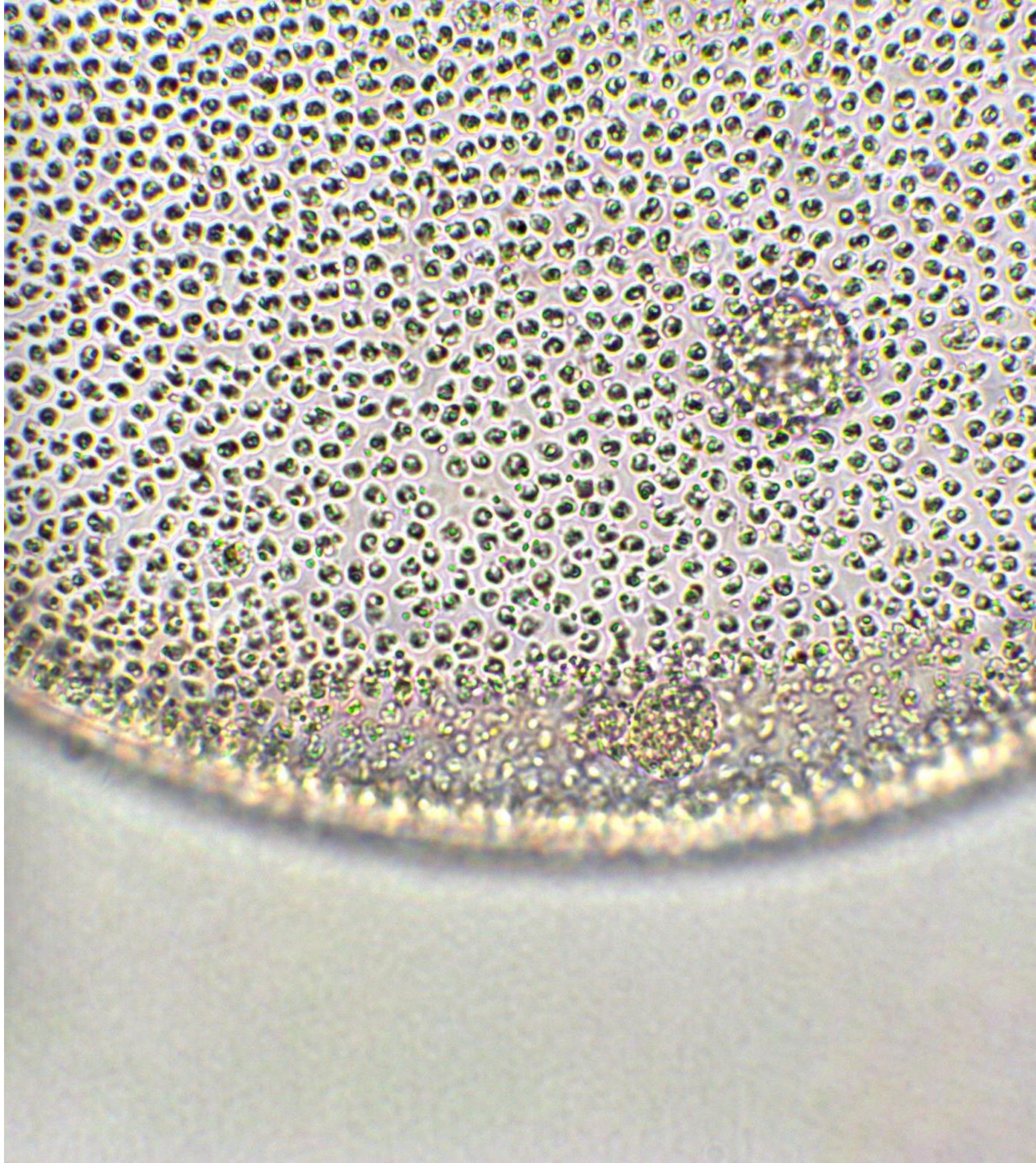
Structure and Function

- At each level of the biological hierarchy we find a correlation between structure and function
- Analyzing a biological structure gives us clues about what it does and how it works
- Conversely, knowing the function of something provides insight into its structure and organization



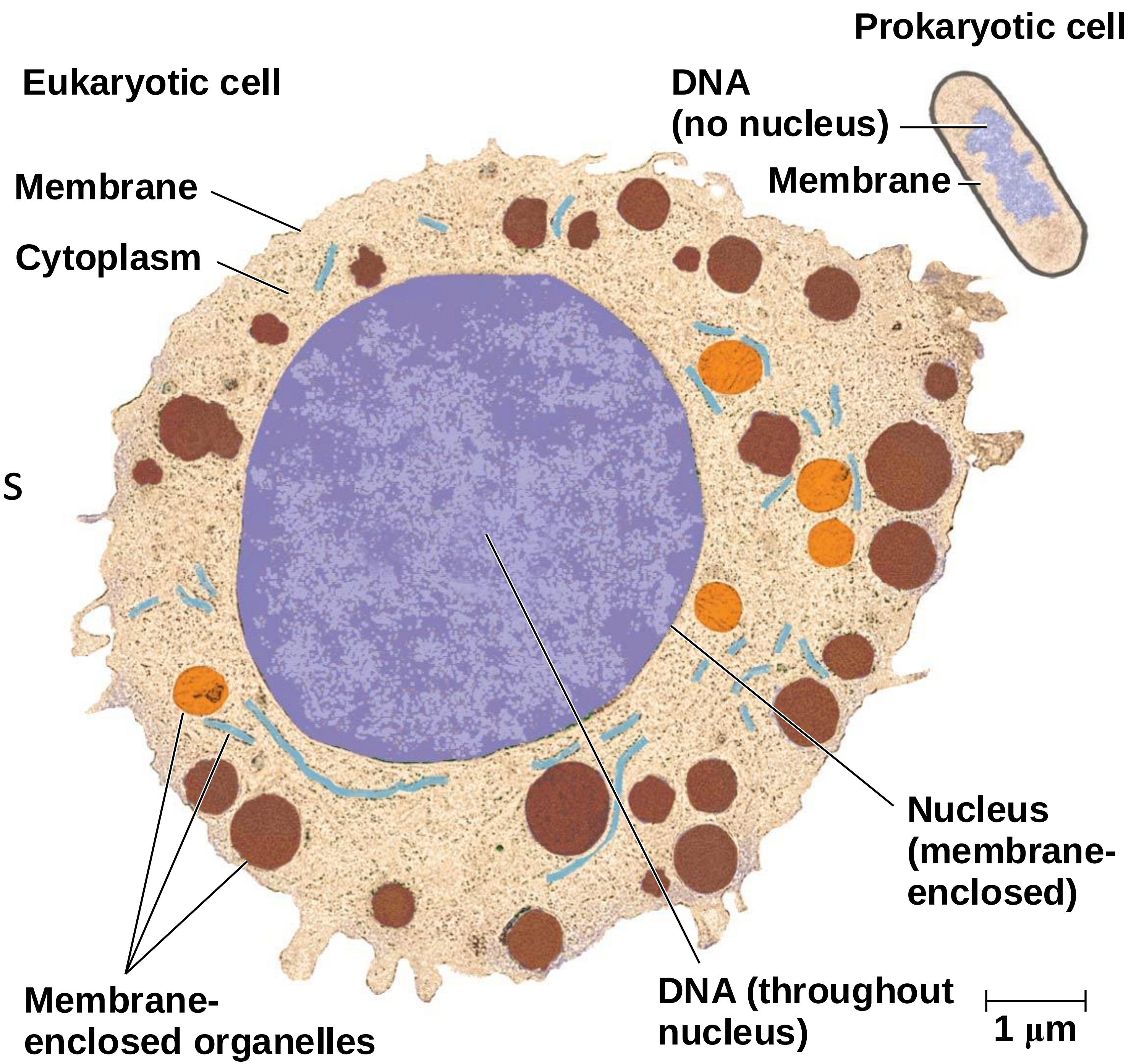
The Cell: An Organism's Basic Unit of Structure and Function

- The cell is the smallest unit of organization that can perform all activities required for life
- Every cell is enclosed by a membrane that regulates passage of materials between the cell and its environment



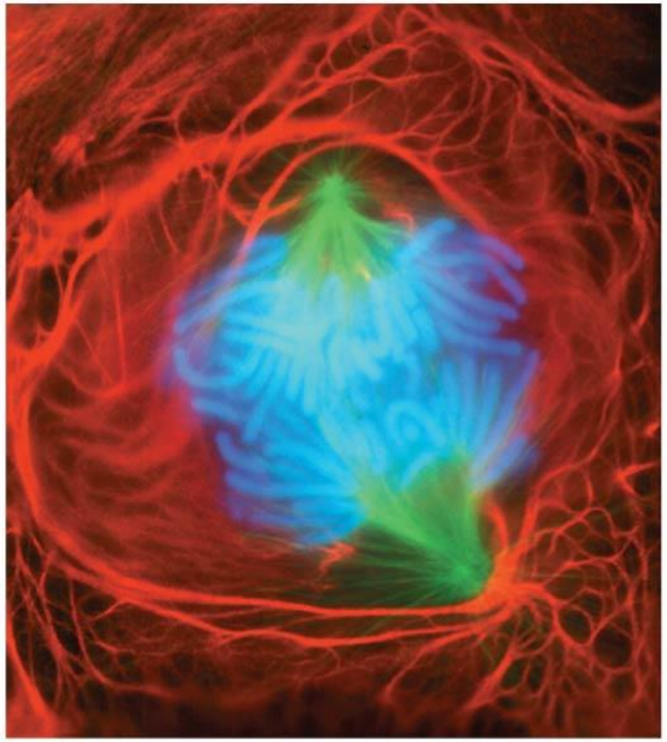
- A **eukaryotic cell** has membrane-enclosed organelles, the largest of which is usually the nucleus

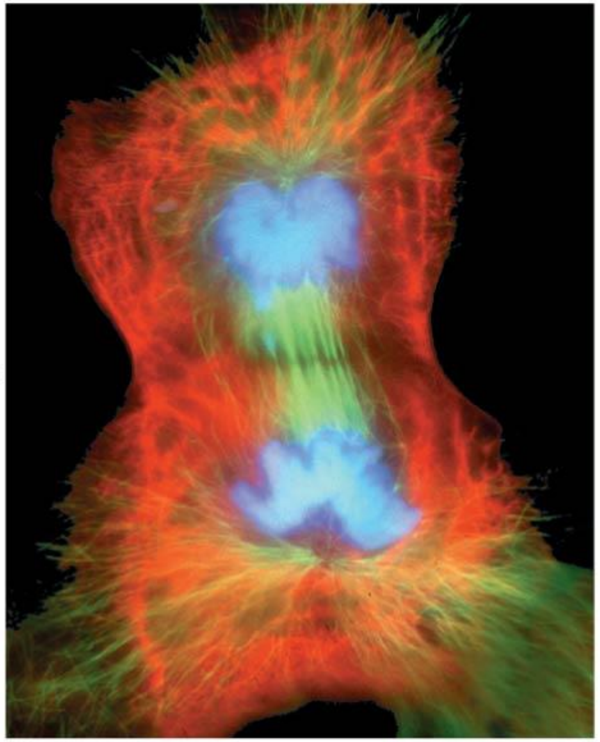
- By comparison, a **prokaryotic cell** is simpler and usually smaller and does not contain a nucleus or other membrane-enclosed organelles



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

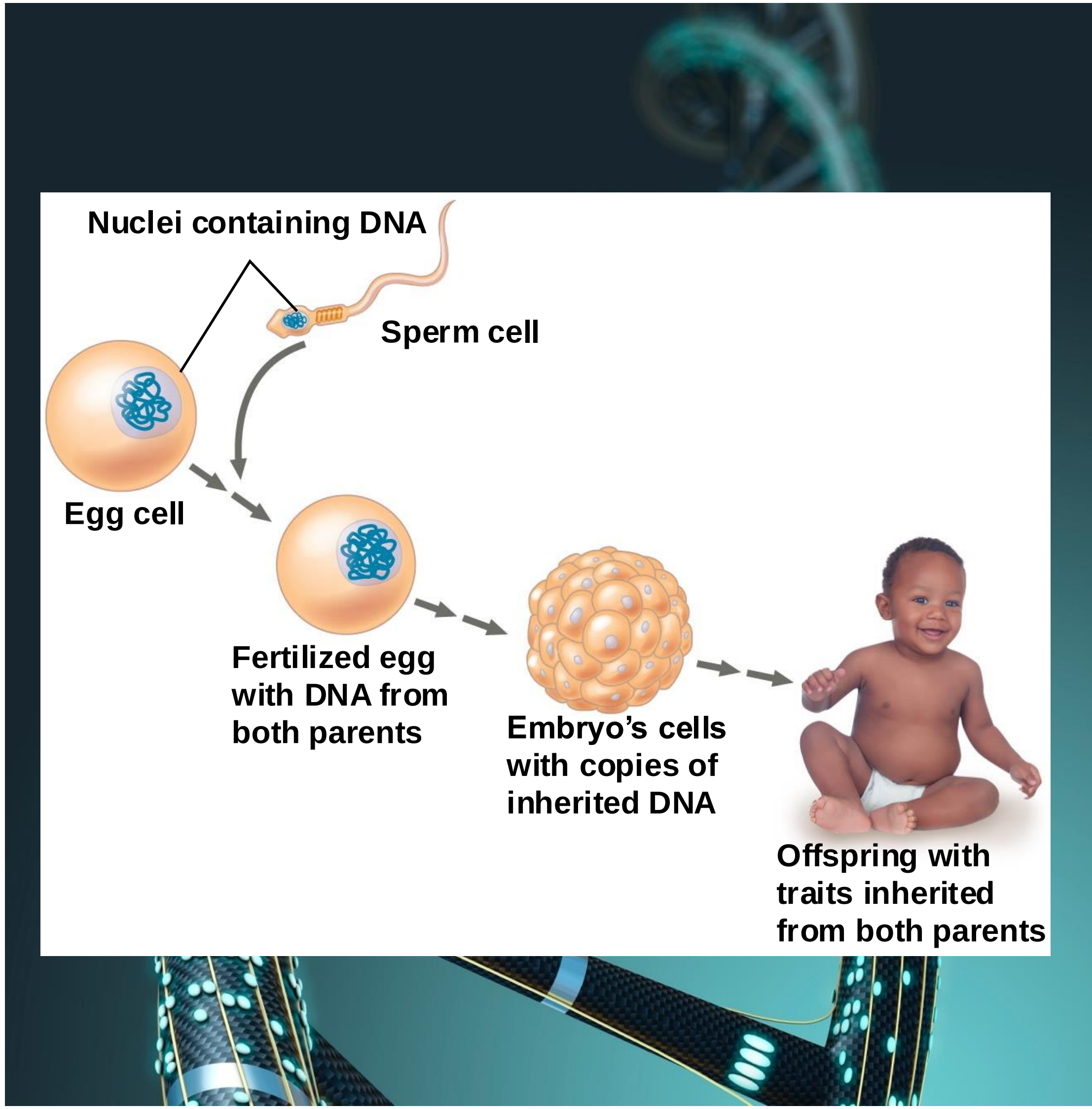
- Within cells, structures called chromosomes contain genetic material in the form of **DNA (deoxyribonucleic acid)**



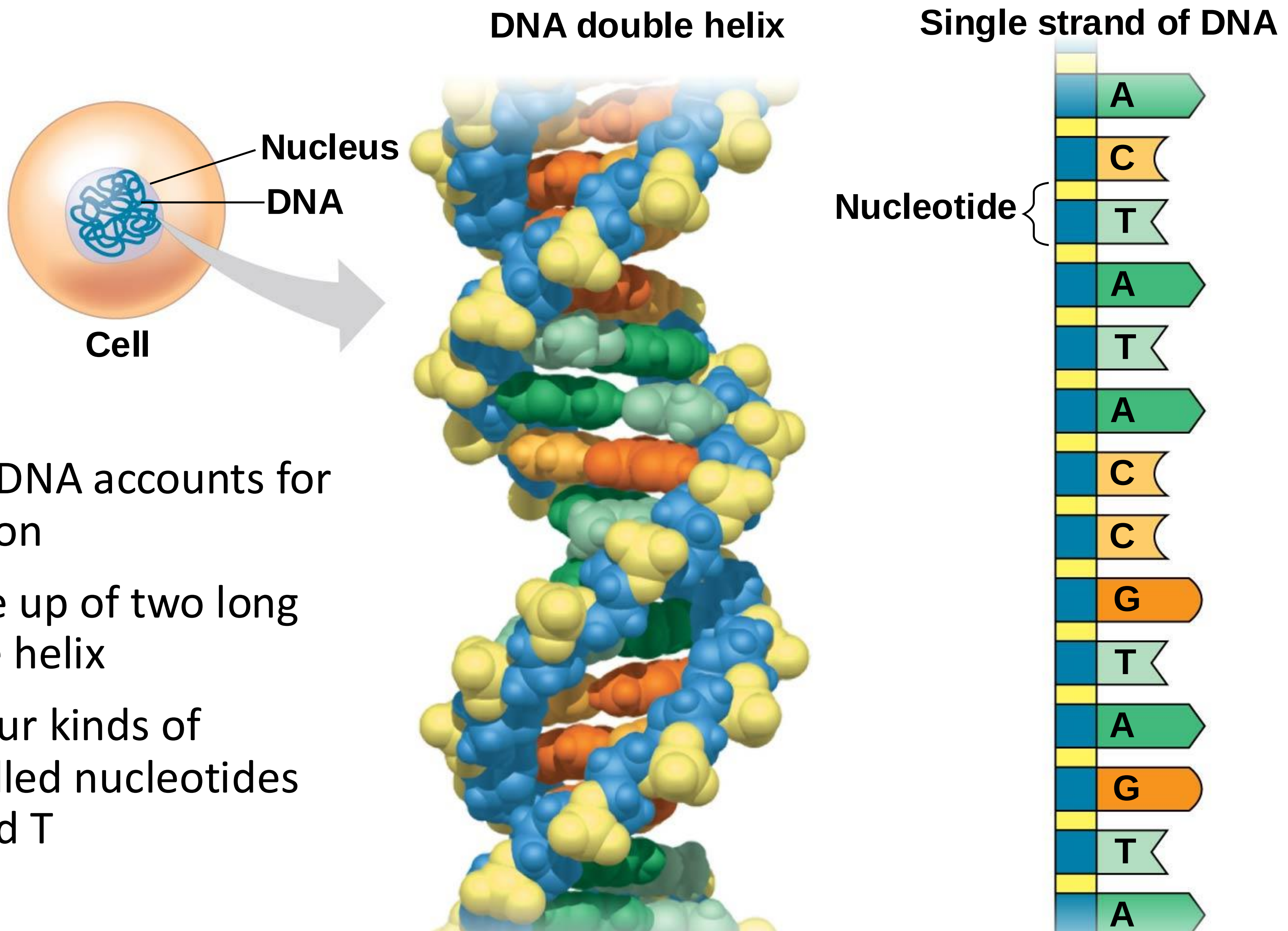


DNA, the Genetic Material

- Each chromosome contains one long DNA molecule with hundreds or thousands of genes
- **Genes** are the units of inheritance
- Genes encode information for building the molecules within the cell
- The genetic information encoded by DNA directs the development of an organism



DNA, the Genetic Material

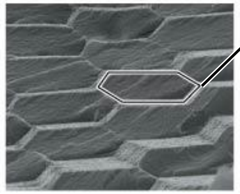


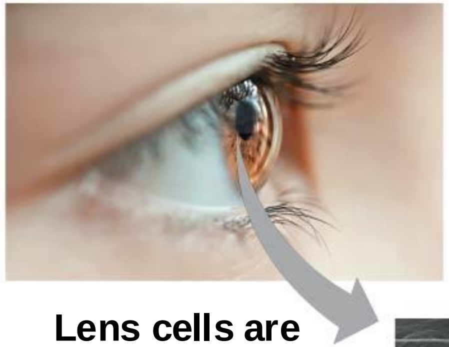
- The molecular structure of DNA accounts for its ability to store information
- Each DNA molecule is made up of two long chains arranged in a double helix
- Each chain is made up of four kinds of chemical building blocks called nucleotides and abbreviated A, G, C, and T

Expression of Proteins

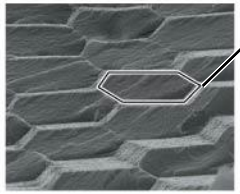
- For many genes, the sequence provides the blueprint for making a protein
- DNA is transcribed into RNA, which is then translated into a protein
- **Gene expression** is the process of converting information from gene to cellular product

Lens cells are tightly packed with transparent proteins called crystallin.

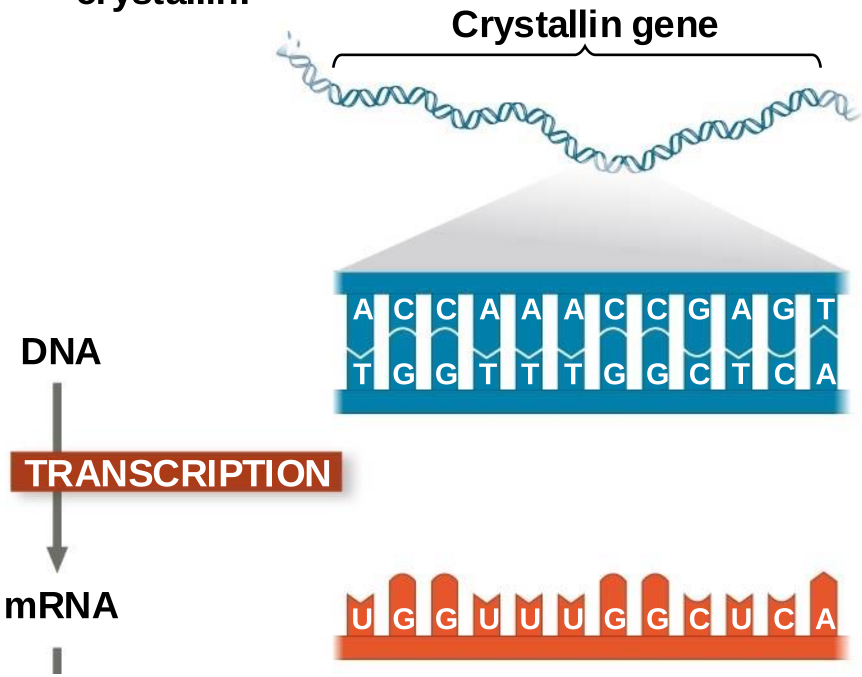


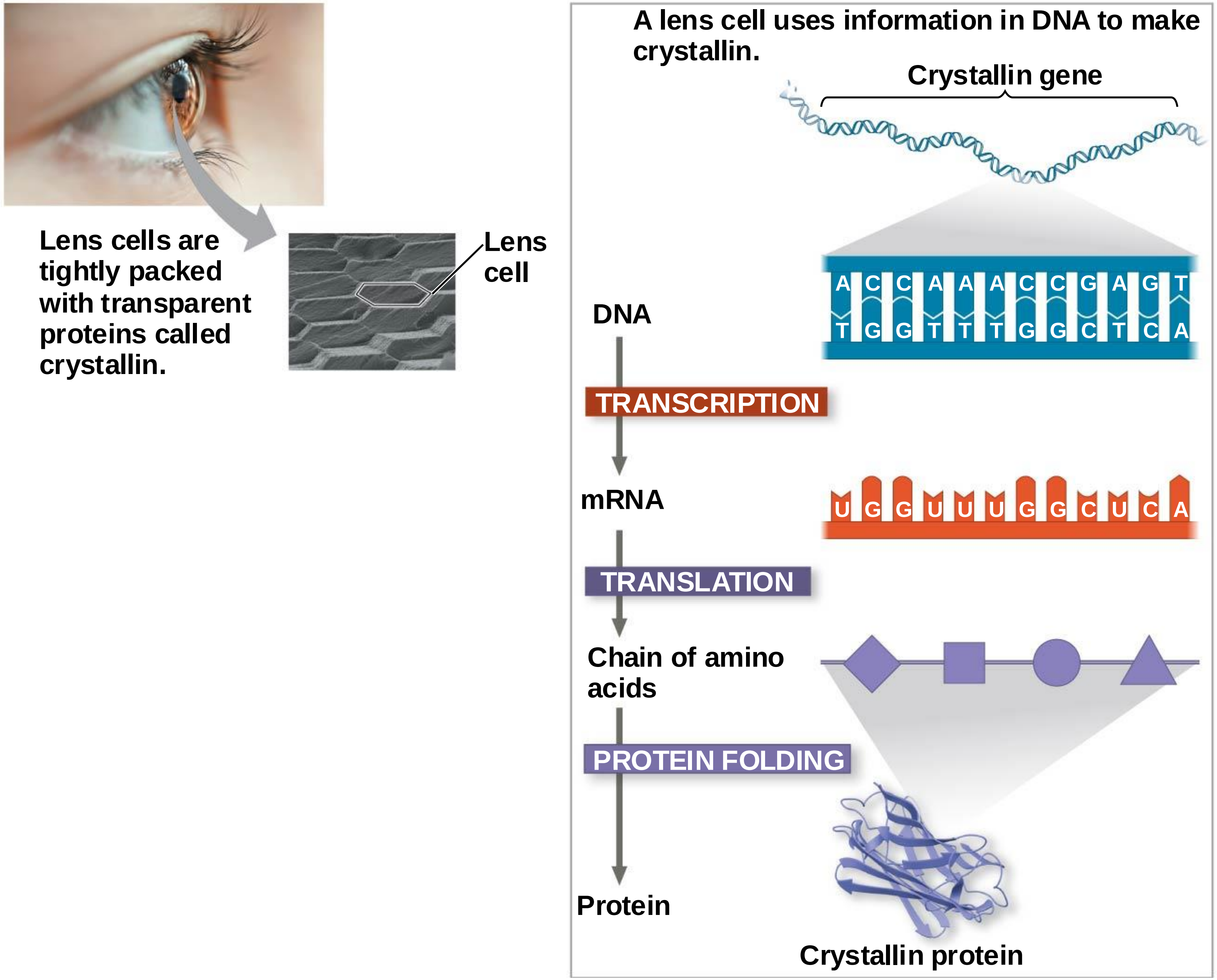


Lens cells are tightly packed with transparent proteins called crystallin.



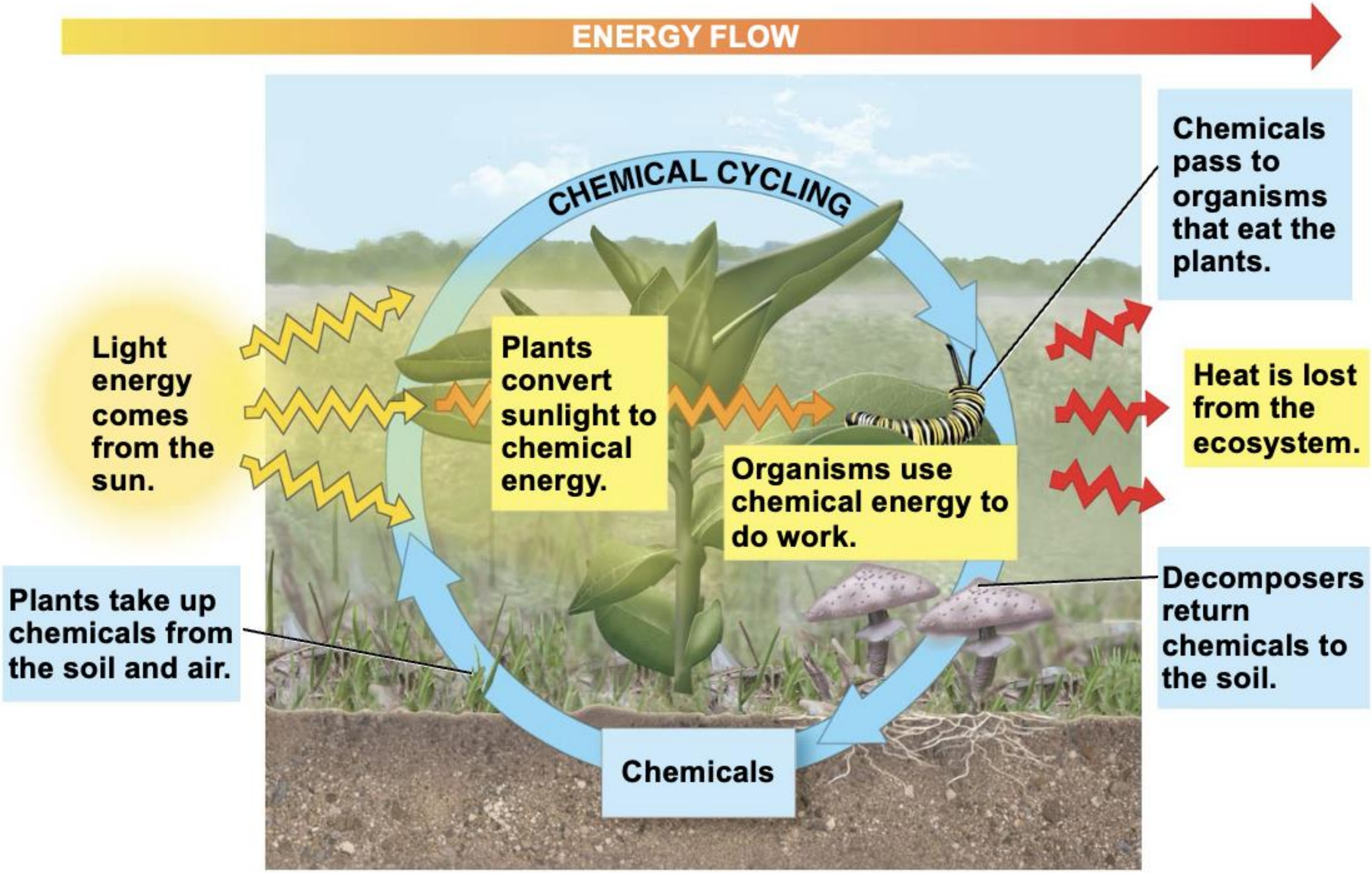
A lens cell uses information in DNA to make crystallin.




Lens cells are tightly packed with transparent proteins called crystallin.
Lens cell
A lens cell uses information in DNA to make crystallin.
Crystallin gene
DNA
A C C A A A C C G A G T
T G G T T T G G C T C A
TRANSCRIPTION
mRNA
U G G U U U G G C U C A
TRANSLATION
Chain of amino acids
PROTEIN FOLDING
Protein
Crystallin protein

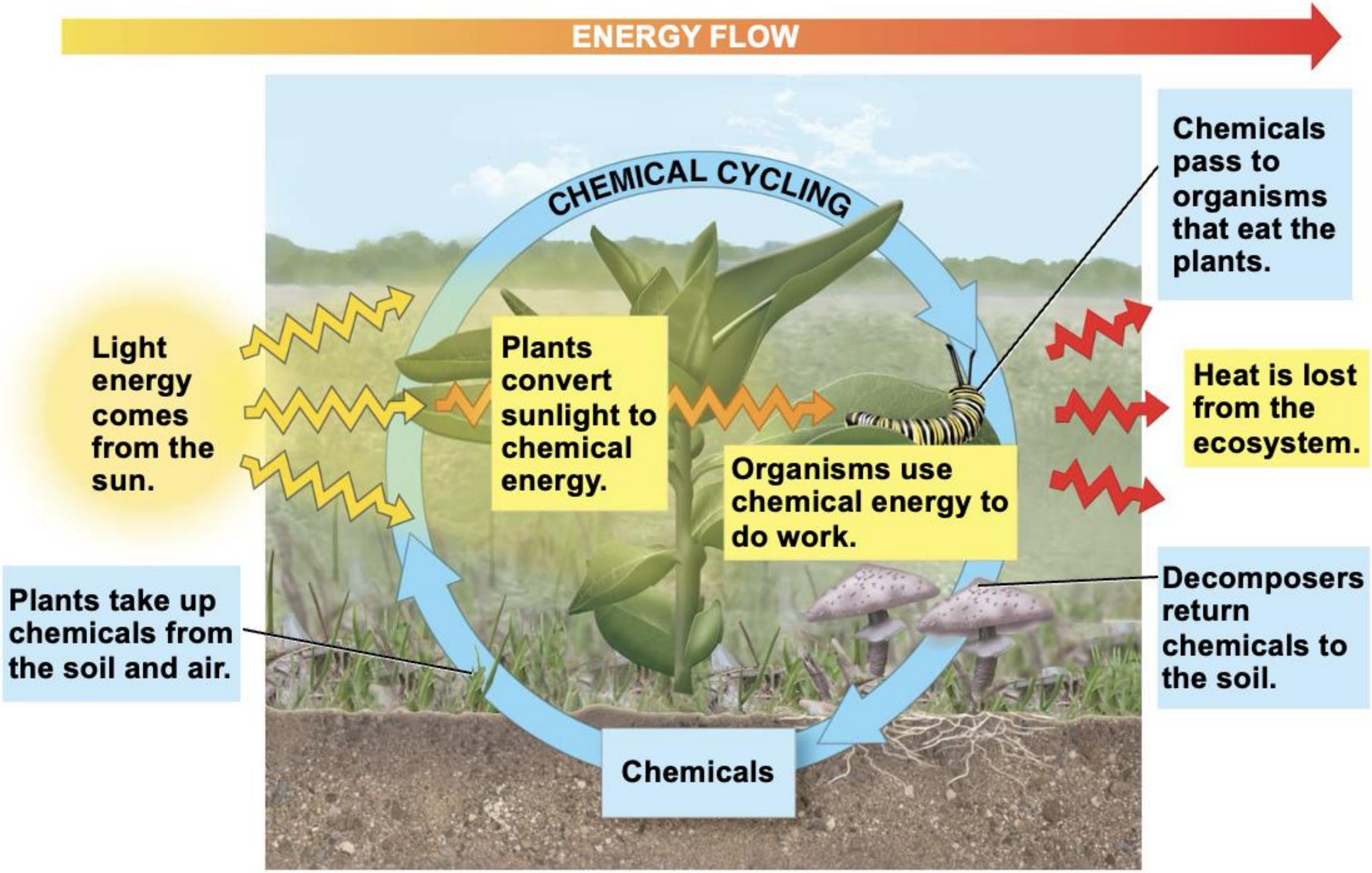
Life Requires the Transfer and Transformation of Energy and Matter

- The input of energy from the sun and the transformation of energy from one form to another make life possible
- The chemical energy generated by plants and other photosynthetic organisms (**producers**) is passed along to consumers
- **Consumers** are organisms that feed on other organisms or their remains

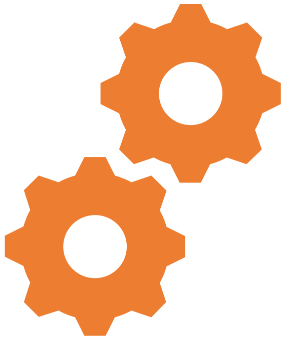


Life Requires the Transfer and Transformation of Energy and Matter

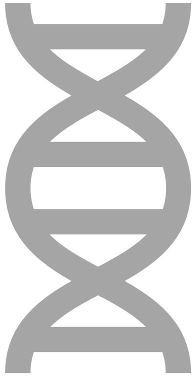
- When organisms use energy to work, some energy is lost to the surroundings as heat
- Energy flows through an ecosystem, usually entering as light and exiting as heat
- Chemicals cycle within an ecosystem, where they are used and then recycled



From Molecules to Ecosystems, Interactions Are Important in Biological Systems



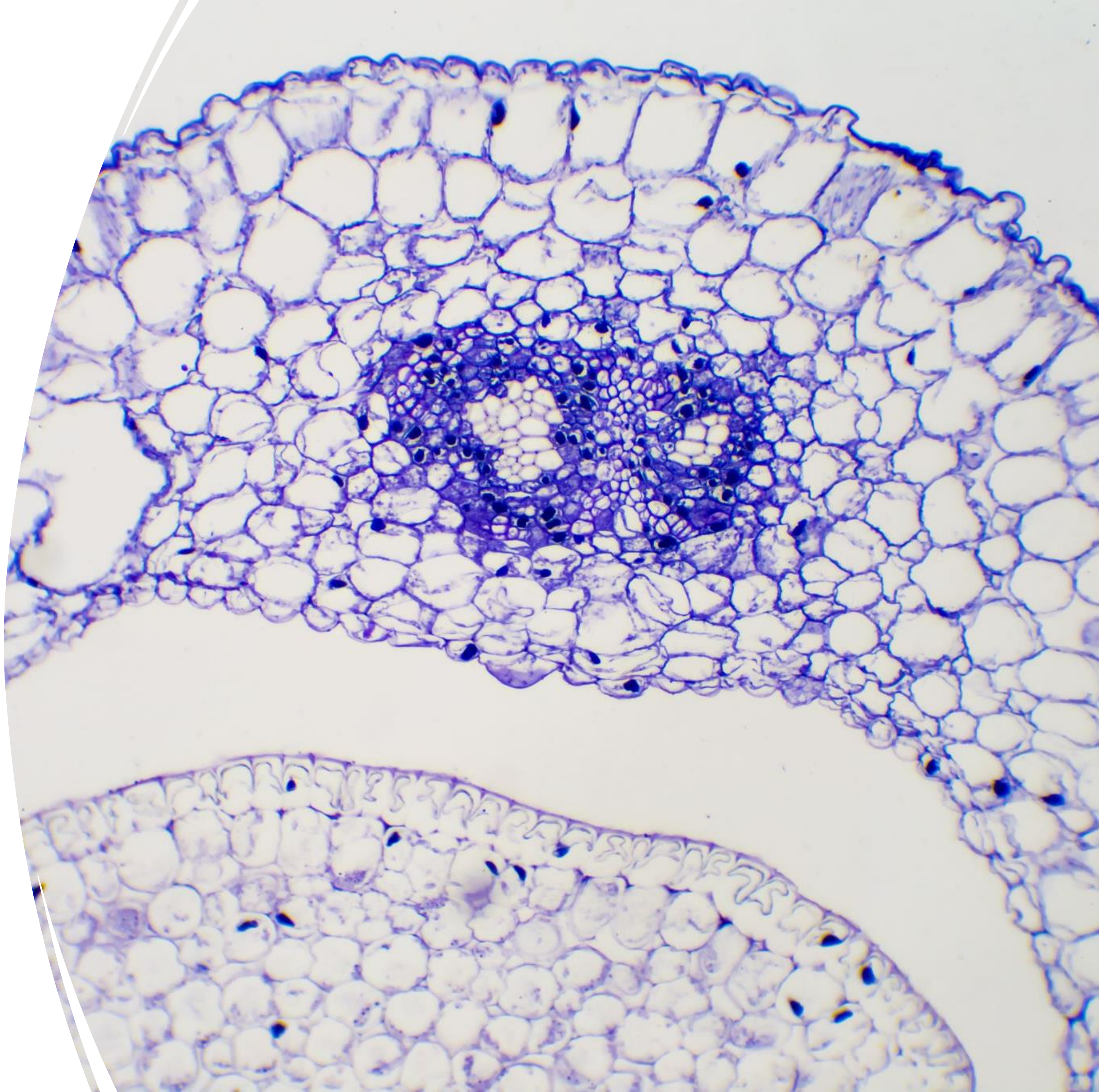
Interactions between the components of the system ensure smooth integration of all the parts



This is true for components of an ecosystem and the molecules in a cell

Molecules: Interactions Within Organisms

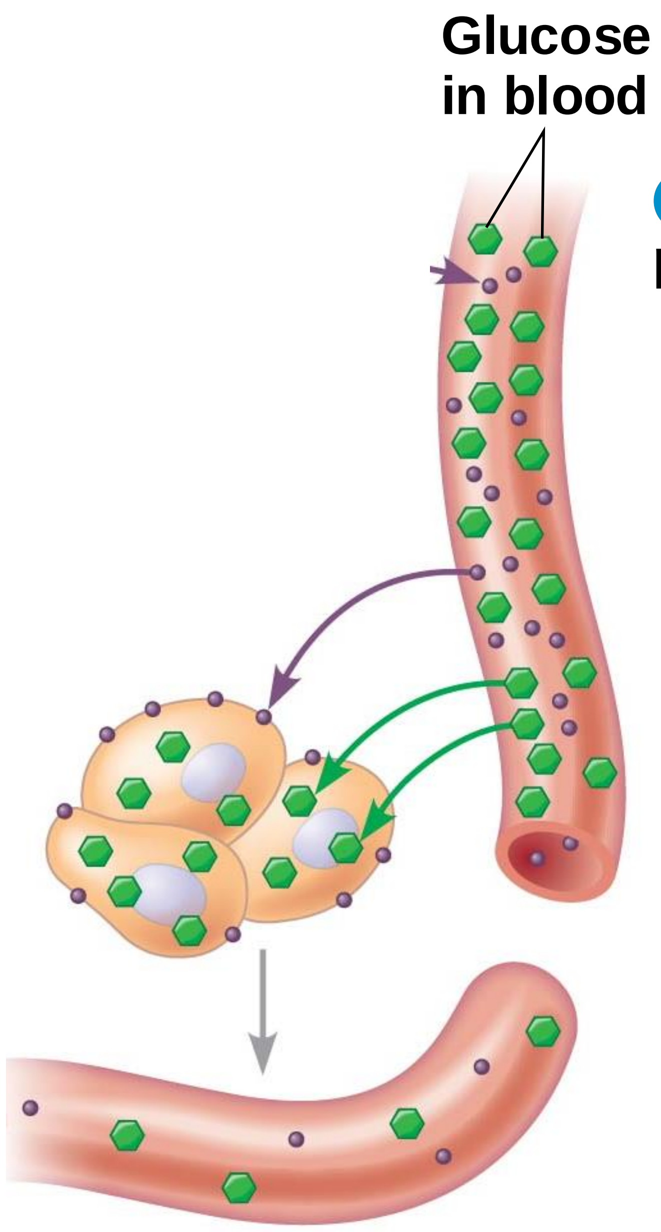
- Interactions between components—organs, tissues, cells, and molecules—that make up living organisms are crucial for operation
- Many biological processes can self-regulate through a mechanism called **feedback**



Feedback regulation

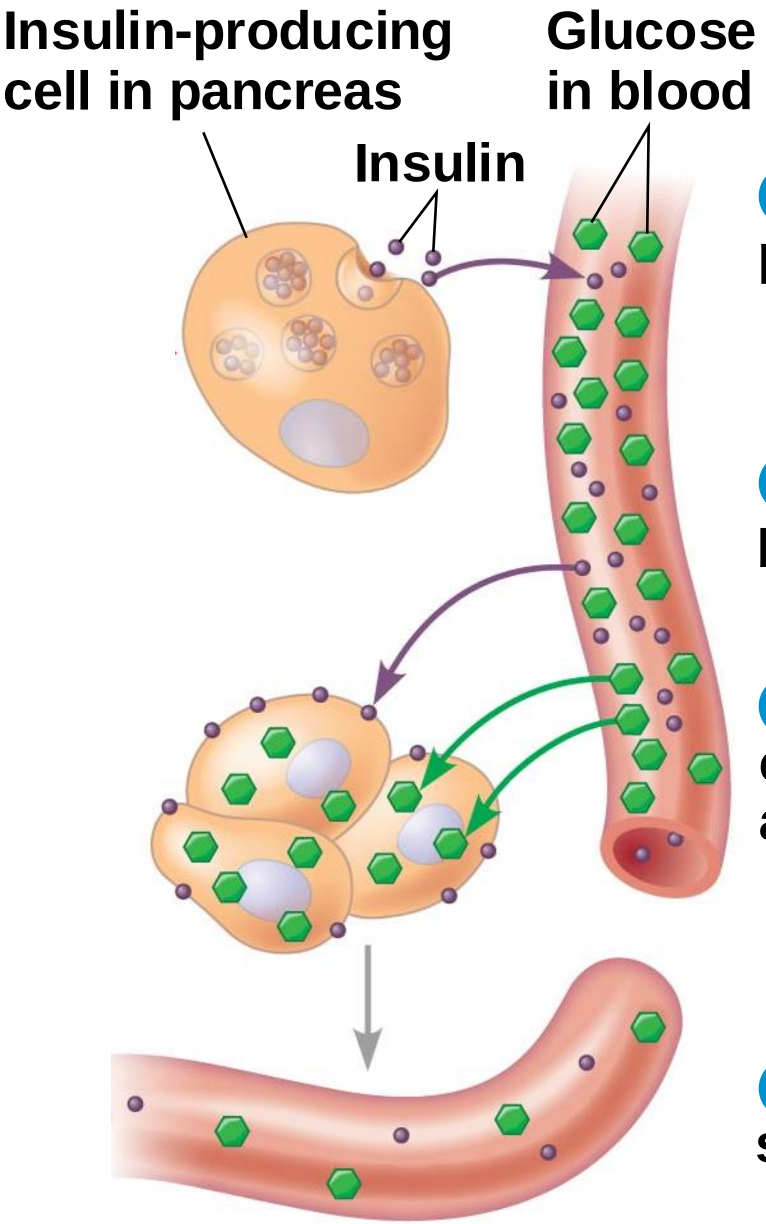
- In **feedback regulation**, the output, or product of a process, regulates that very process
- The most common form of regulation in living organisms is **negative feedback**, in which the response reduces the initial stimulus
- A less common form of regulation is **positive feedback**, in which an end product speeds up its own production

Feedback regulation



1 High blood glucose stimulates the pancreas to secrete insulin.

Feedback regulation



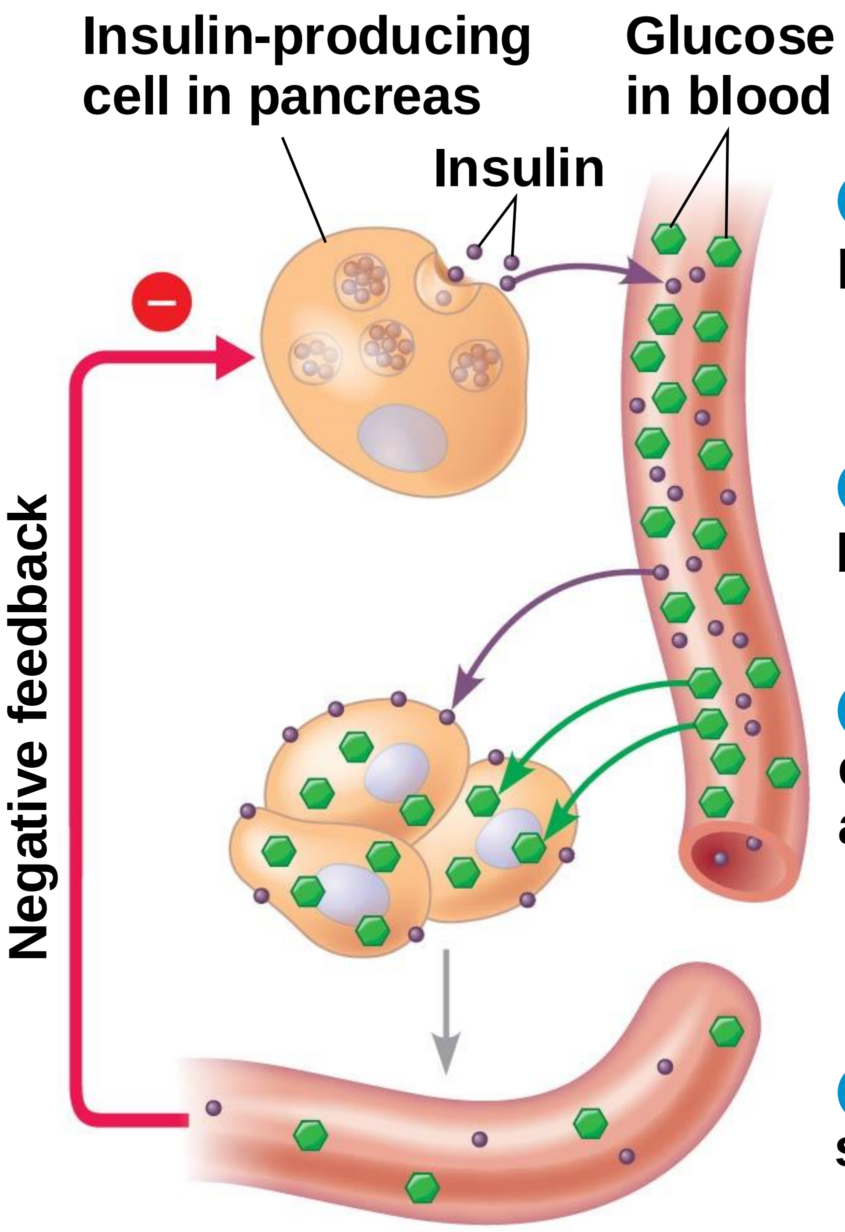
1 High blood glucose stimulates the pancreas to secrete insulin.

2 Insulin circulates throughout the body.

3 Insulin binds to body cells, causing them to take up glucose and for liver cells to store glucose.

4 Lowered blood glucose does not stimulate insulin secretion.

Feedback regulation



1 High blood glucose stimulates the pancreas to secrete insulin.

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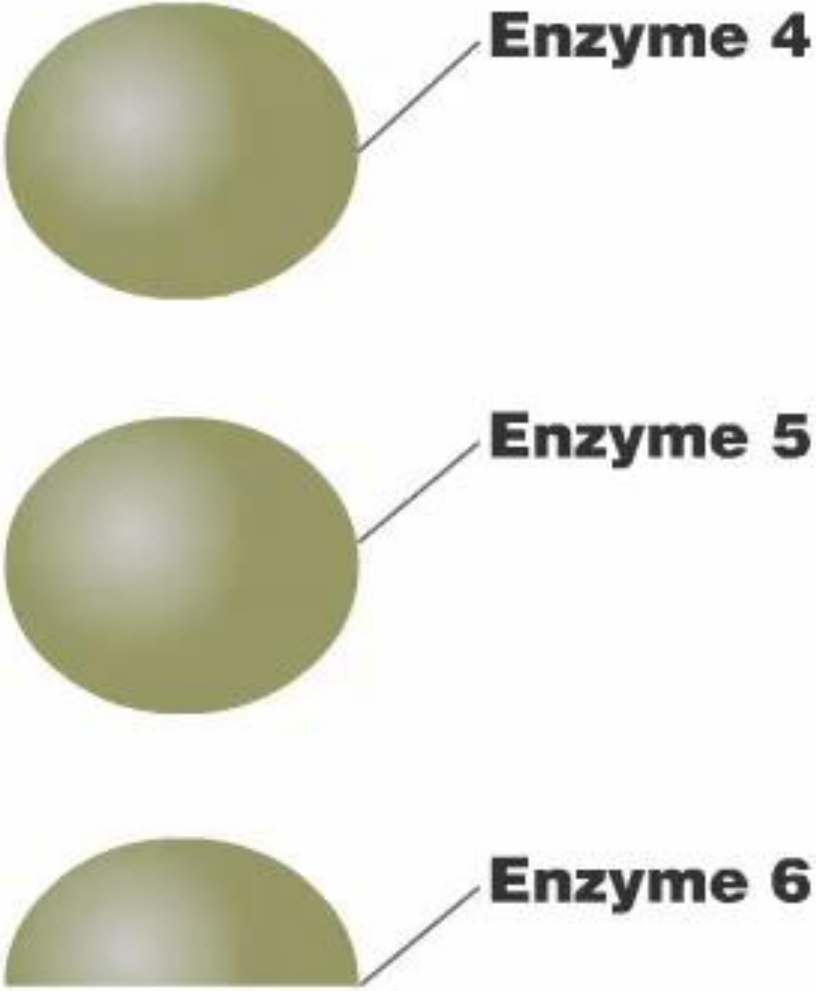
4 Lowered blood glucose does not stimulate insulin secretion.

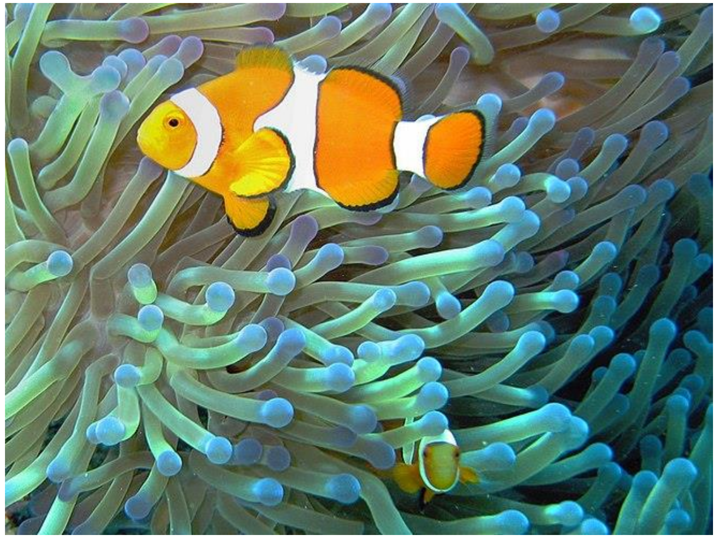
Negative Feedback

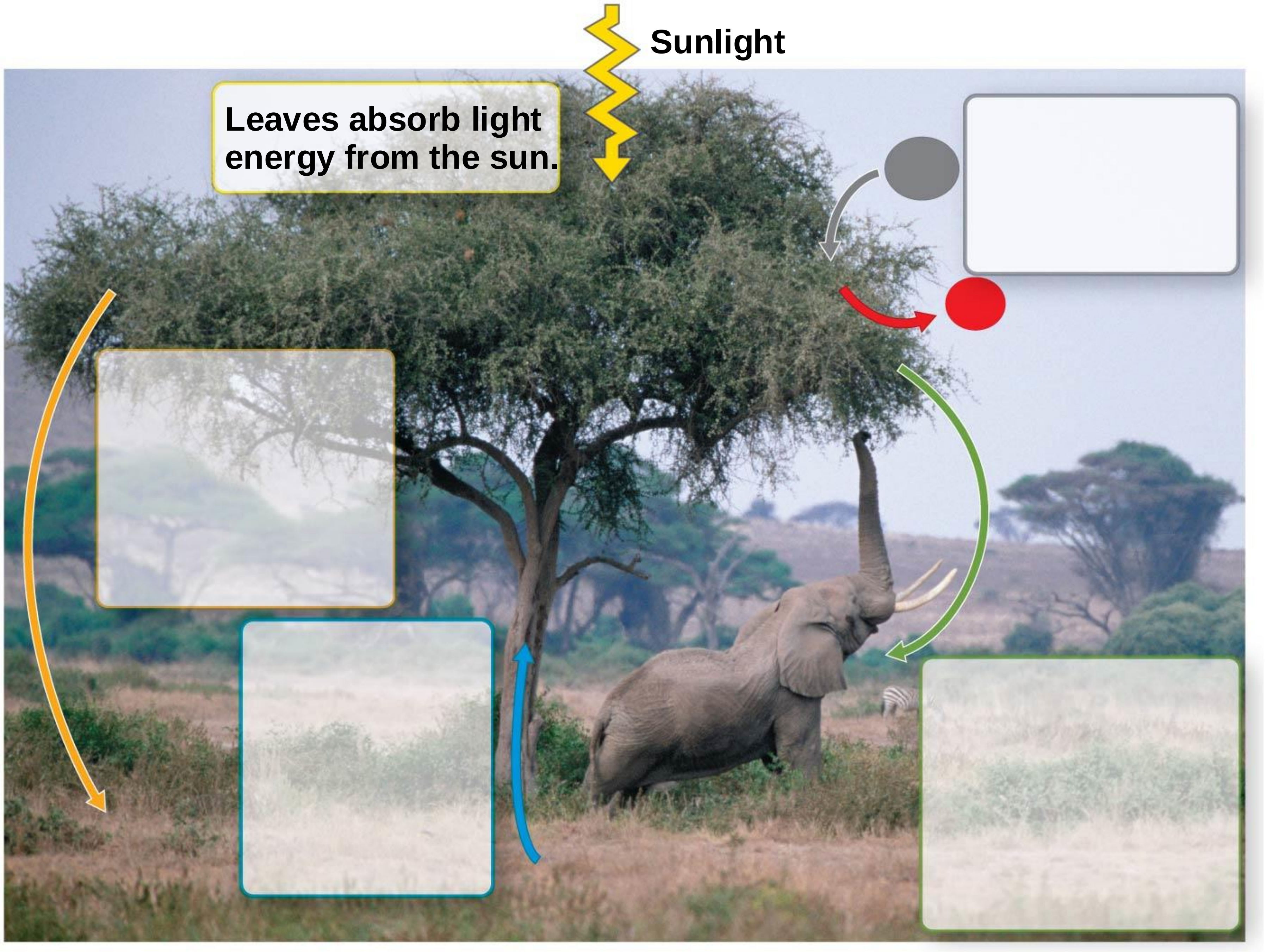
Positive Feedback

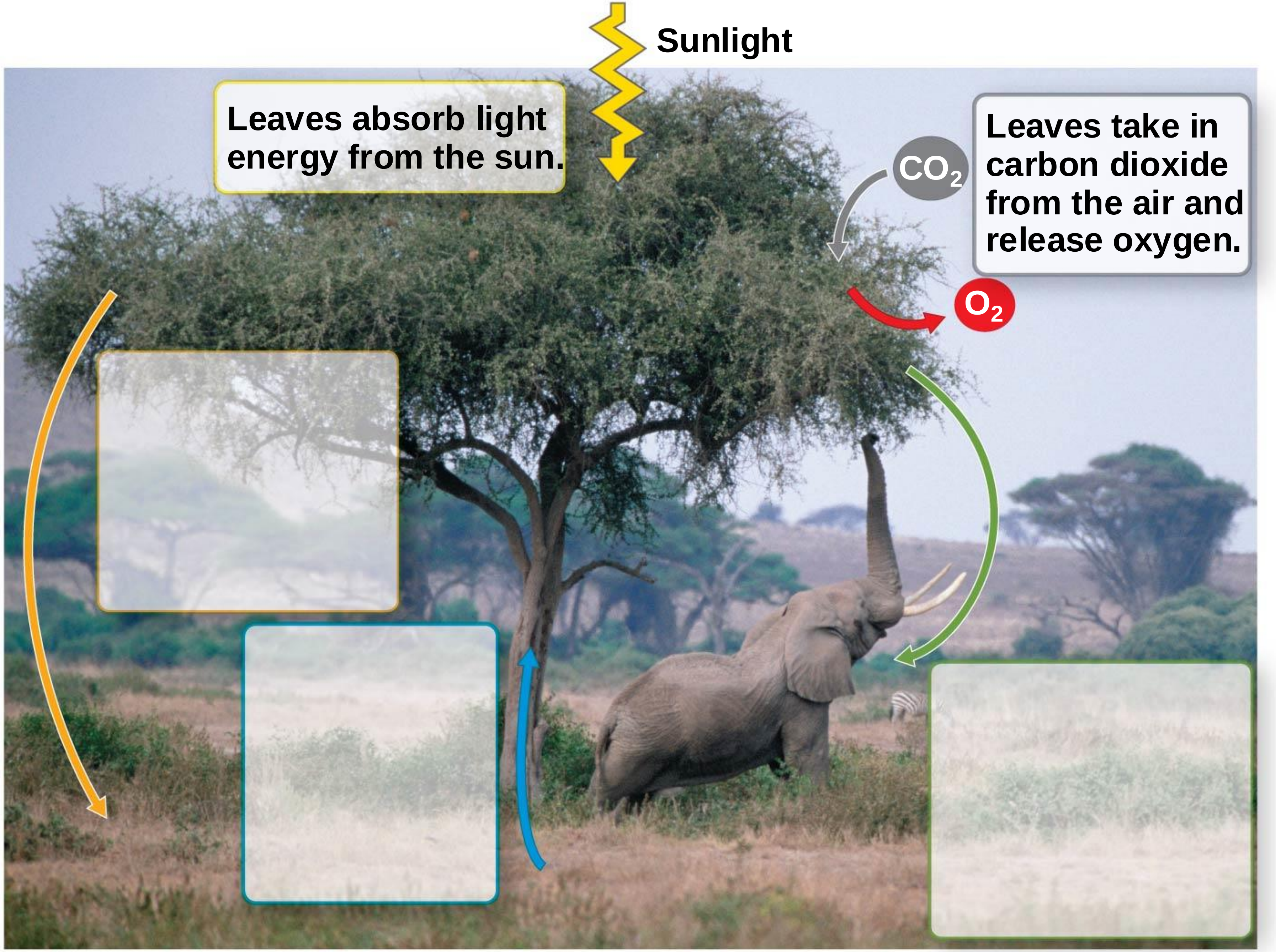


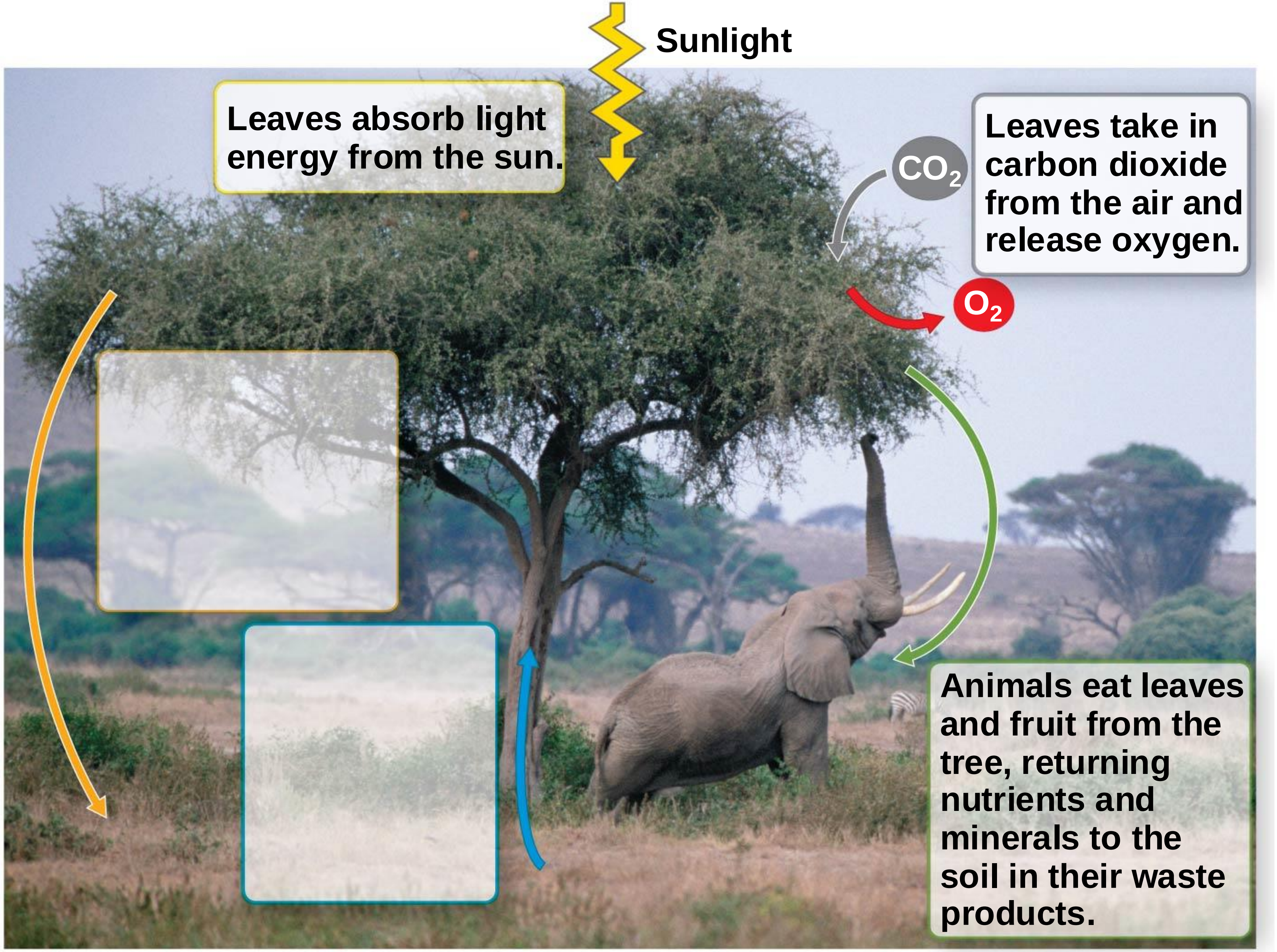
Ecosystems: An Organism's Interactions with Other Organisms and the Physical Environment

- At the ecosystem level, each organism interacts with other organisms
- These interactions may be beneficial or harmful to one or both of the organisms
- Organisms also interact continuously with the physical environment, and in turn the environment is affected by the organisms living there

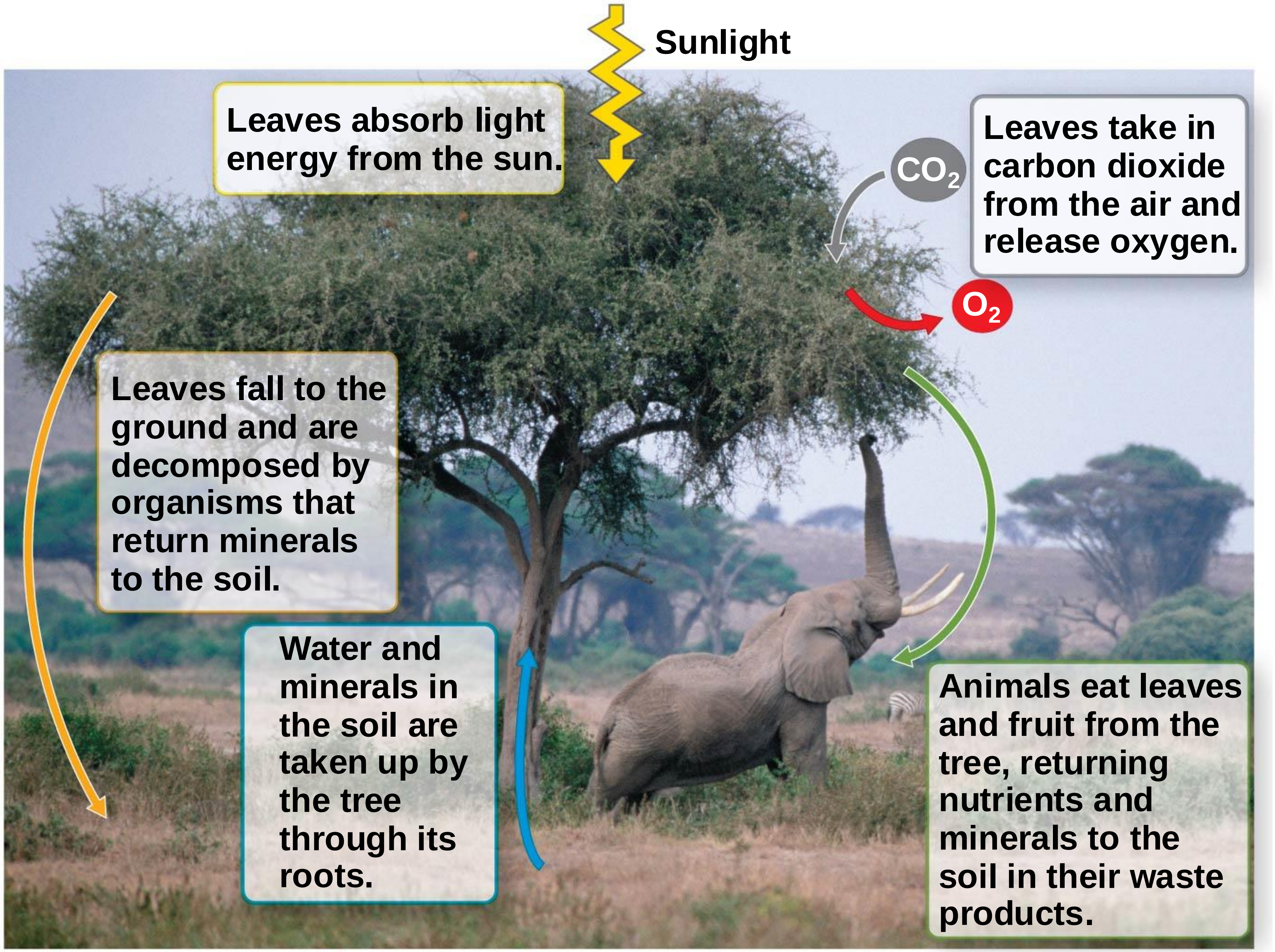



Sunlight
Leaves absorb light energy from the sun.


Sunlight
Leaves absorb light energy from the sun.
Leaves take in carbon dioxide from the air and release oxygen.
CO_2
O_2



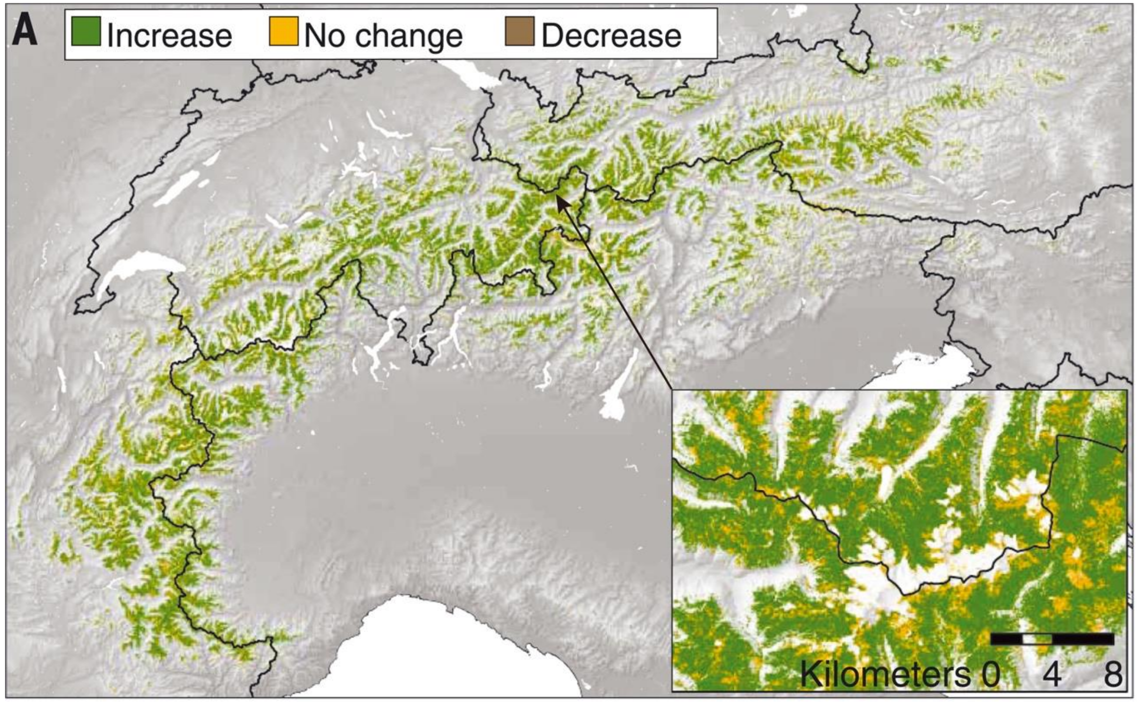
Sunlight
Leaves absorb light energy from the sun.
CO_2
Leaves take in carbon dioxide from the air and release oxygen.
O_2
Animals eat leaves and fruit from the tree, returning nutrients and minerals to the soil in their waste products.

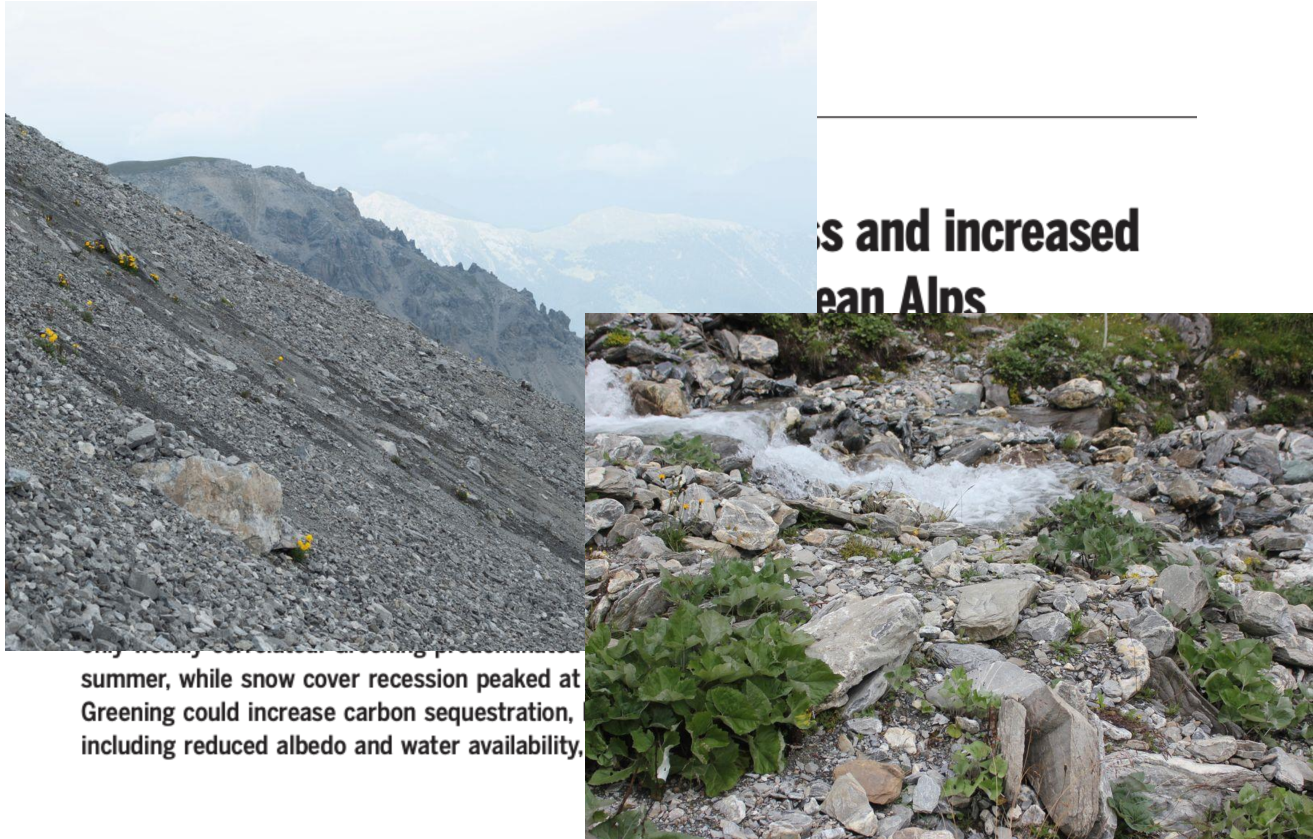


Sunlight
Leaves absorb light energy from the sun.
CO_2
Leaves take in carbon dioxide from the air and release oxygen.
O_2
Leaves fall to the ground and are decomposed by organisms that return minerals to the soil.
Water and minerals in the soil are taken up by the tree through its roots.
Animals eat leaves and fruit from the tree, returning nutrients and minerals to the soil in their waste products.

- Human interaction with our environment – consequences?
- Over the past 150 years, humans have greatly increased the burning of fossil fuels and the release of carbon dioxide (CO_2) into the atmosphere
- The resulting global warming is just one aspect of **climate change**

- Wind and precipitation patterns are also shifting
- Extreme weather events such as storms and droughts are occurring more often
- As habitats deteriorate, plant and animal species shift their ranges to more suitable locations





Classifying the Diversity of Life

- Approximately 1.8 million species have been identified and named to date

- Each species is given a two-part name: The genus, to which the species belongs, and a species name unique to that species

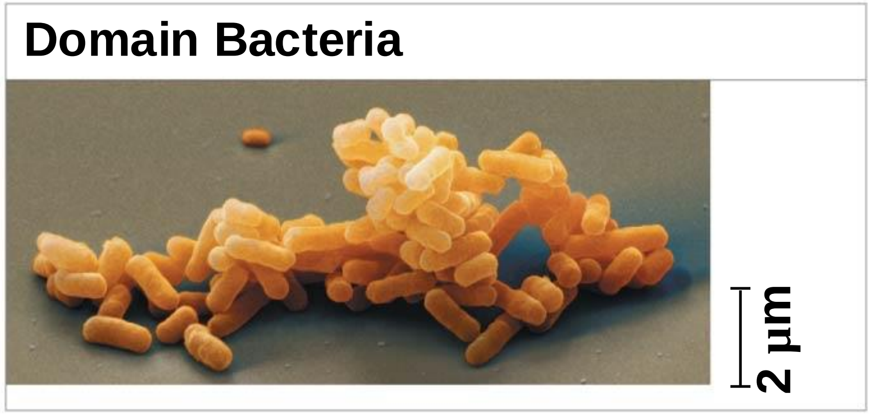
- E.g., *Homo sapiens*, the name of our species

- Estimates of the total number of species that actually exist range from 10 million to over 100 million

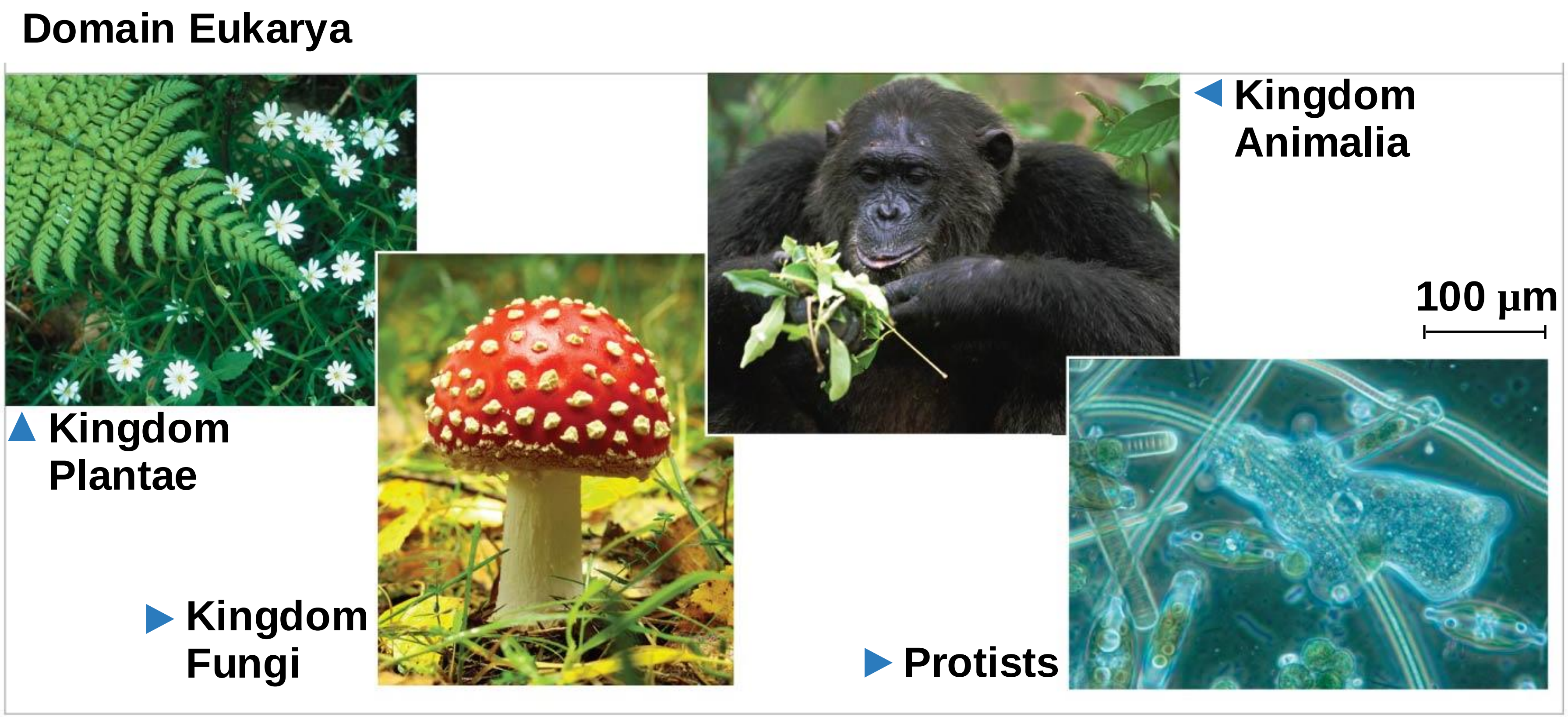
The Three Domains of Life

- Organisms are currently divided into three domains, named **Bacteria**, **Archaea**, and **Eukarya**

- The prokaryotes include the domains Bacteria and Archaea



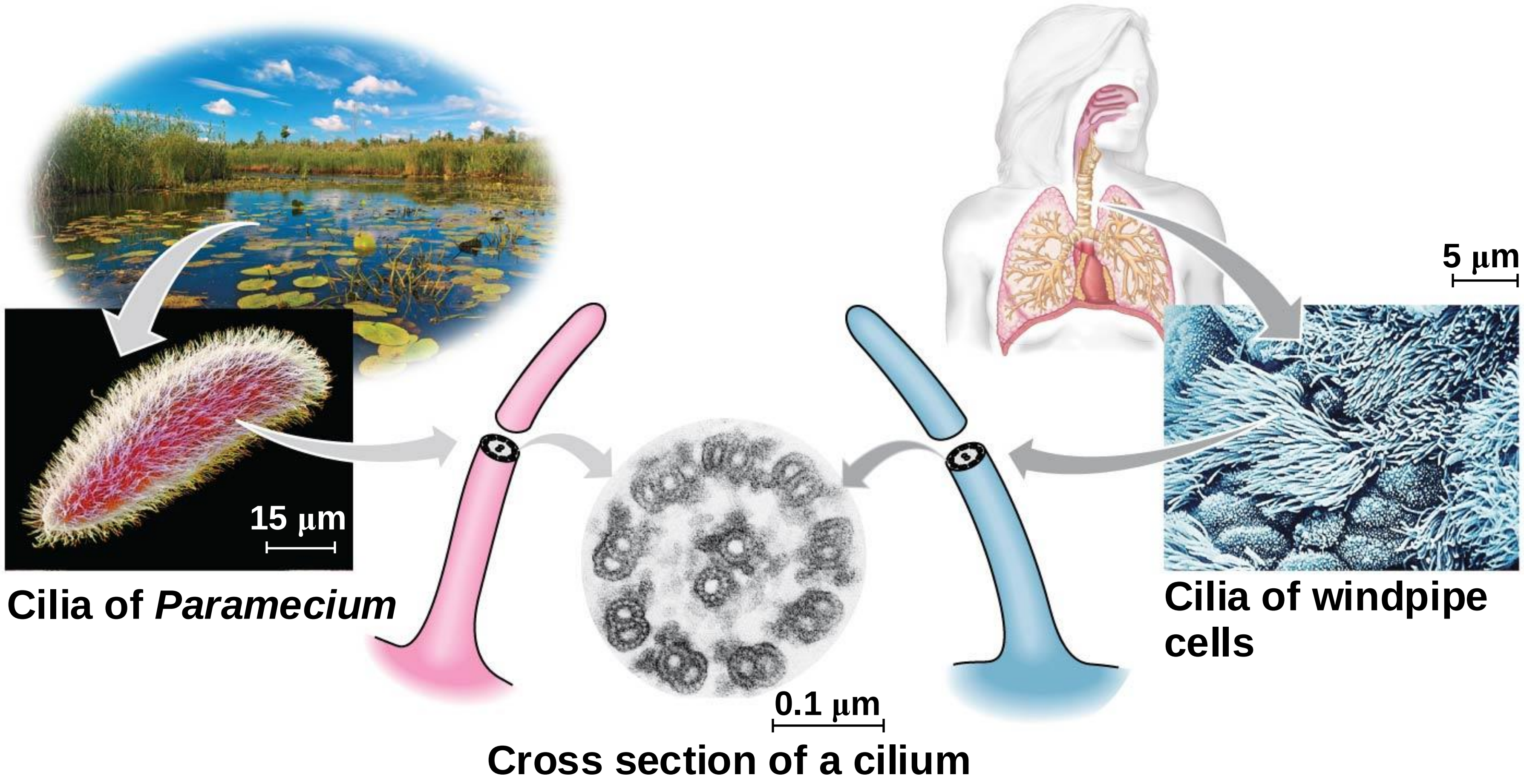
- Domain **Eukarya** includes all eukaryotic organisms
- Domain Eukarya includes the protists and three kingdoms
  - Plants, which produce their own food by photosynthesis
  - Fungi, which absorb nutrients
  - Animals, which ingest their food



Unity in the Diversity of Life

- Unity underlies the diversity of life; for example:
  - DNA is the universal genetic language common to all organisms
  - Unity is present in many features of cell structure

An example of unity underlying the diversity of life: the architecture of cilia in eukaryotes

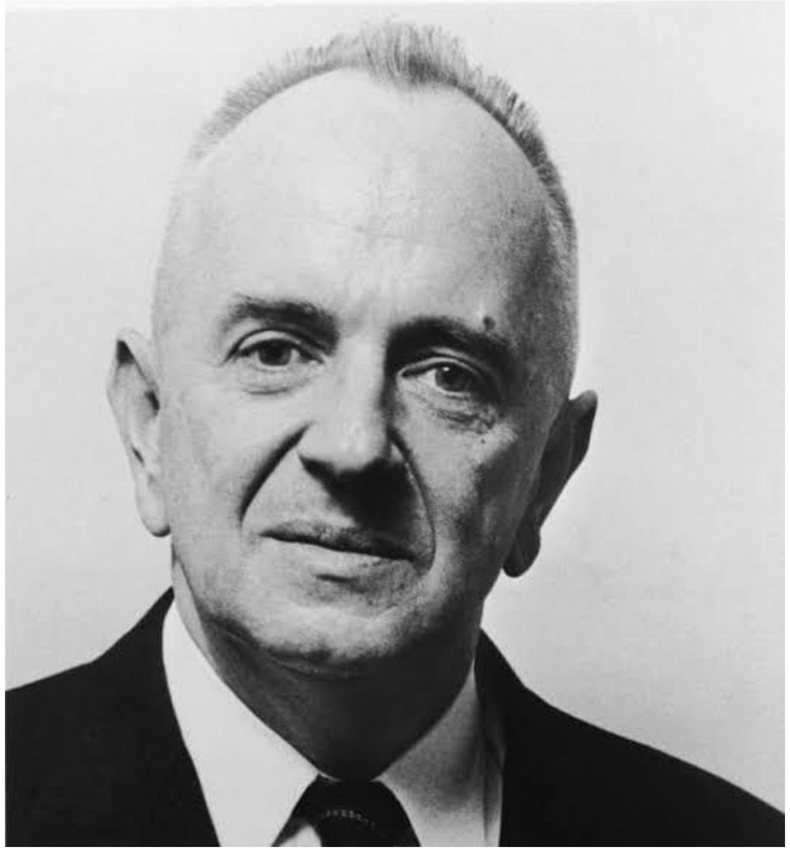


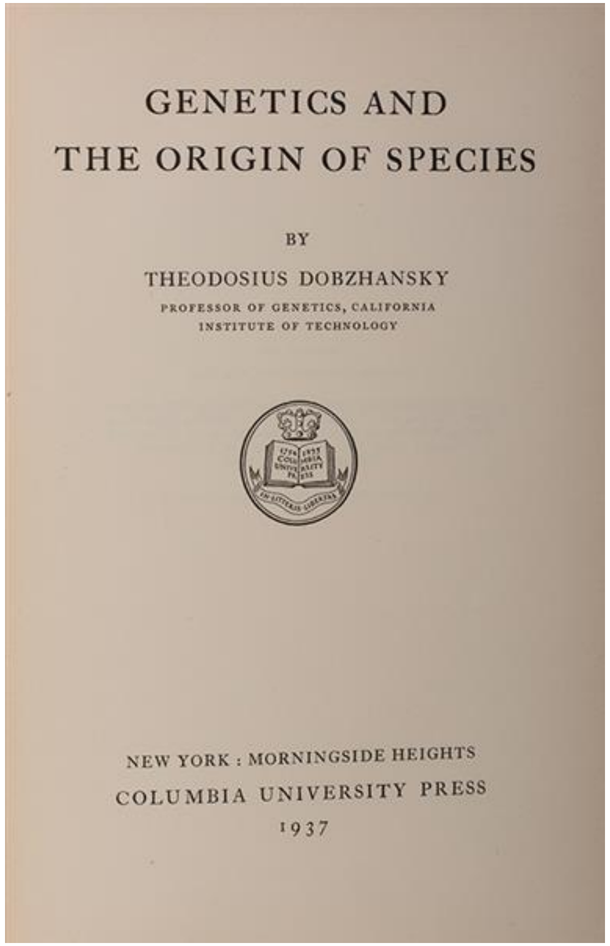
Evolution accounts for the unity and diversity of life

- Evolution is the one idea that makes logical sense of everything we know about living organisms

- The scientific explanation for both the unity and diversity of organisms is **evolution**, the concept that living organisms are modified descendants of common ancestors

"Nothing in biology makes sense except in the light of evolution"—Theodosius Dobzhansky





GENETICS AND
THE ORIGIN OF SPECIES

BY

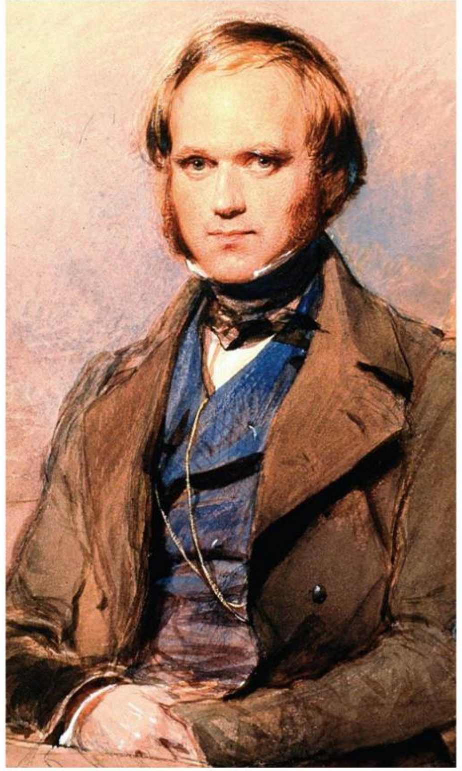
THEODOSIUS DOBZHANSKY

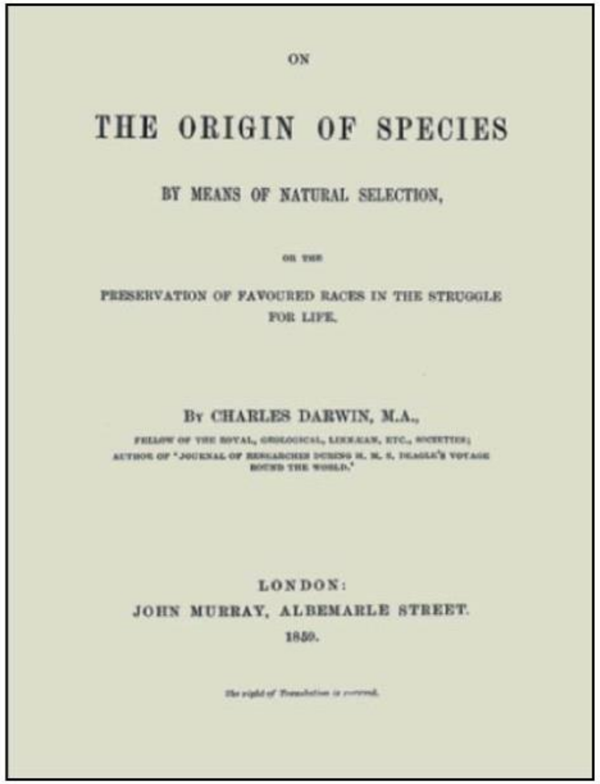
PROFESSOR OF GENETICS, CALIFORNIA
INSTITUTE OF TECHNOLOGY

NEW YORK : MORNINGSIDE HEIGHTS
COLUMBIA UNIVERSITY PRESS
1937

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 explained the duality of unity and diversity





ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

ON THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

By CHARLES DARWIN, M.A.,

LONDON:

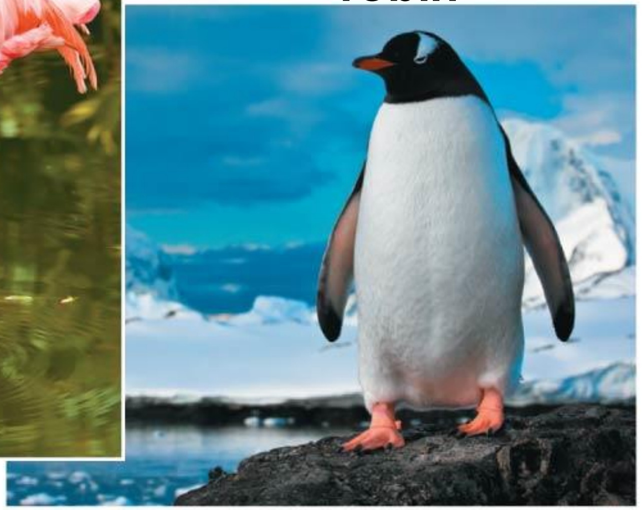
JOHN MURRAY, ALBEMARLE STREET.

1859.

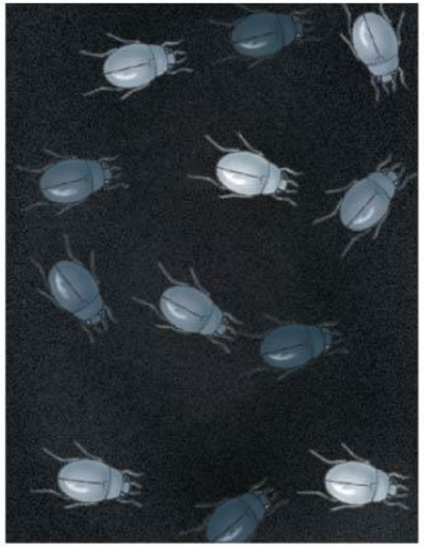
▼ Red-shouldered hawk

▲ European robin

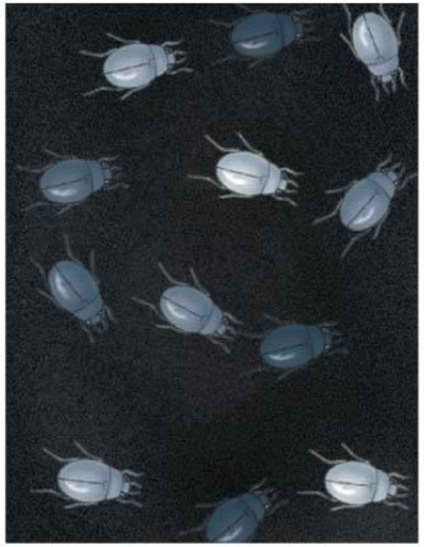
▼ American flamingo



▲ Gentoo penguin

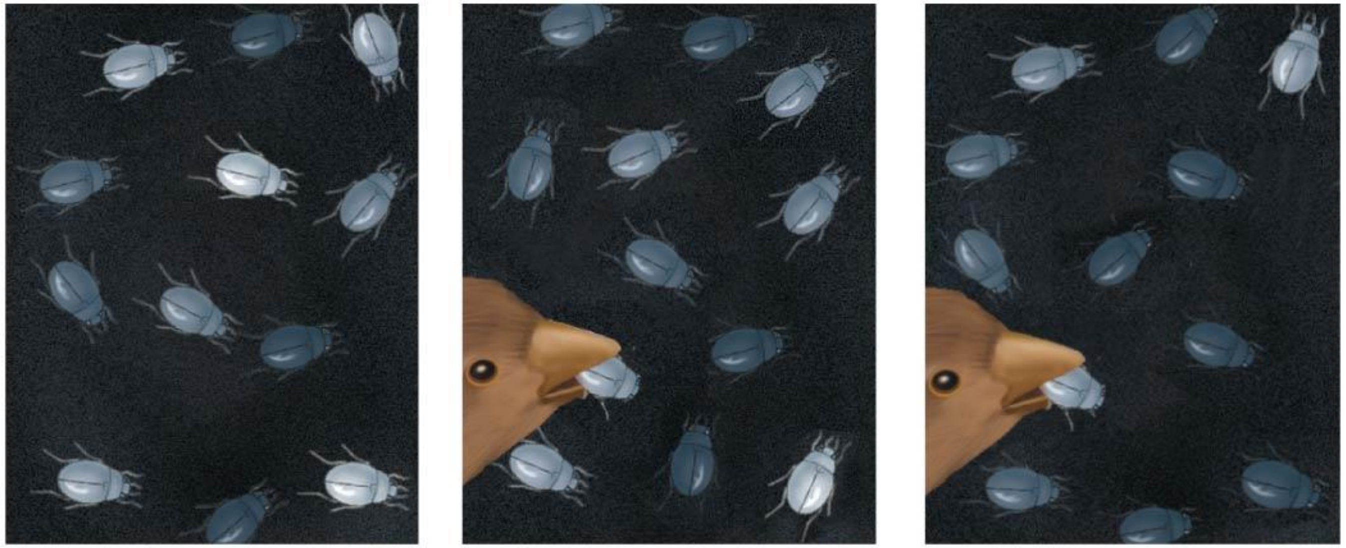


1 Population with varied inherited traits



1 Population with varied inherited traits

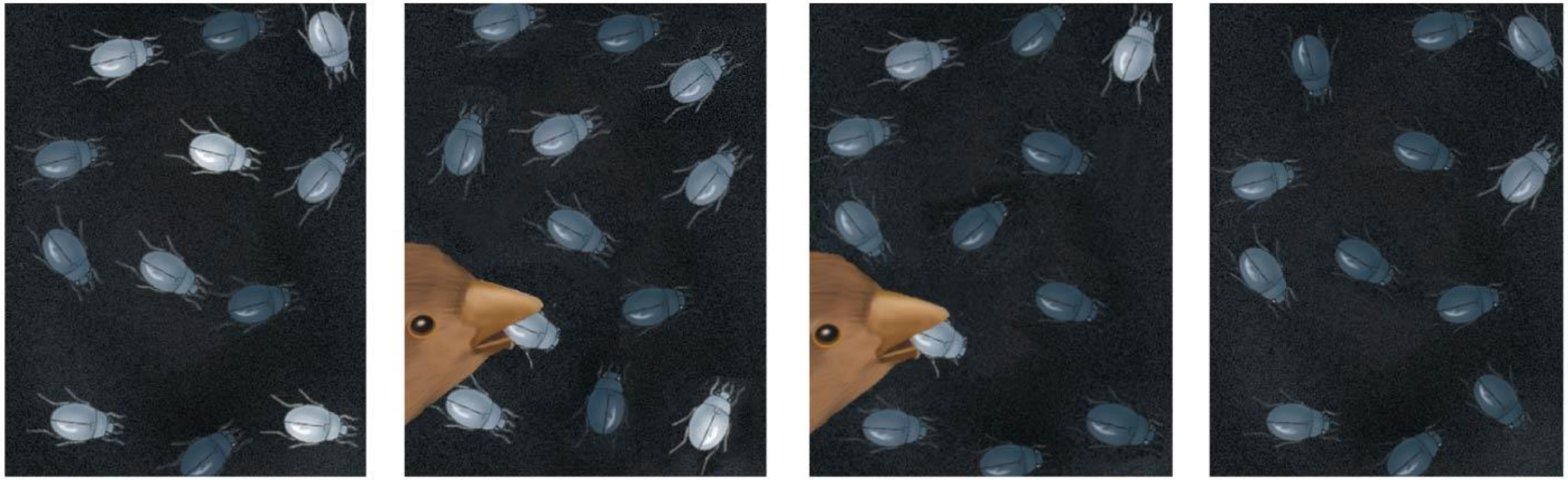
2 Elimination of individuals with certain traits



1 Population with varied inherited traits

2 Elimination of individuals with certain traits

3 Reproduction of survivors



1 Population with varied inherited traits

2 Elimination of individuals with certain traits

3 Reproduction of survivors

4 Increased frequency of traits that enhance survival

The Process of Science

In studying nature, scientists make observations and form and test hypotheses

- The word **science** is derived from Latin and means “to know”
- Evidence-based process to investigate the natural world
- Scientific process includes making observations, forming logical hypotheses, and testing them
- A scientific **theory** is supported by a large body of evidence

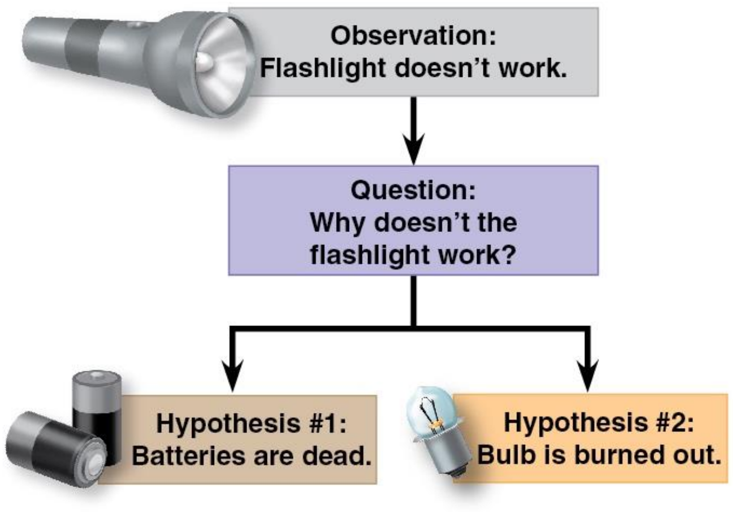
Exploration and Observation

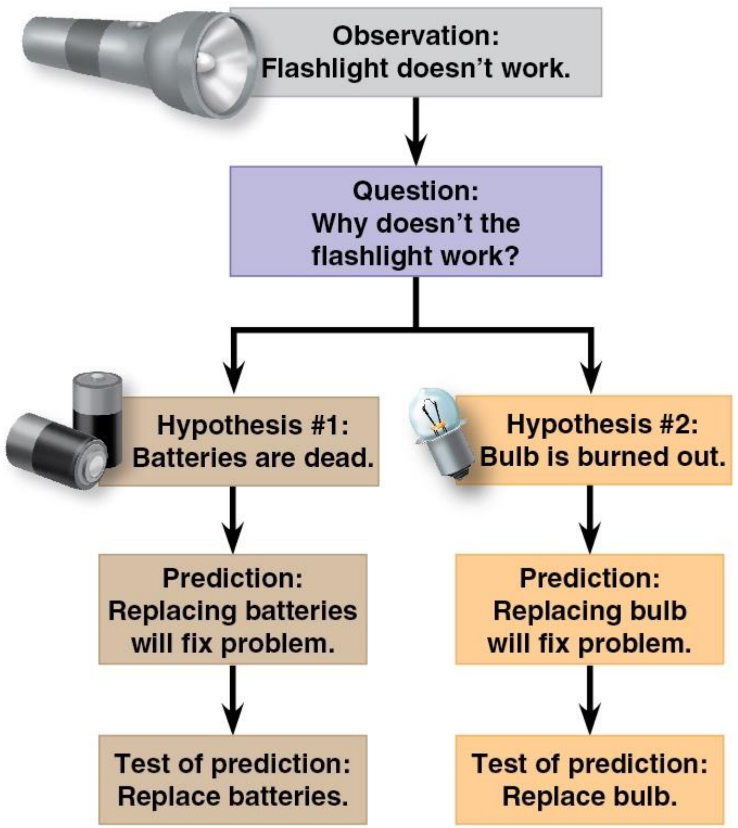
- Biologists describe natural structures and processes
  - based on observation and the analysis of data

- Recorded observations are called **data**
  - **Qualitative** data often take the form of recorded descriptions
  - **Quantitative** data are expressed as numerical measurement, often organized into tables and graphs

Forming and Testing Hypotheses

- In science, a **hypothesis** is an explanation, based on observations and assumptions, that leads to a testable prediction
- It must lead to predictions that can be tested by making additional observations or by performing experiments
- An **experiment** is a scientific test, carried out under controlled conditions


Observation:
Flashlight doesn't work.
Question:
Why doesn't the flashlight work?
Hypothesis #1:
Batteries are dead.
Hypothesis #2:
Bulb is burned out.


Observation:
Flashlight doesn't work.
Question:
Why doesn't the flashlight work?
Hypothesis #1:
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Hypothesis #2:
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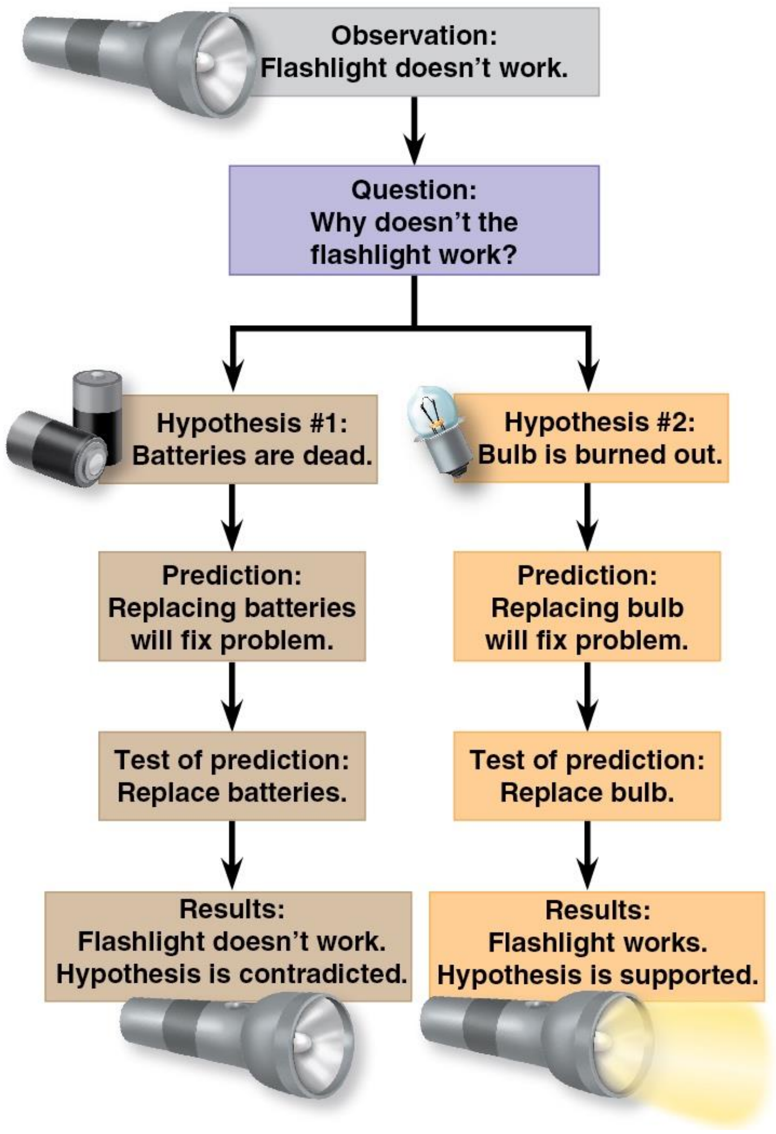
Prediction:
Replacing batteries will fix problem.
Prediction:
Replacing bulb will fix problem.
Test of prediction:
Replace batteries.
Test of prediction:
Replace bulb.


Observation:
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Bulb is burned out.
Prediction:
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Prediction:
Replacing bulb will fix problem.
Test of prediction:
Replace batteries.
Test of prediction:
Replace bulb.
Results:
Flashlight doesn't work.
Hypothesis is contradicted.
Results:
Flashlight works.
Hypothesis is supported.

What is the main requirement for a scientific hypothesis?

Hypotheses Can Be Tested Using Controlled Experiments

- In an experimental test of a hypothesis, researchers often manipulate one component in a system and observe the effects of this change.
  - The factor that is manipulated is called the **independent variable**.
  - The measure used to judge the outcome of the experiment is called the **dependent variable**. This variable depends on the manipulated variable.
  - A **controlled experiment** compares an experimental group with a control group.

Spontaneous Generation

Hypothesis that some vital force can create living organisms from inanimate objects (without descent from similar organisms).

Widely accepted throughout the middle ages and into the 19^{th} century.

Some recipes:

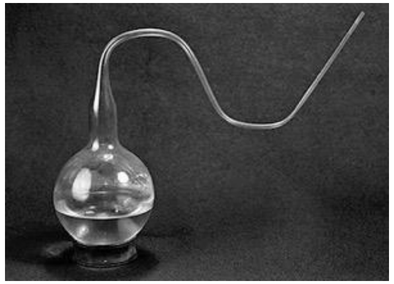
Box + Grain = Mice

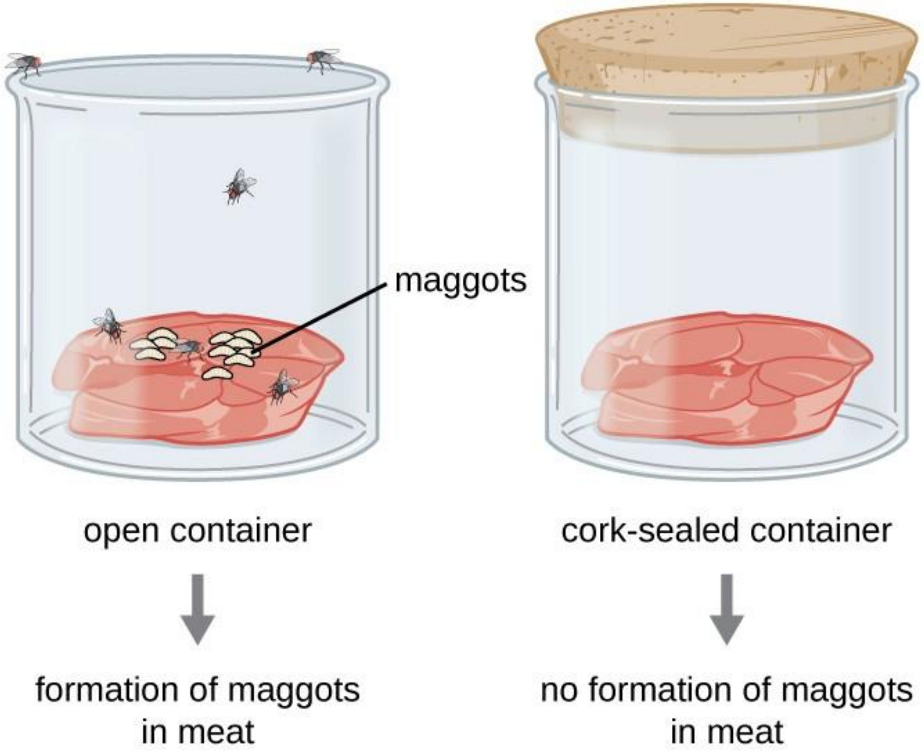
Meat + Warmth = Maggots

Spontaneous Generation

Hypothesis that some vital force can create living organisms from inanimate objects (without descent from similar organisms).

Widely accepted throughout the middle ages and into the 19^{th} century.





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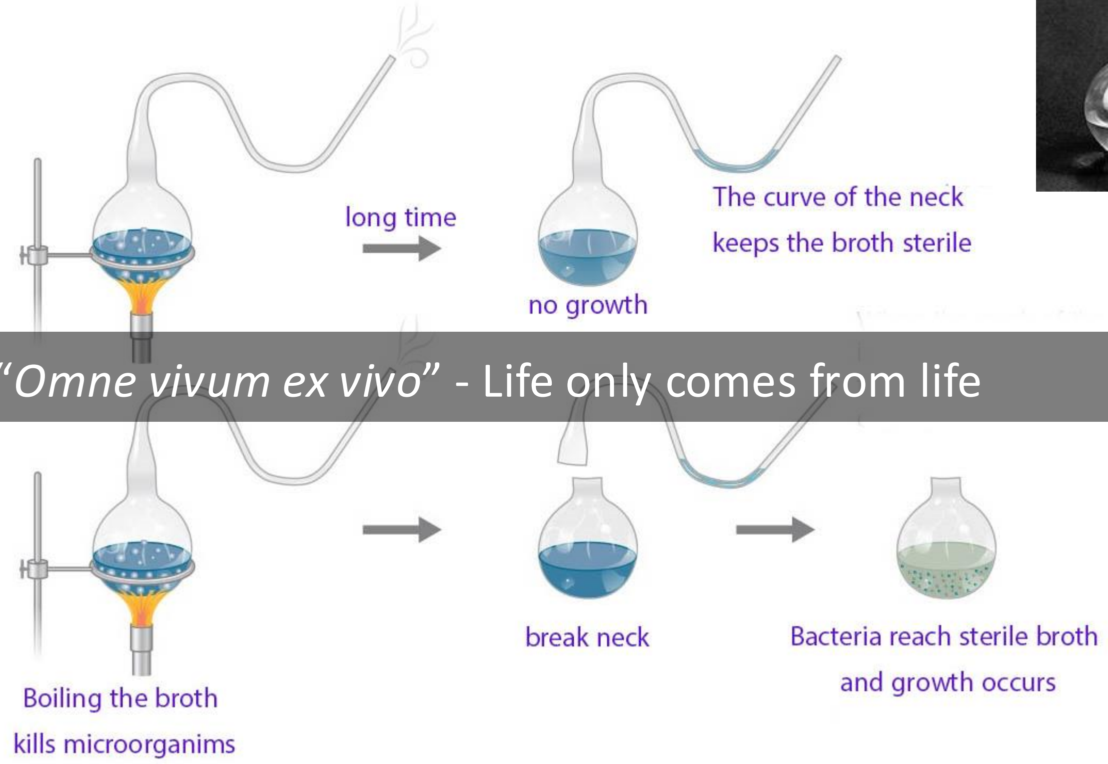
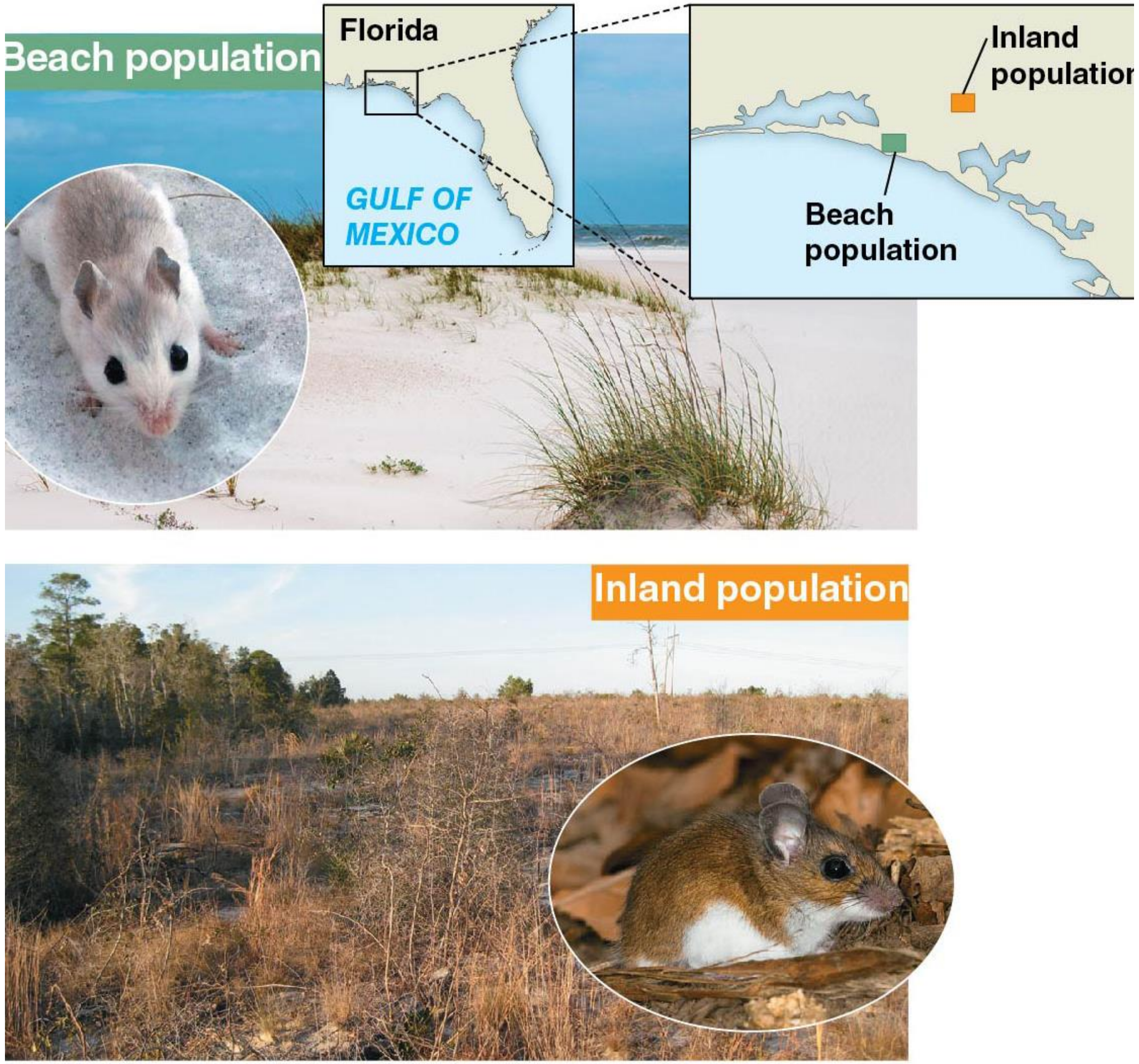


"Omne vivum ex vivo" - Life only comes from life

Pasteur

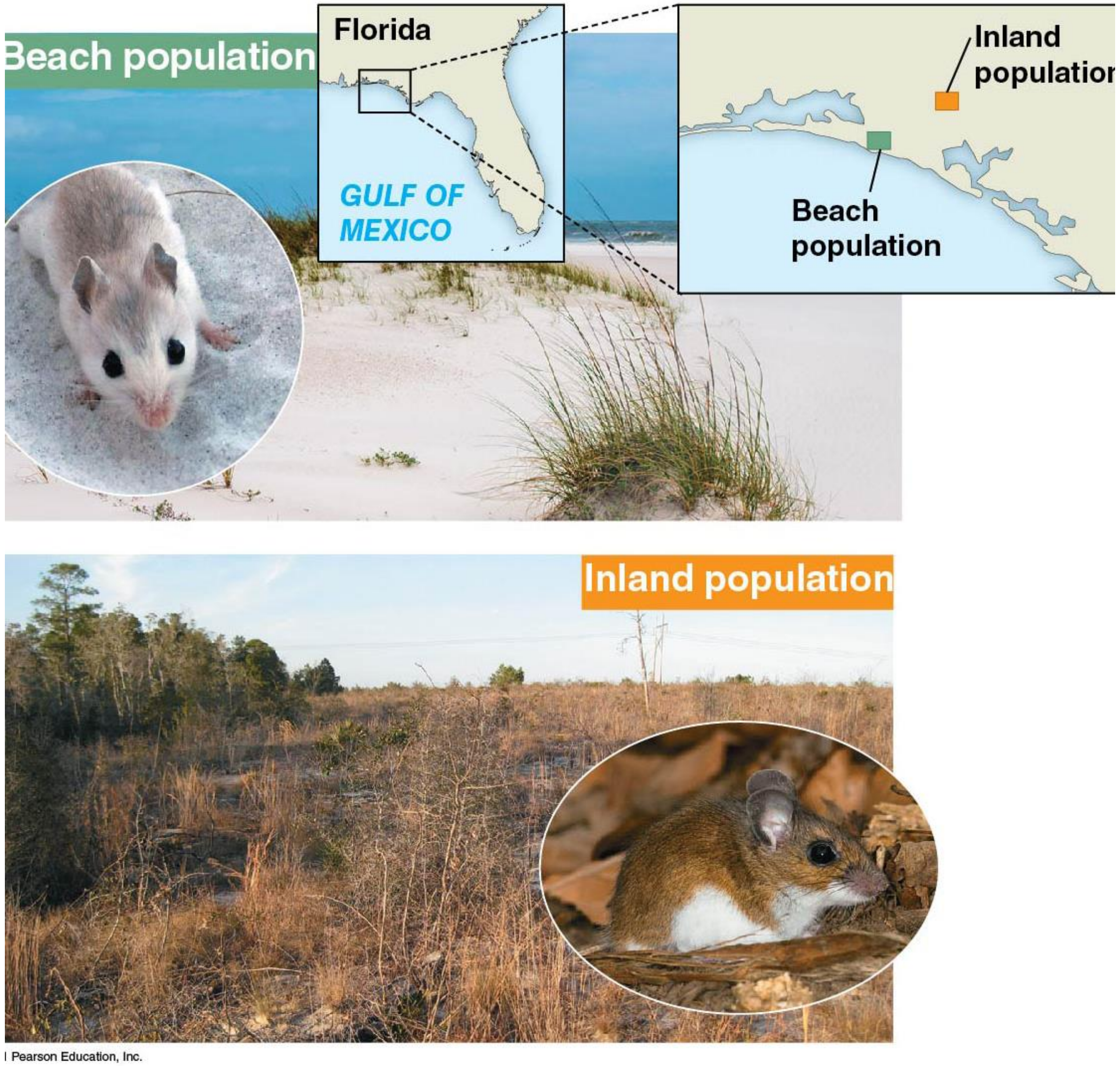
A Case Study in Scientific Inquiry:
Investigating Coat Coloration in Mouse Populations

- Color patterns of animals vary widely in nature, sometimes even between members of the same species
- Two populations of mice of the same species (*Peromyscus polionotus*), but with different color patterns reside in different environments
- The beach mouse lives on white sand dunes with sparse vegetation; the inland mouse lives on darker soil



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

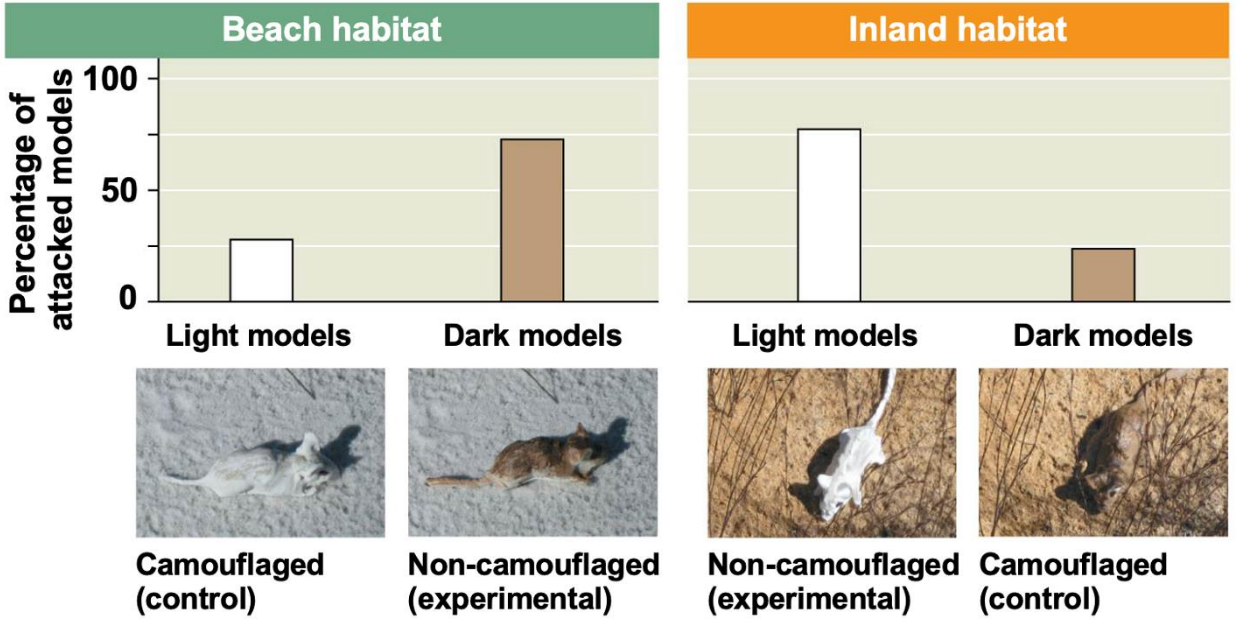
- The two types of mice match the coloration of their habitats
- Predators of these mice are all visual hunters
- Hypothesis is that the color patterns had evolved as adaptations to protect the mice from predators



Data from S. N. Vignieri et al., The selective advantage of crypsis in mice, *Evolution* 64: 2153–8 (2010).

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

- The researchers predicted that mice that did not match their habitat would be preyed on more heavily than mice that did match the surroundings
- They built models of mice, painted them to match one of the surroundings, and placed equal numbers of each type of model in each habitat
- They then recorded signs of predation

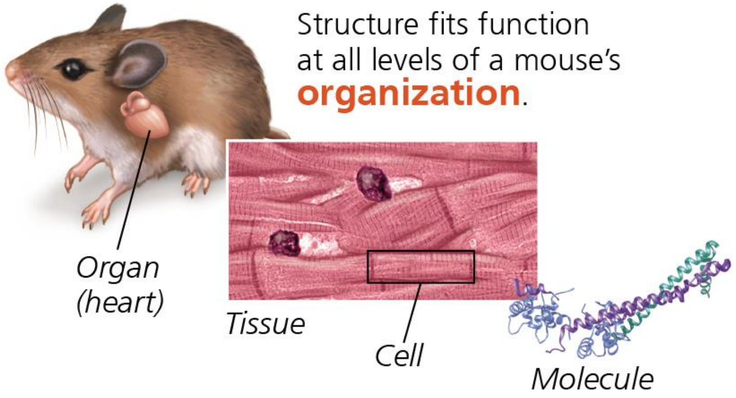


Data from S. N. Vignieri et al., The selective advantage of crypsis in mice, *Evolution* 64: 2153–8 (2010).

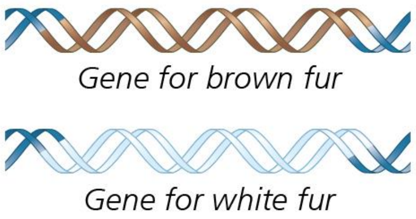
How do these mice illustrate the unifying themes of biology?

As a result of **evolution** through natural selection over long periods of time, the fur colors of these two populations of mice resemble their surroundings, providing protection from predators.

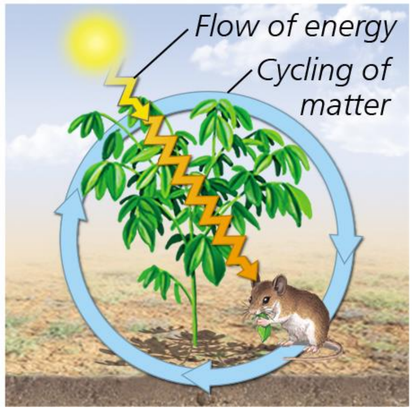
Structure fits function at all levels of a mouse's **organization**.



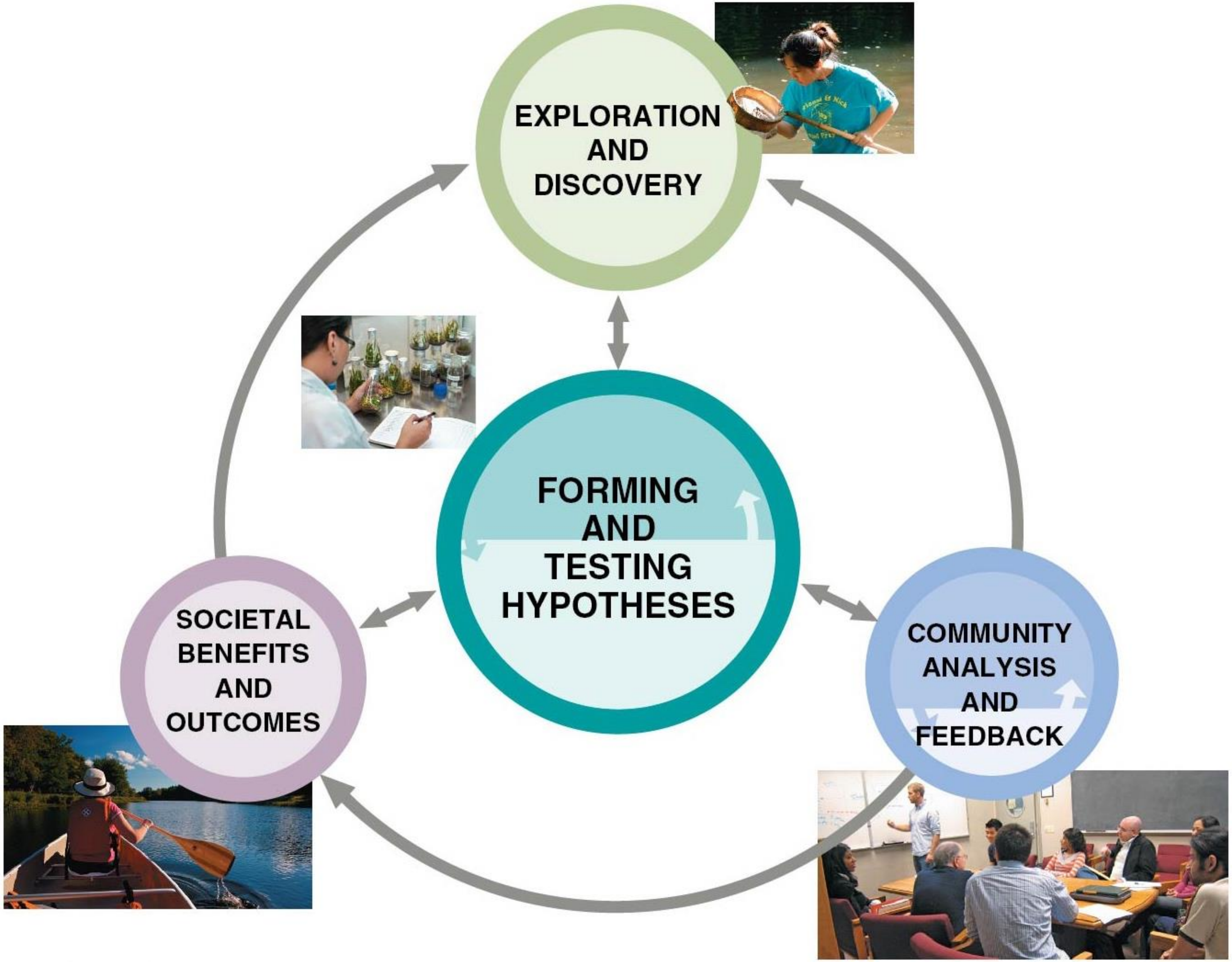
Genetic **information** encoded in DNA determines a mouse's fur colors.

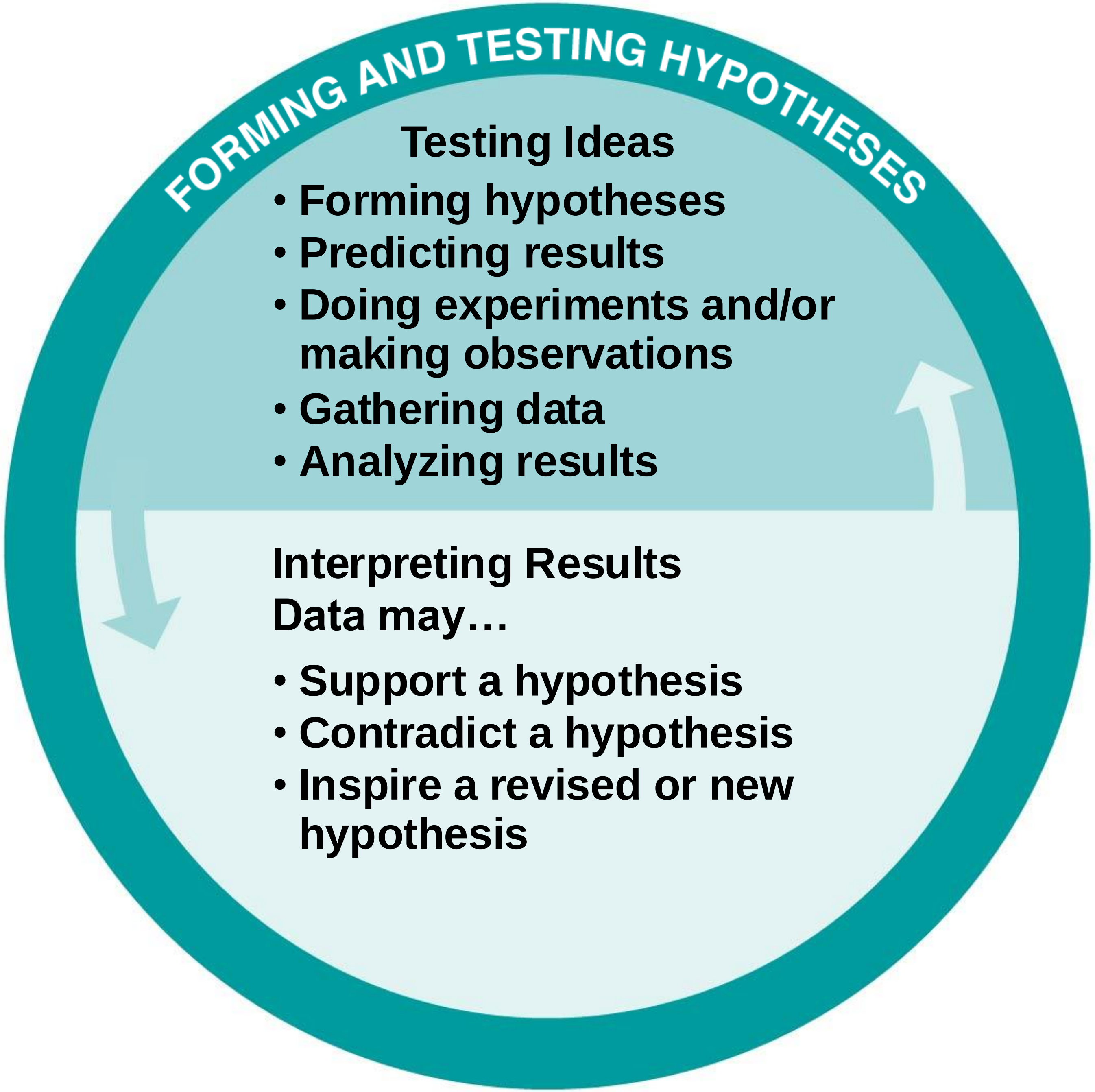


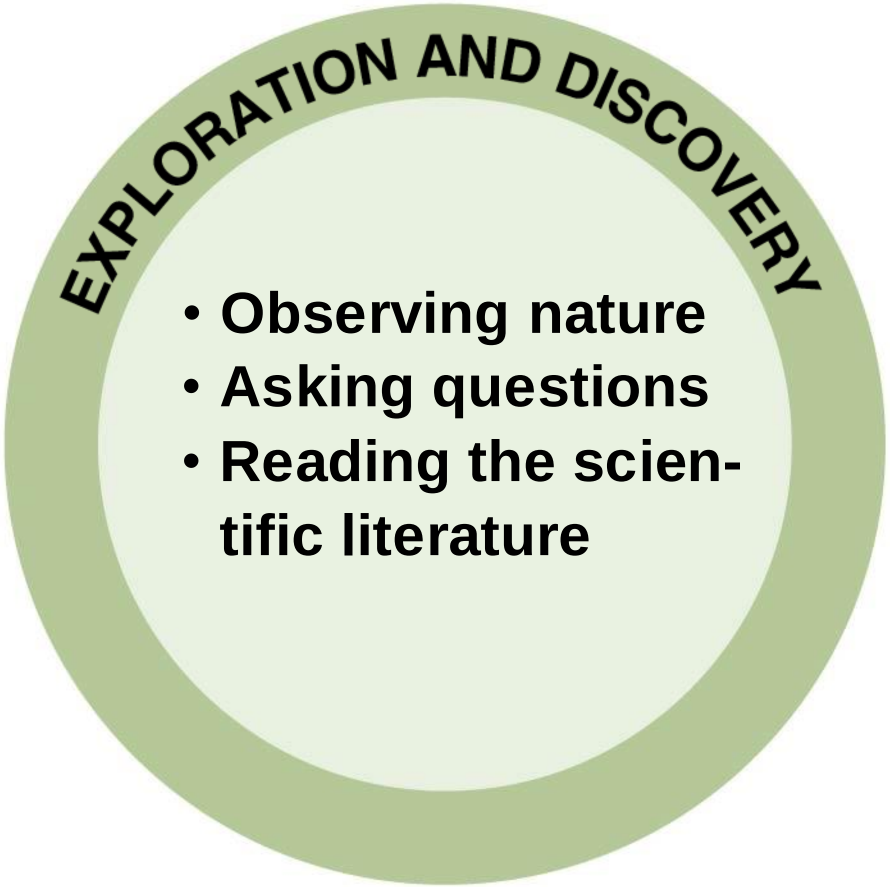
Energy flows one way from the sun to plants to a mouse; **matter** cycles between a mouse and its environment.



A plant being eaten by a mouse and a mouse being preyed upon by a hawk are **interactions** within a system.


EXPLORATION AND DISCOVERY
FORMING AND TESTING HYPOTHESES
SOCIETAL BENEFITS AND OUTCOMES
COMMUNITY ANALYSIS AND FEEDBACK


FORMING AND TESTING HYPOTHESES
Testing Ideas
• Forming hypotheses
• Predicting results
• Doing experiments and/or making observations
• Gathering data
• Analyzing results
Interpreting Results
Data may…
• Support a hypothesis
• Contradict a hypothesis
• Inspire a revised or new hypothesis


EXPLORATION AND DISCOVERY
• Observing nature
• Asking questions
• Reading the scientific literature

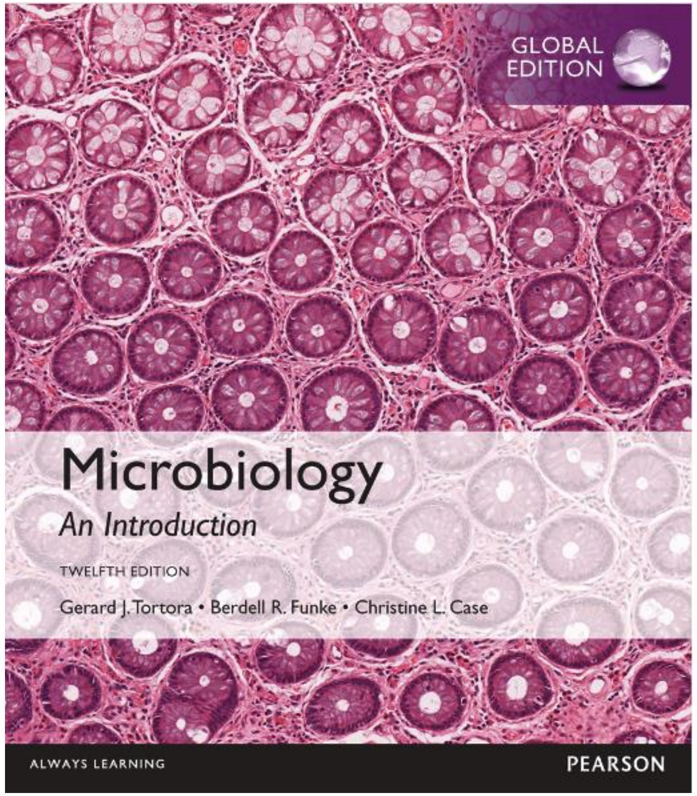

SOCIETAL BENEFITS AND OUTCOMES
• Developing technology
• Informing policy
• Solving problems
• Building knowledge


COMMUNITY ANALYSIS AND FEEDBACK
• Feedback and peer review
• Replication of findings
• Publication
• Consensus building

Biology, Technology, and Society Are Connected in Important Ways

- The goal of science is to understand natural phenomena.
- In contrast, the goal of **technology** is to apply scientific knowledge for some specific purpose.
- These two fields, however, are interdependent. Technological advances stem from scientific research, and research benefits from new technologies.

Sources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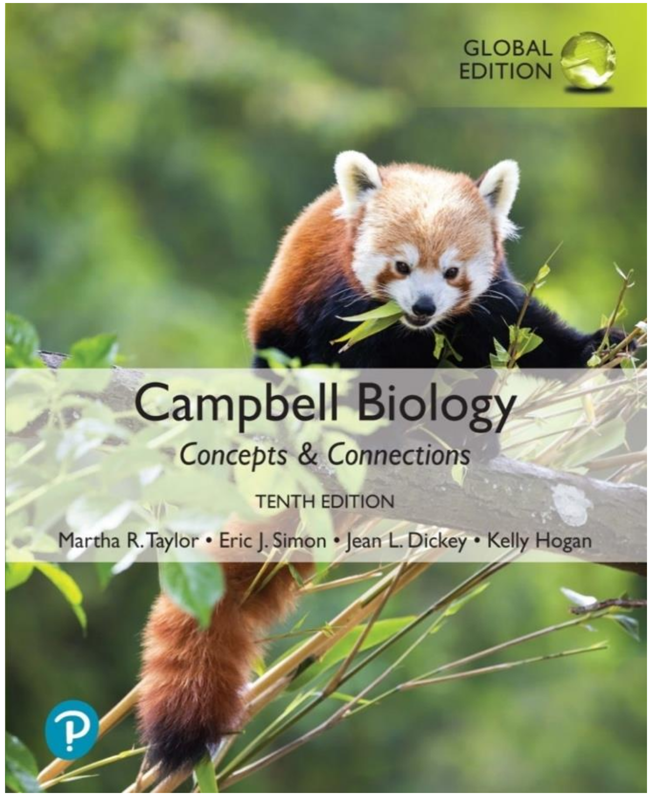
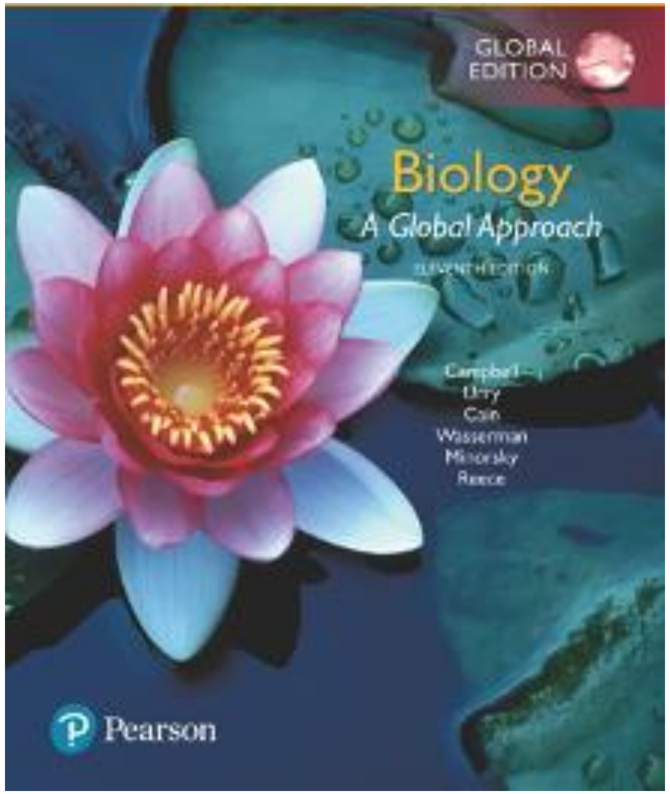
Microbiology
An Introduction
TWELFTH EDITION
Gerard J. Tortora • Berdell R. Funke • Christine L. Case
ALWAYS LEARNING
PEARSON


GLOBAL EDITION
Campbell Biology
Concepts & Connections
TENTH EDITION
Martha R. Taylor • Eric J. Simon • Jean L. Dickey • Kelly Hogan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Biology
A Global Approach
Urry
Cain
Wasserman
Minorsky
Reece
Pearson

◀1 The Biosphere

Even from space, we can see signs of Earth's life—in the mosaic of greens indicating forests, for example. We can also see the **biosphere**, which consists of all life on Earth and all the places where life exists: most regions of land, most bodies of water, the atmosphere to an altitude of several kilometers, and even sediments far below the ocean floor.

◀2 Ecosystems

Our first scale change brings us to a North American mountain meadow, which is an example of an ecosystem, as are a tropical forest, grassland, desert, and coral reef. An **ecosystem** consists of all the living things in a particular area, along with all the nonliving components of the environment with which life interacts, such as soil, water, atmospheric gases, and light.

◀3 Communities

The array of organisms inhabiting a particular ecosystem is called a biological **community**. The community in our meadow ecosystem includes many kinds of plants, various animals, mushrooms and other fungi, and enormous numbers of diverse microorganisms, such as bacteria, that are too small to see without a microscope. Each of these forms of life belongs to a *species*—a group whose members can only reproduce with other members of the group.

◀4 Populations

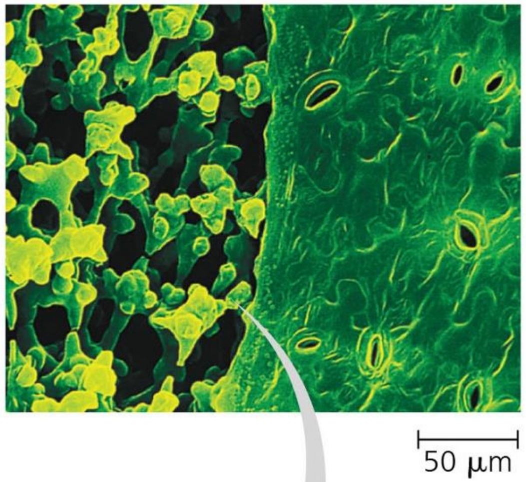
A **population** consists of all the individuals of a species living within the bounds of a specified area. For example, our meadow includes a population of lupines (some of which are shown here) and a population of mule deer. A community is therefore the set of populations that inhabit a particular area.

◀ 5 Organisms

Individual living things are called **organisms**. Each plant in the meadow is an organism, and so is each animal, fungus, and bacterium.

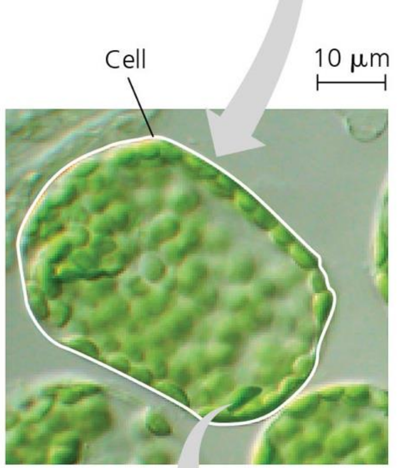
◀ 6 Organs

The structural hierarchy of life continues to unfold as we explore the architecture of a complex organism. A leaf is an example of an **organ**, a body part that is made up of multiple tissues and has specific functions in the body. Leaves, stems, and roots are the major organs of plants. Within an organ, each tissue has a distinct arrangement and contributes particular properties to organ function.



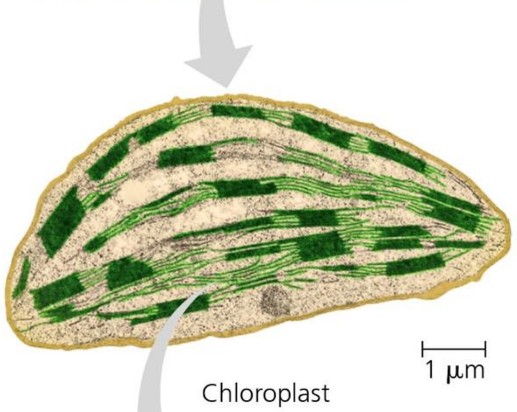
◀ 7 Tissues

Viewing the tissues of a leaf requires a microscope. Each **tissue** is a group of cells that work together, performing a specialized function. The leaf shown here has been cut on an angle. The honeycombed tissue in the interior of the leaf (left side of photo) is the main location of photosynthesis, the process that converts light energy to the chemical energy of sugar. The jigsaw puzzle–like "skin" on the surface of the leaf (right side of photo) is a tissue called epidermis. The pores through the epidermis allow entry of the gas CO_2, a raw material for sugar production.



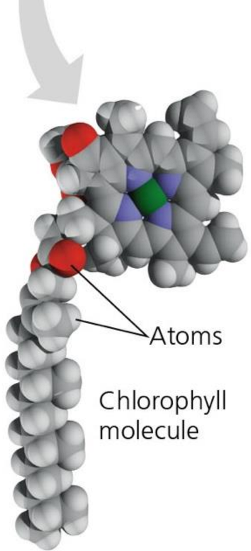
◄ 8 Cells

The **cell** is life's fundamental unit of structure and function. Some organisms consist of a single cell, which performs all the functions of life. Other organisms are multicellular and feature a division of labor among specialized cells. Here we see a magnified view of a cell in a leaf tissue. This cell is about 40 micrometers (μm) across—about 500 of them would reach across a small coin. Within these tiny cells are even smaller green structures called chloroplasts, which are responsible for photosynthesis.



◄ 9 Organelles

Chloroplasts are examples of **organelles**, the various functional components present in cells. The image, taken by a powerful microscope, shows a single chloroplast.



◄ 10 Molecules

Our last scale change drops us into a chloroplast for a view of life at the molecular level. A **molecule** is a chemical structure consisting of two or more units called atoms, represented as balls in this computer graphic of a chlorophyll molecule. Chlorophyll is the pigment that makes a leaf green, and it absorbs sunlight during photosynthesis. Within each chloroplast, millions of chlorophyll molecules are organized into systems that convert light energy to the chemical energy of food.