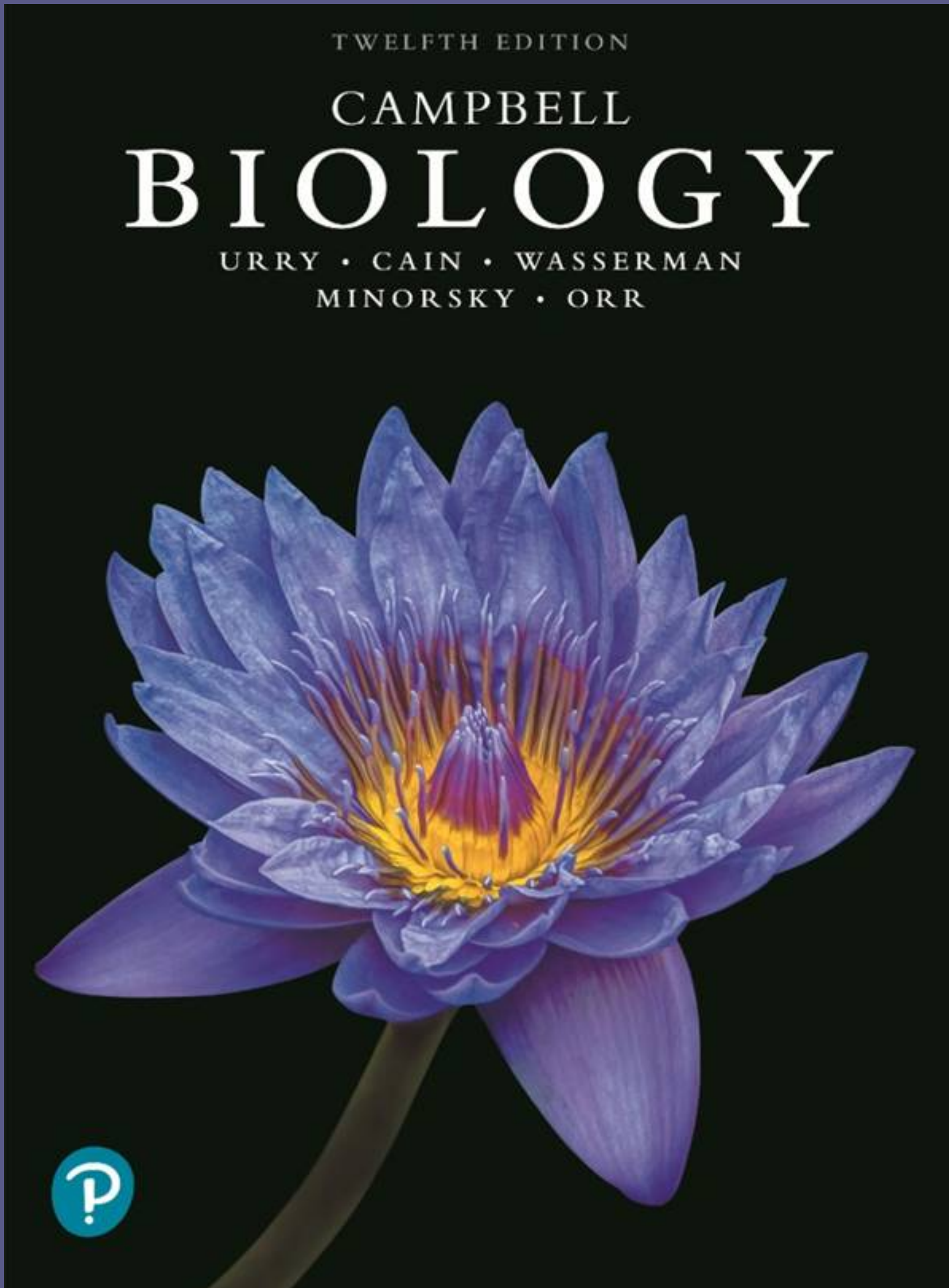


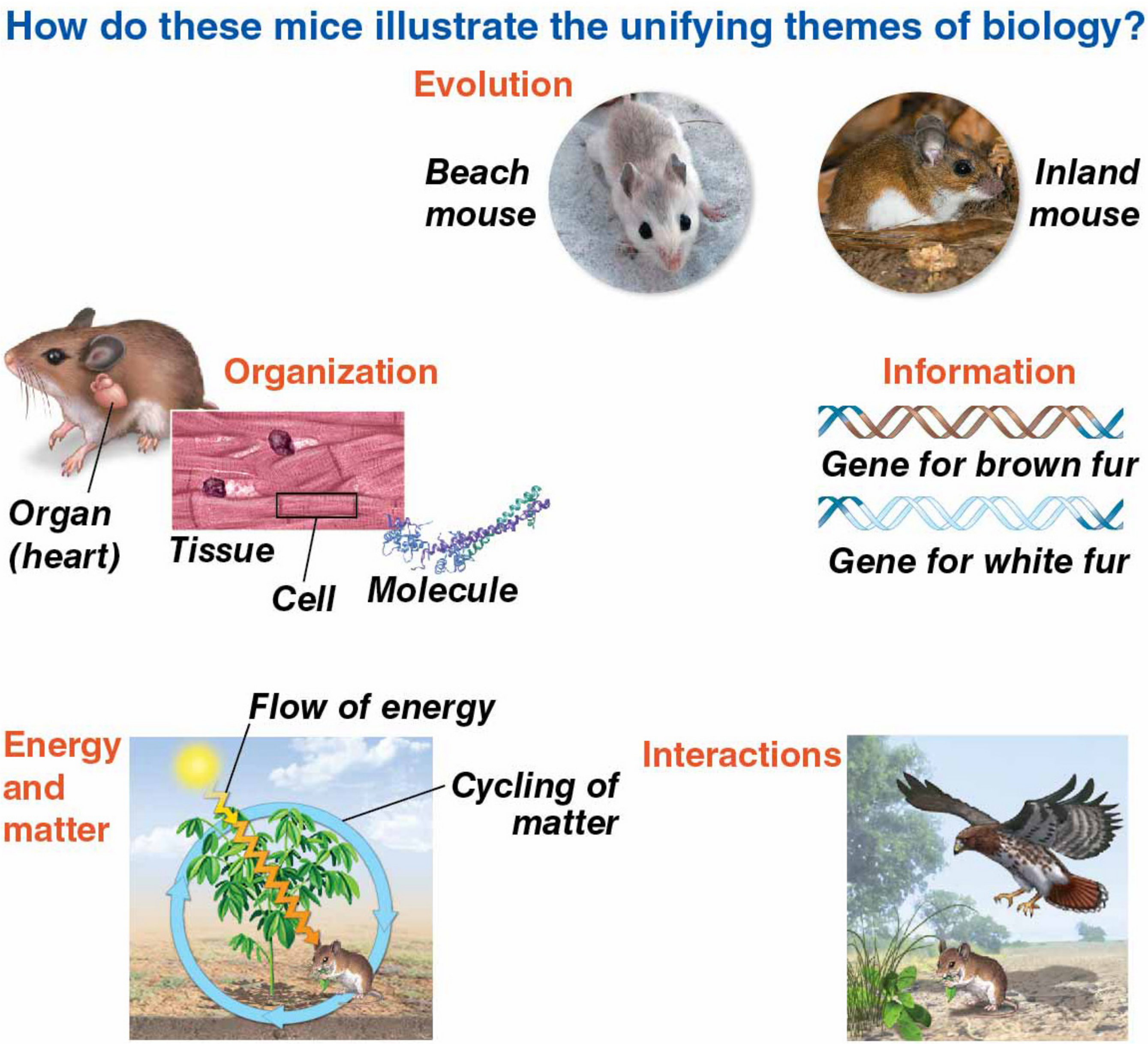
Chapter 1

Evolution, the Themes of Biology, and Scientific Inquiry

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 1.1a

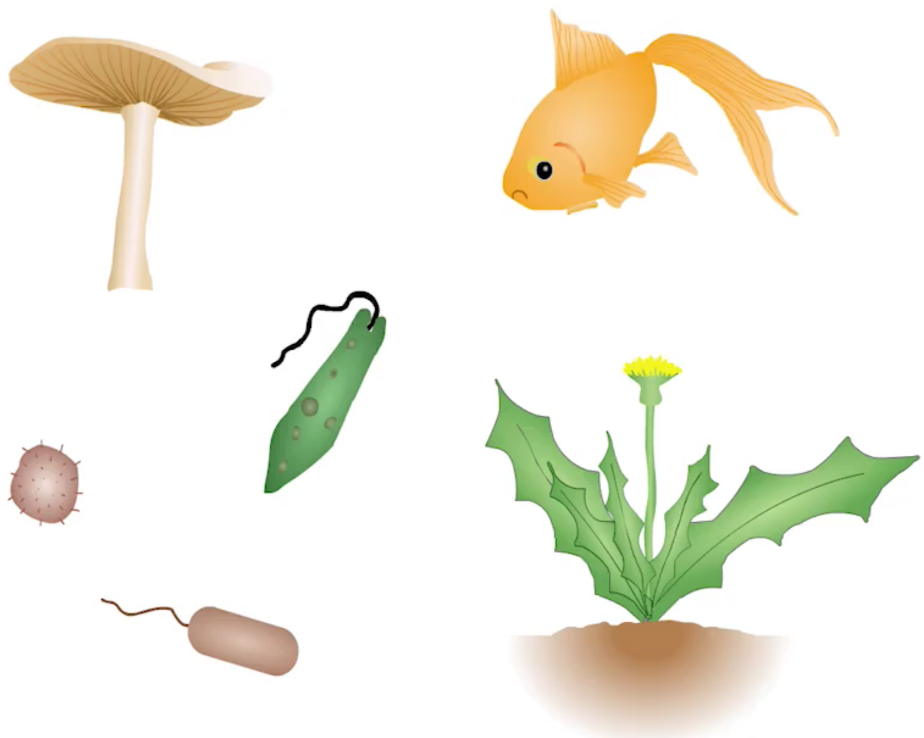
Figure 1.1b


How do these mice illustrate the unifying themes of biology?
Evolution
Beach mouse
Inland mouse
Organization
Organ (heart)
Tissue
Cell
Molecule
Information
Gene for brown fur
Gene for white fur
Energy and matter
Flow of energy
Cycling of matter
Interactions

CONCEPT 1.1: The study of life reveals unifying themes

- **Biology** is the scientific study of life
- We recognize life by what living things do
- Biology is a subject of enormous scope

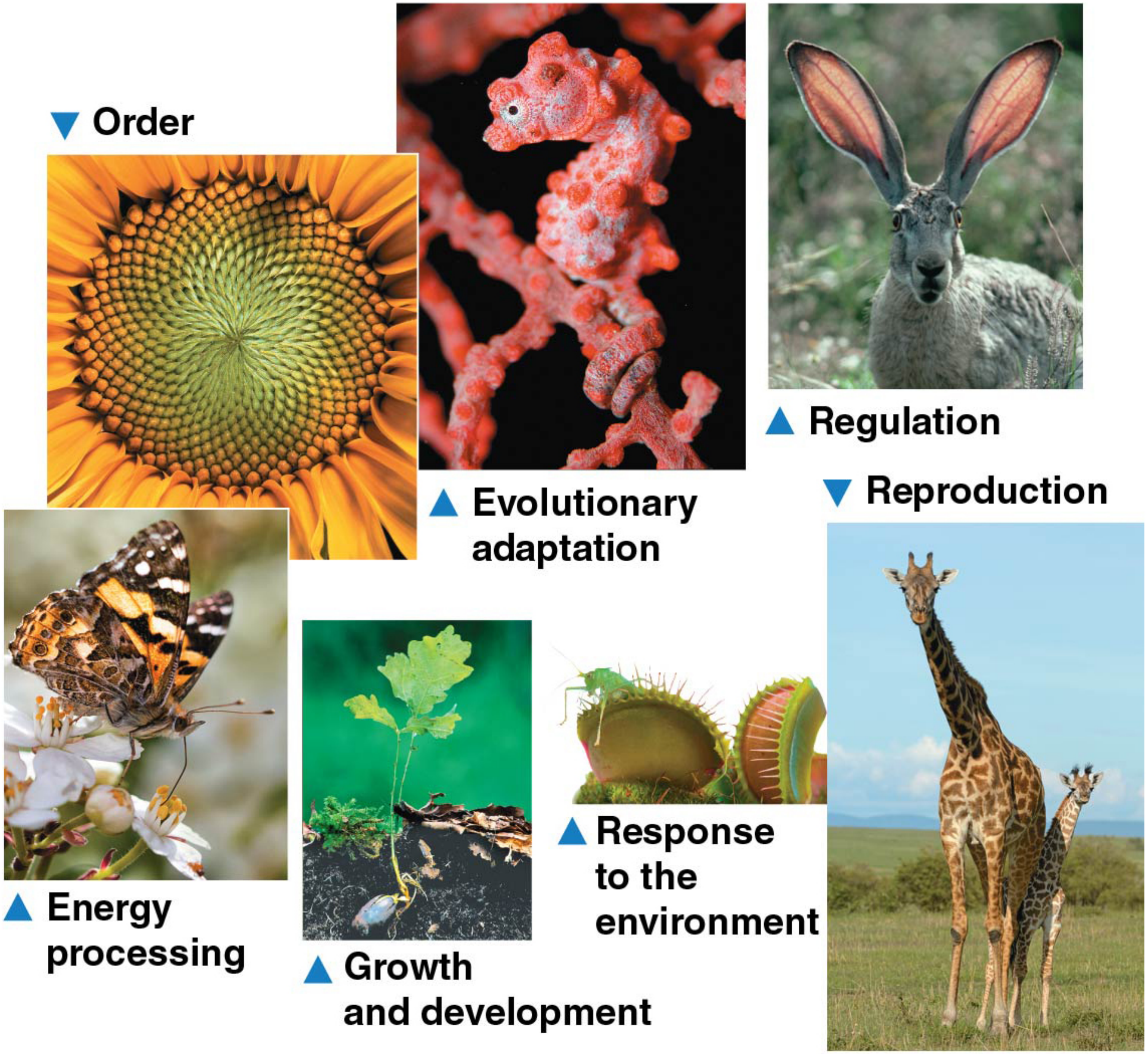
Animation: Signs of Life



[redacted]

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

Figure 1.2

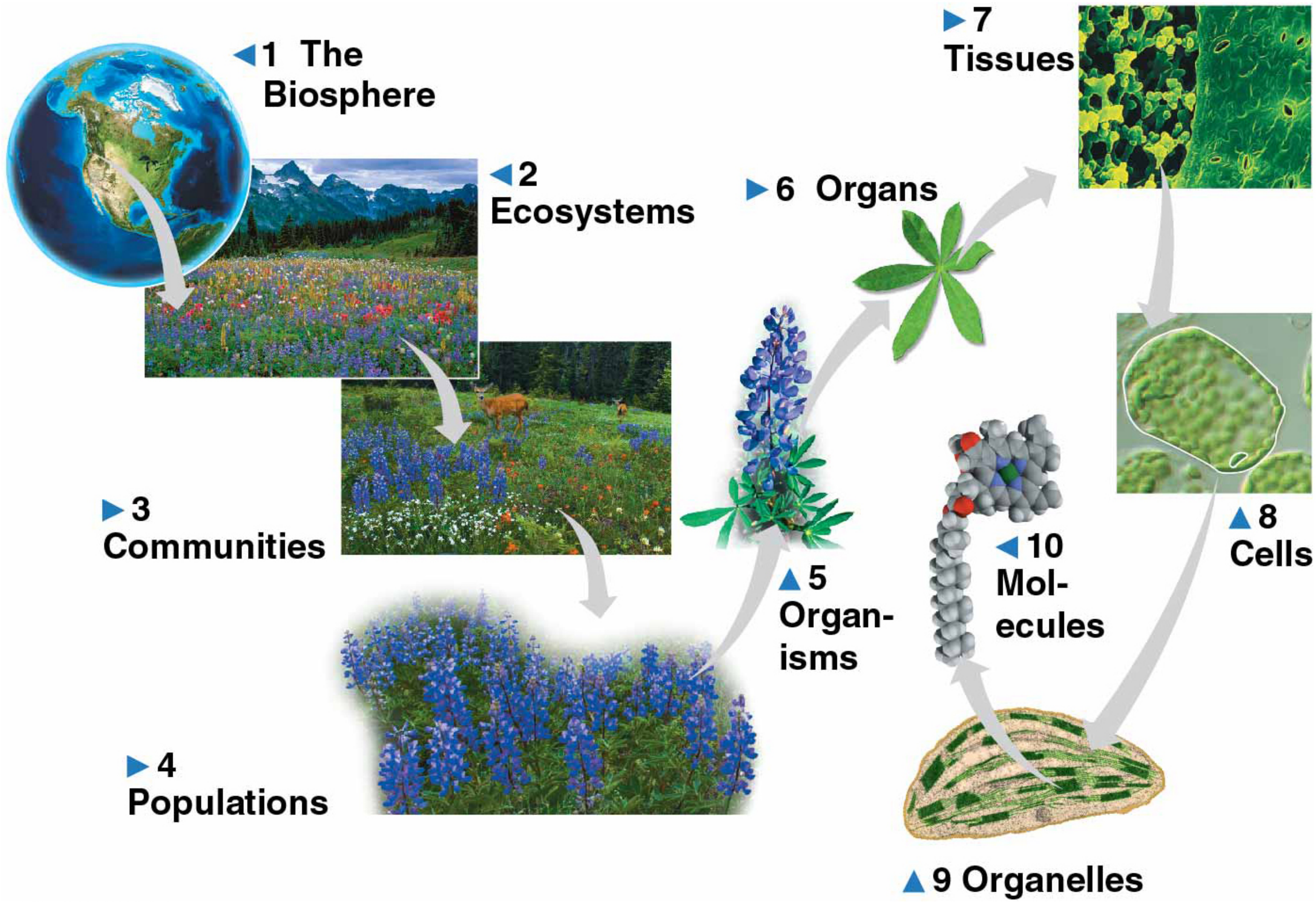

Order
Evolutionary adaptation
Regulation
Reproduction
Energy processing
Growth and development
Response to the environment

Video: Sea Horse Camouflage

Theme: New Properties Emerge at Successive Levels of Biological Organization

- Life can be studied at different levels, from molecules to the entire living planet
- This enormous range can be divided into different levels of biological organization
- Reductionism is an approach that reduces complex systems to simple components that are manageable to study

Figure 1.3


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

Emergent Properties

- **Emergent properties** result from the arrangement and interaction of parts as complexity increases
- 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 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
- Systems biology can be used to study life at all levels

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

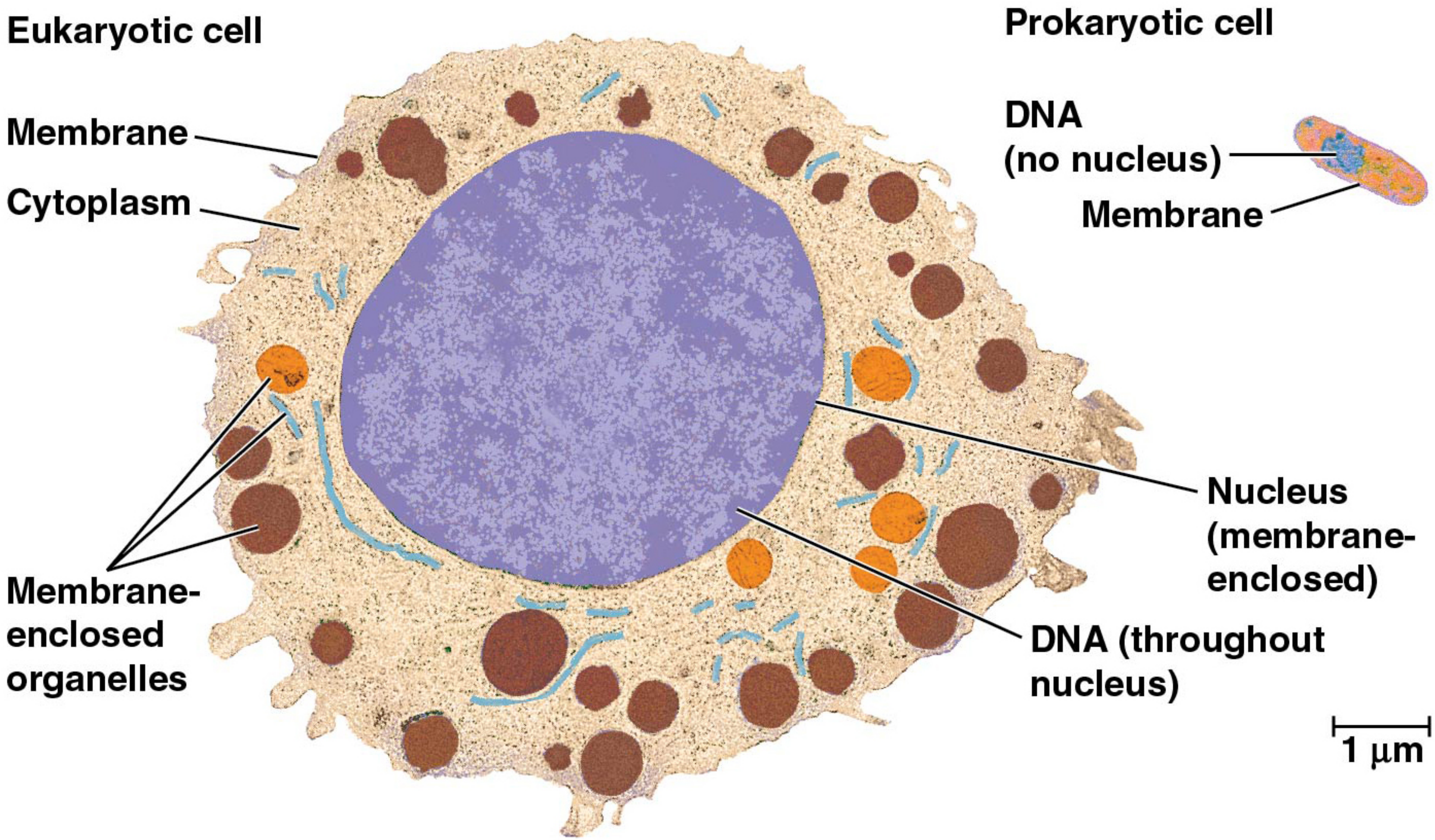
Figure 1.UN01

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
- The cell theory states that all living organisms are made from cells
- Every cell is enclosed by a membrane that regulates passage of materials between the cell and its environment
- The cells of bacteria and archaea are prokaryotic, while all other forms of life are composed of eukaryotic cells

- 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

Figure 1.4

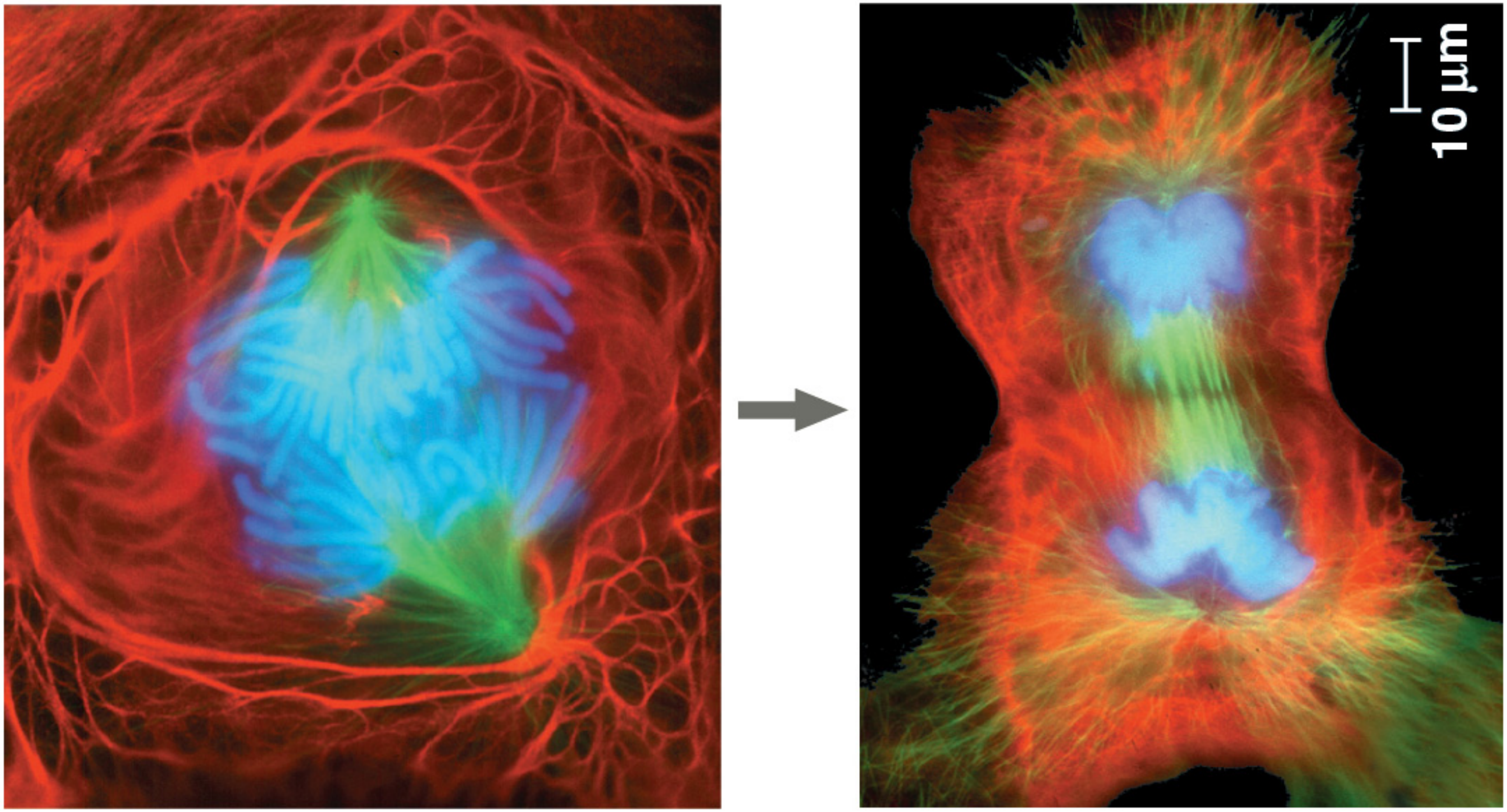


Eukaryotic cell
Membrane
Cytoplasm
Membrane-enclosed organelles
Prokaryotic cell
DNA (no nucleus)
Membrane
Nucleus (membrane-enclosed)
DNA (throughout nucleus)
1 μm

Theme: 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)**

Figure 1.5



DNA, the Genetic Material

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

Animation: Heritable Information: DNA

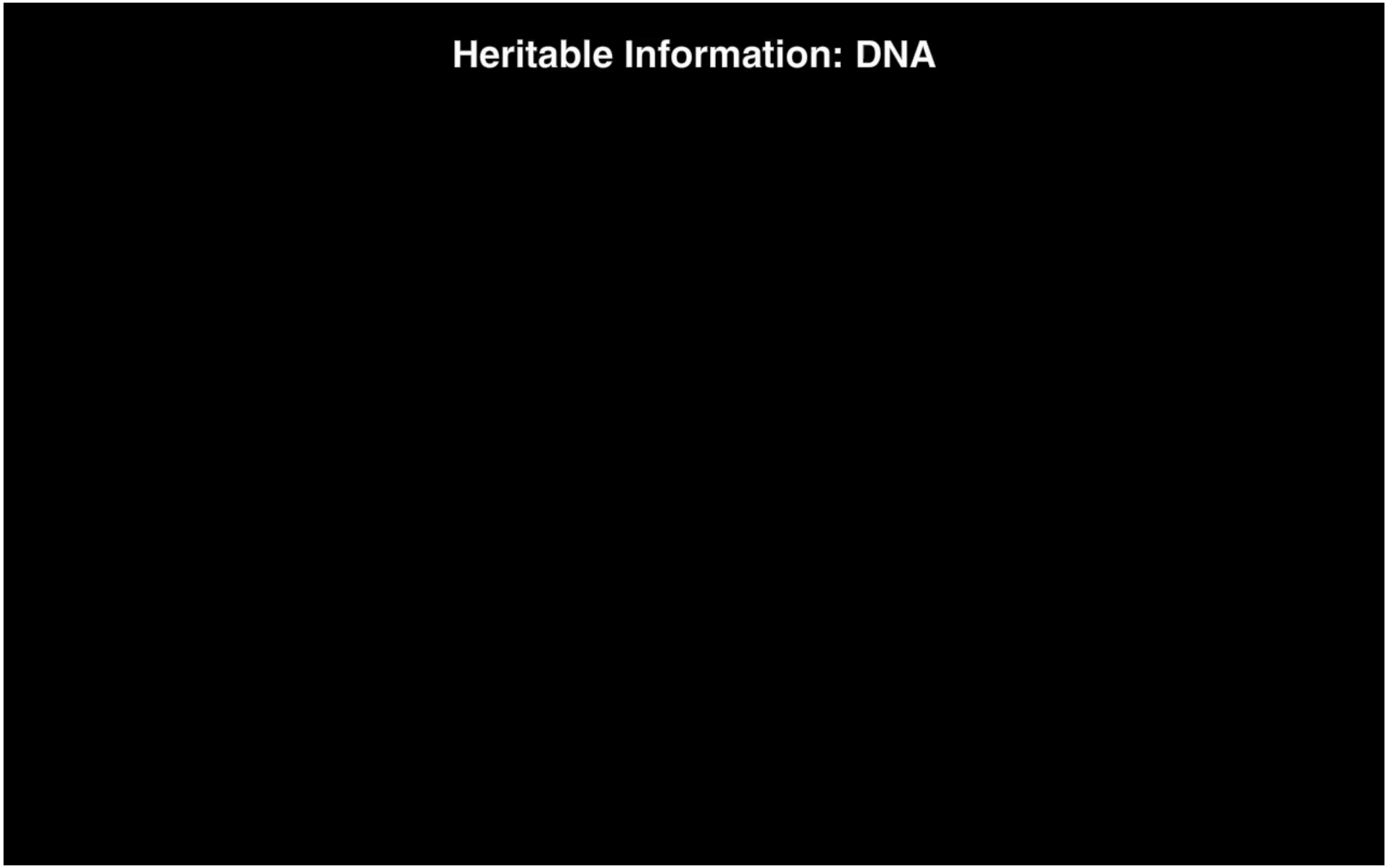
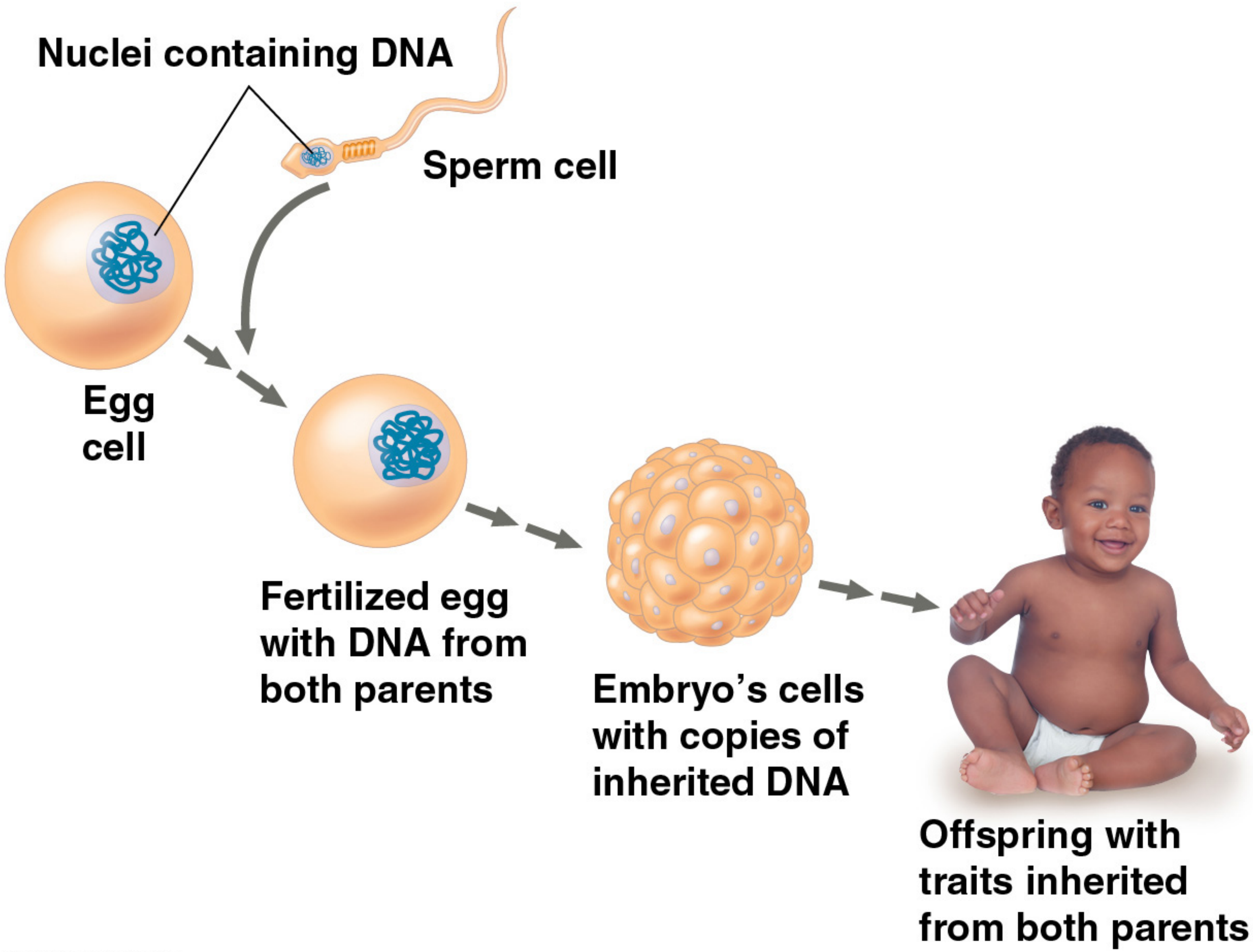
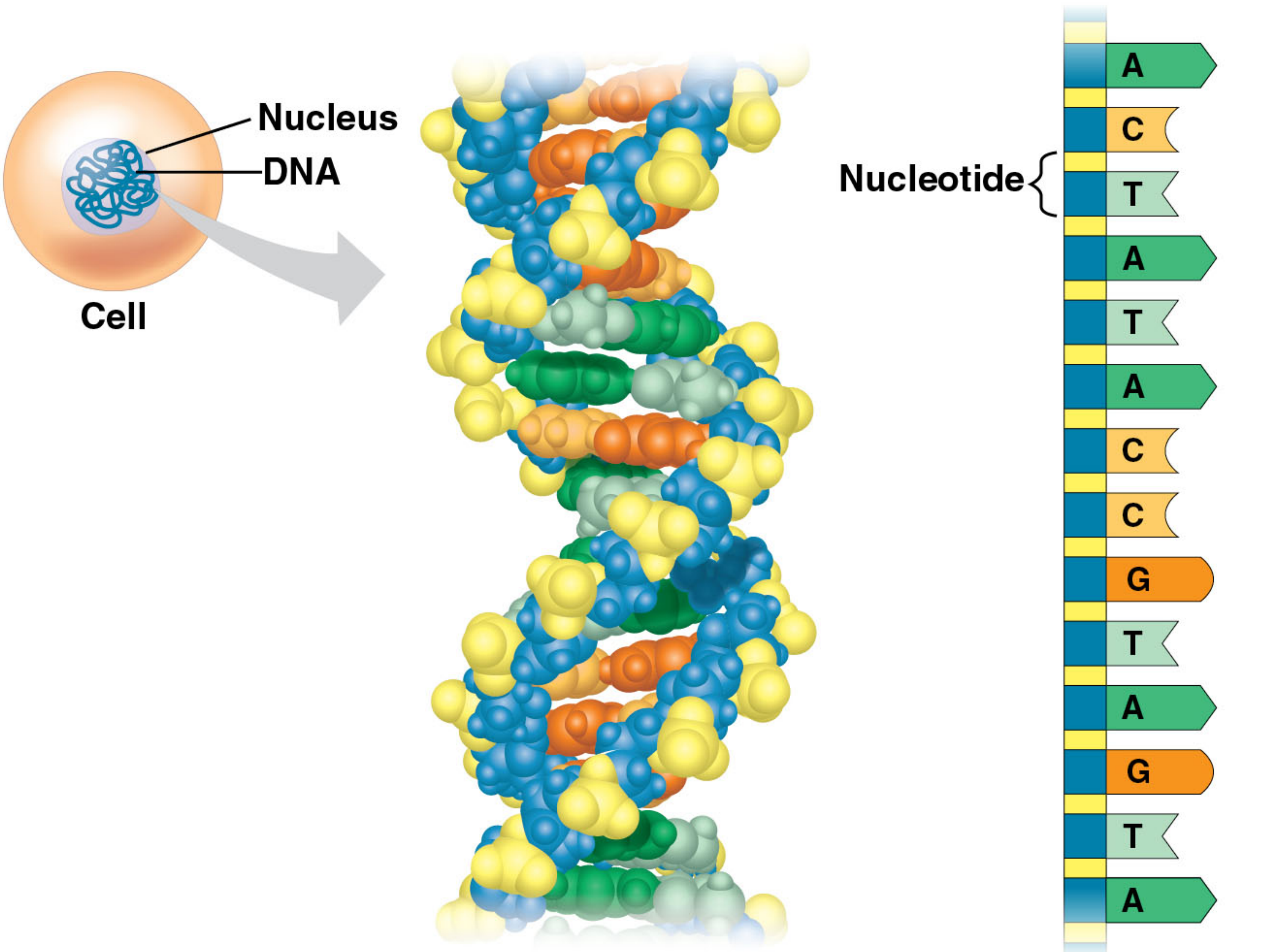


Figure 1.6


Nuclei containing DNA
Sperm cell
Egg
cell
Fertilized egg
with DNA from
both parents
Embryo's cells
with copies of
inherited DNA
Offspring with
traits inherited
from both parents

- 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

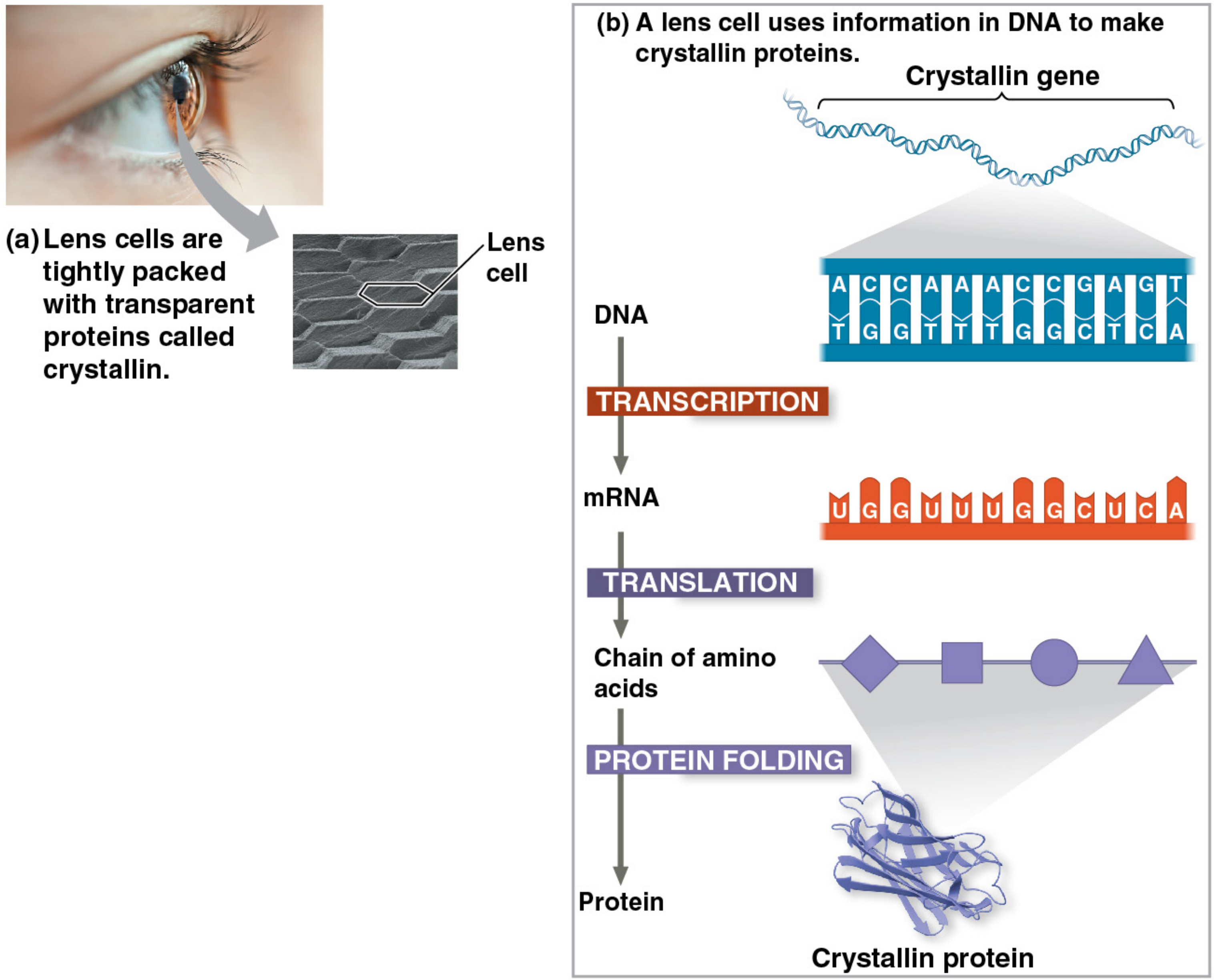
Figure 1.7



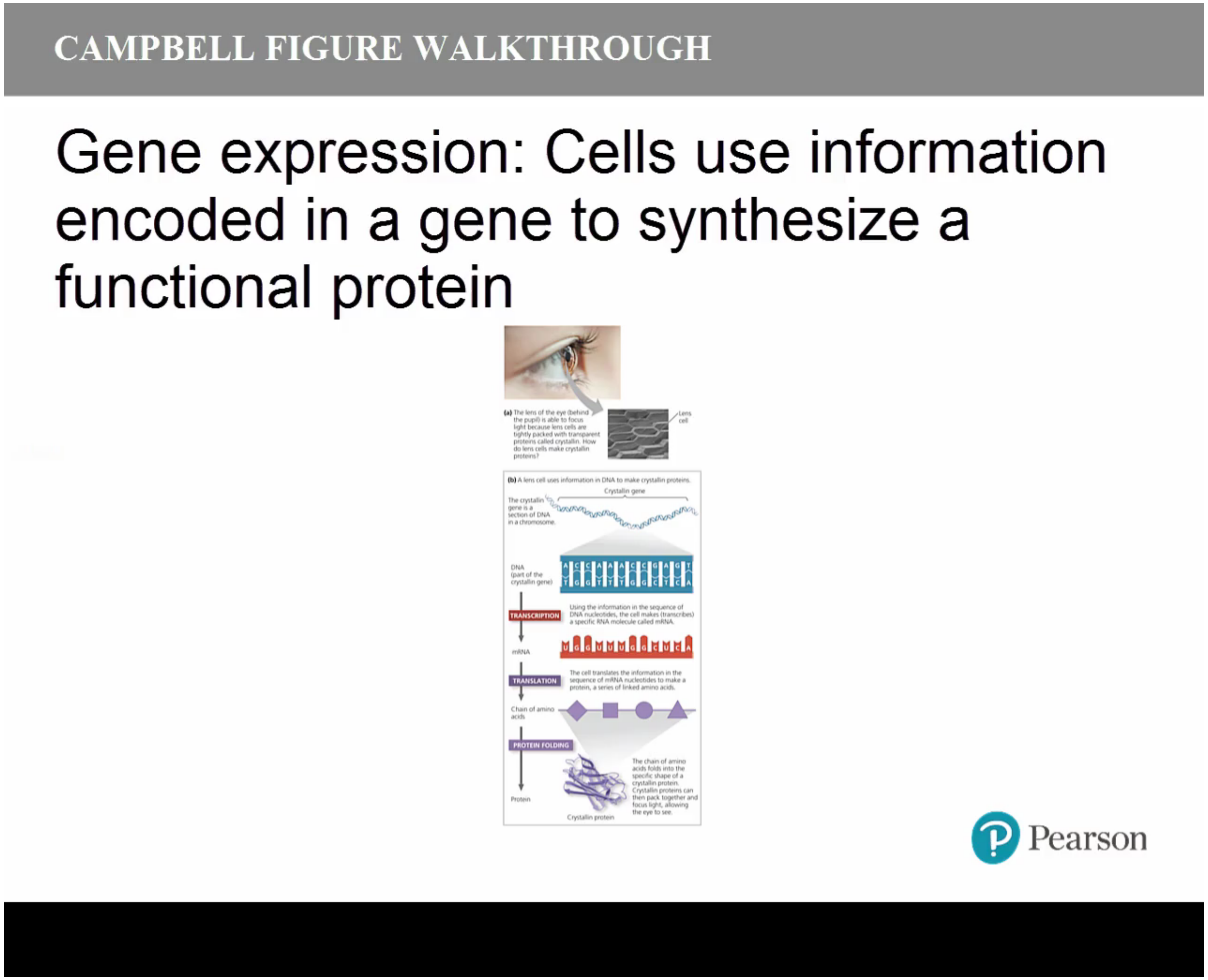
(a) DNA double helix (b) Single strand of DNA

- For many genes, the sequence provides the blueprint for making a protein
- Protein-encoding genes control protein production indirectly
- 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

Figure 1.8


(a) Lens cells are tightly packed with transparent proteins called crystallin.
Lens cell
(b) A lens cell uses information in DNA to make crystallin proteins.
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

Video: Gene Expression



Genomics: Large-Scale Analysis of DNA Sequences

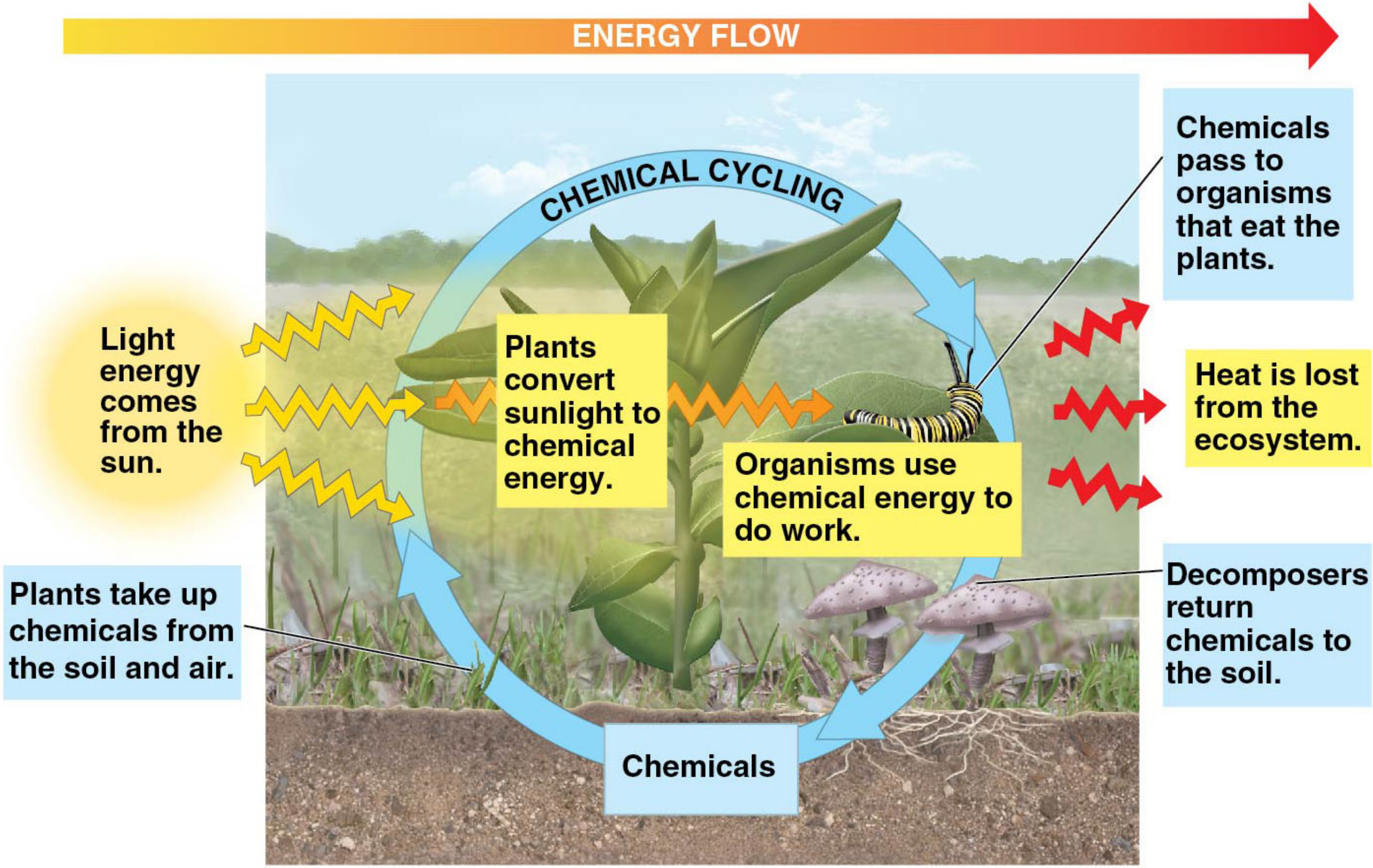
- An organism's **genome** is its entire "library" of genetic instructions
- **Genomics** is the study of whole sets of genes in one or more species
- **Proteomics** is the study of whole sets of proteins and their properties
- The entire set of proteins expressed by a given cell, tissue, or organ is called a **proteome**

- The genomics approach depends 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 very rapidly
  - Interdisciplinary research teams

Theme: 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

Figure 1.9


ENERGY FLOW
CHEMICAL CYCLING
Light energy comes from the sun.
Plants convert sunlight to chemical energy.
Organisms use chemical energy to do work.
Chemicals pass to organisms that eat the plants.
Heat is lost from the ecosystem.
Plants take up chemicals from the soil and air.
Chemicals
Decomposers return chemicals to the soil.

- When organisms use energy to perform work, some energy is lost to the surroundings as heat
- As a result, 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

Theme: From Molecules to Ecosystems, Interactions Are Important in Biological Systems

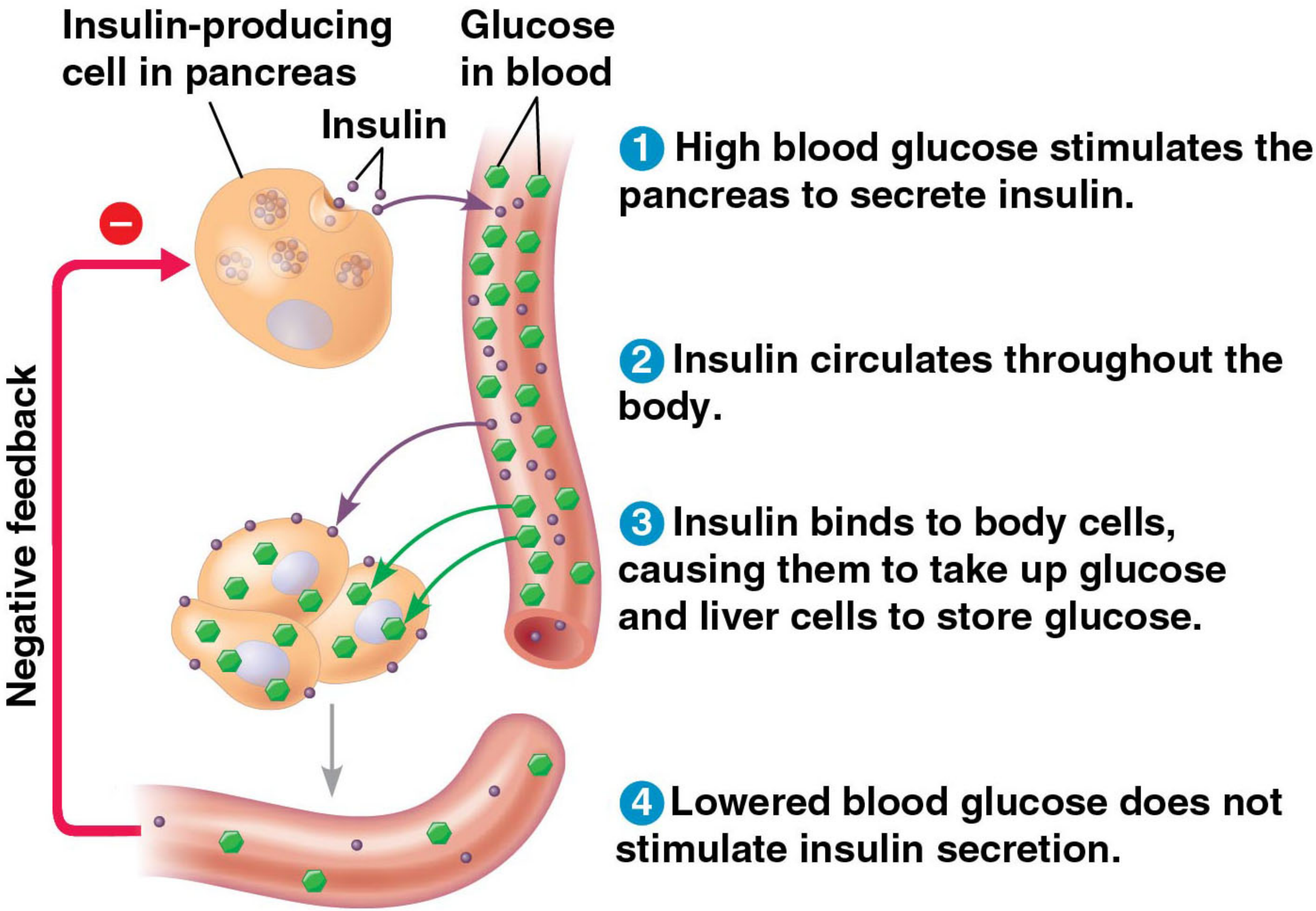
- Interactions between the components of the system ensure smooth integration of all the parts
- This holds true equally well for molecules in a cell and the components of an ecosystem

Molecules: Interactions Within Organisms

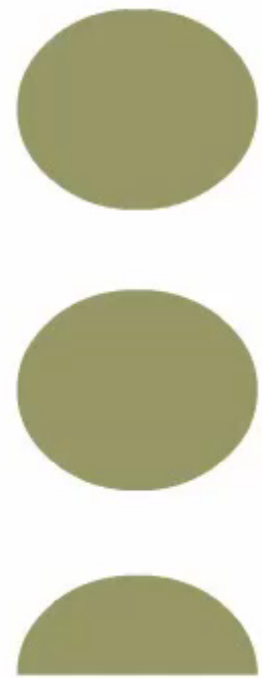
- Interactions between components that make up living organisms—organs, tissues, cells, and molecules—are crucial to their smooth operation
- Many biological processes can self-regulate through a mechanism called feedback

- 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

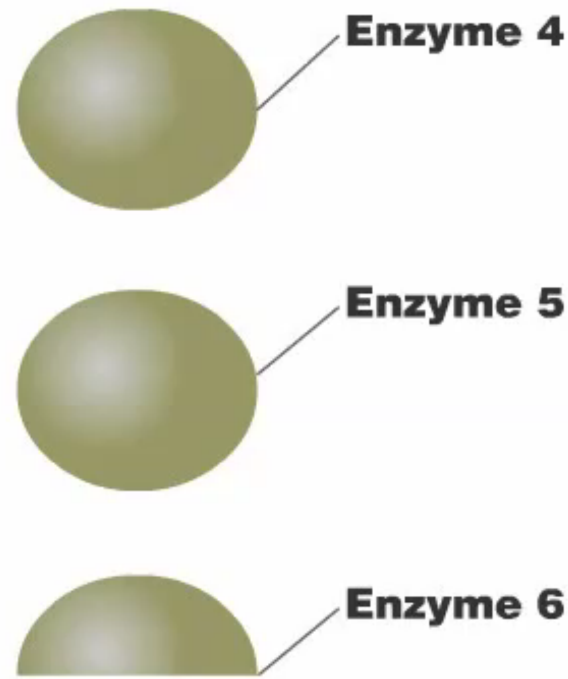
Figure 1.10


Insulin-producing cell in pancreas
Glucose in blood
Insulin
Negative feedback
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 liver cells to store glucose.
4 Lowered blood glucose does not stimulate insulin secretion.

Animation: Negative Feedback



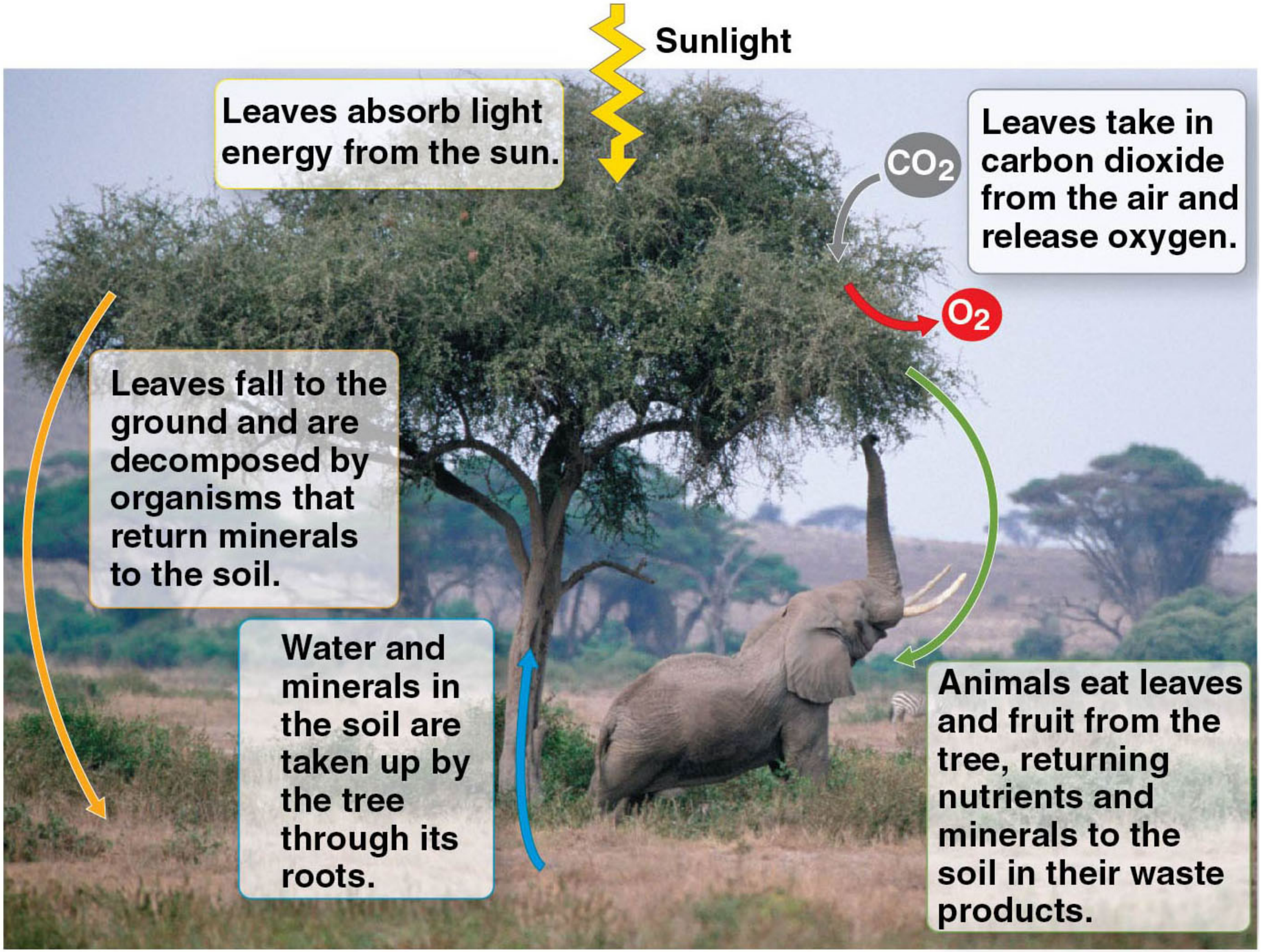
Animation: Positive Feedback



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 factors in their environment, and the environment is affected by the organisms living there

Figure 1.11


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.

- Each organism interacts continuously with physical factors in its environment
- Humans interact with our environment, sometimes with dire 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
- For some, there is insufficient suitable habitat
- Populations of many species are shrinking in size or even disappearing

Figure 1.12

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

- An understanding of evolution helps us to make sense of everything we know about life on earth
- The scientific explanation for both the unity and diversity of organisms is **evolution**, the concept that living organisms are modified descendants of common ancestors
- An abundance of evidence supports the occurrence of evolution

- “Nothing in biology makes sense except in the light of evolution”—Theodosius Dobzhansky

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*, is the name of our species
- Estimates of the total number of species that actually exist range from 10 million to over 100 million

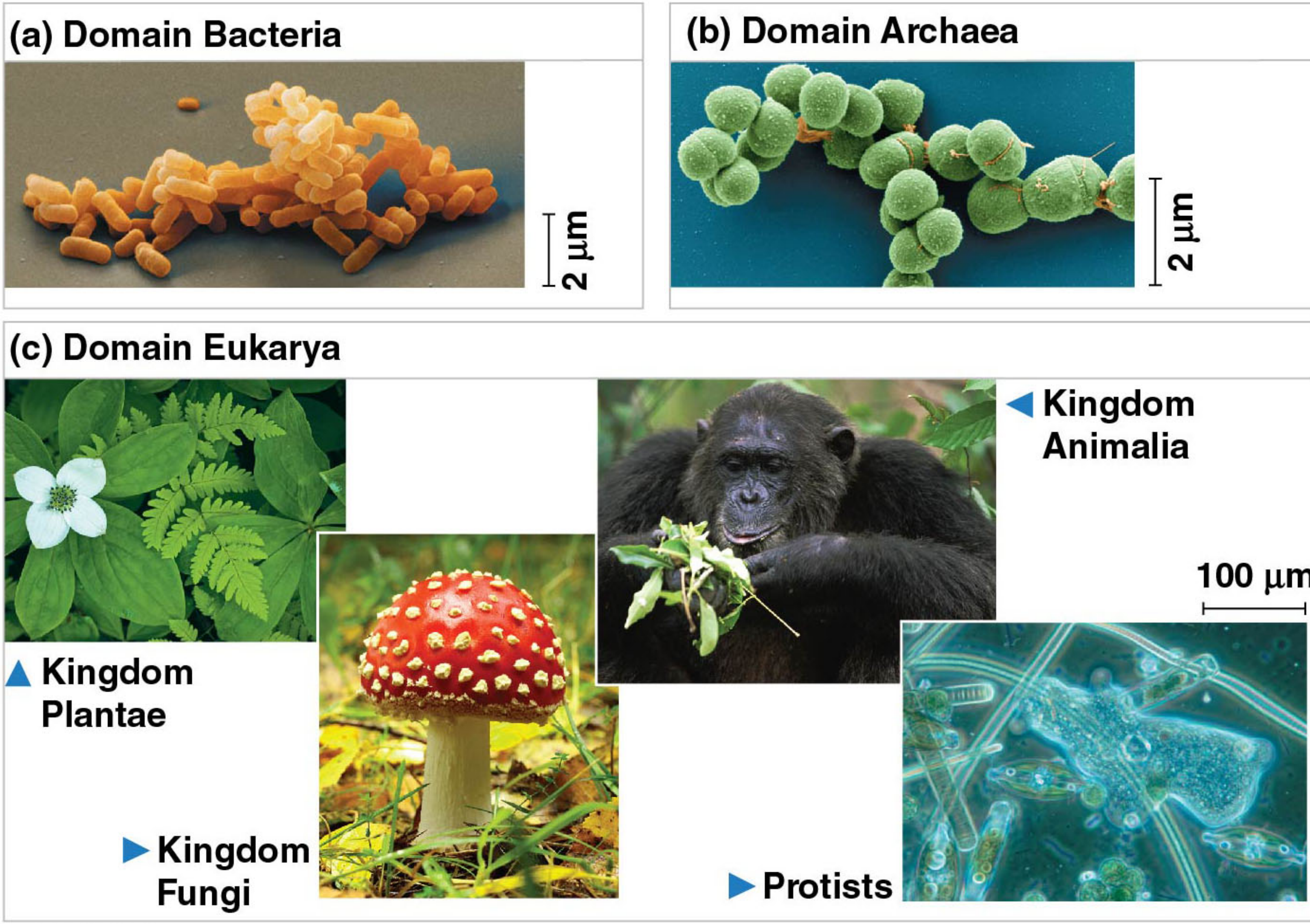
The Three Domains of Life

- 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 four subgroups
  - Plants, which produce their own food by photosynthesis
  - Fungi, which absorb nutrients
  - Animals, which ingest their food
  - Protists

- Protists are the most numerous and diverse eukaryotes
- These are mostly single-celled organisms
- They are classified into several groups
- Some protists are less closely related to other protists than they are to plants, animals, or fungi

Figure 1.13



(a) Domain Bacteria
2 µm
(b) Domain Archaea
2 µm
(c) Domain Eukarya
Kingdom Plantae
Kingdom Fungi
Kingdom Animalia
100 µm
Protists

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 the similar skeletons of different animals
- The history of life as documented by fossils and other evidence is the saga of a changing Earth, billions of years old

Figure 1.14

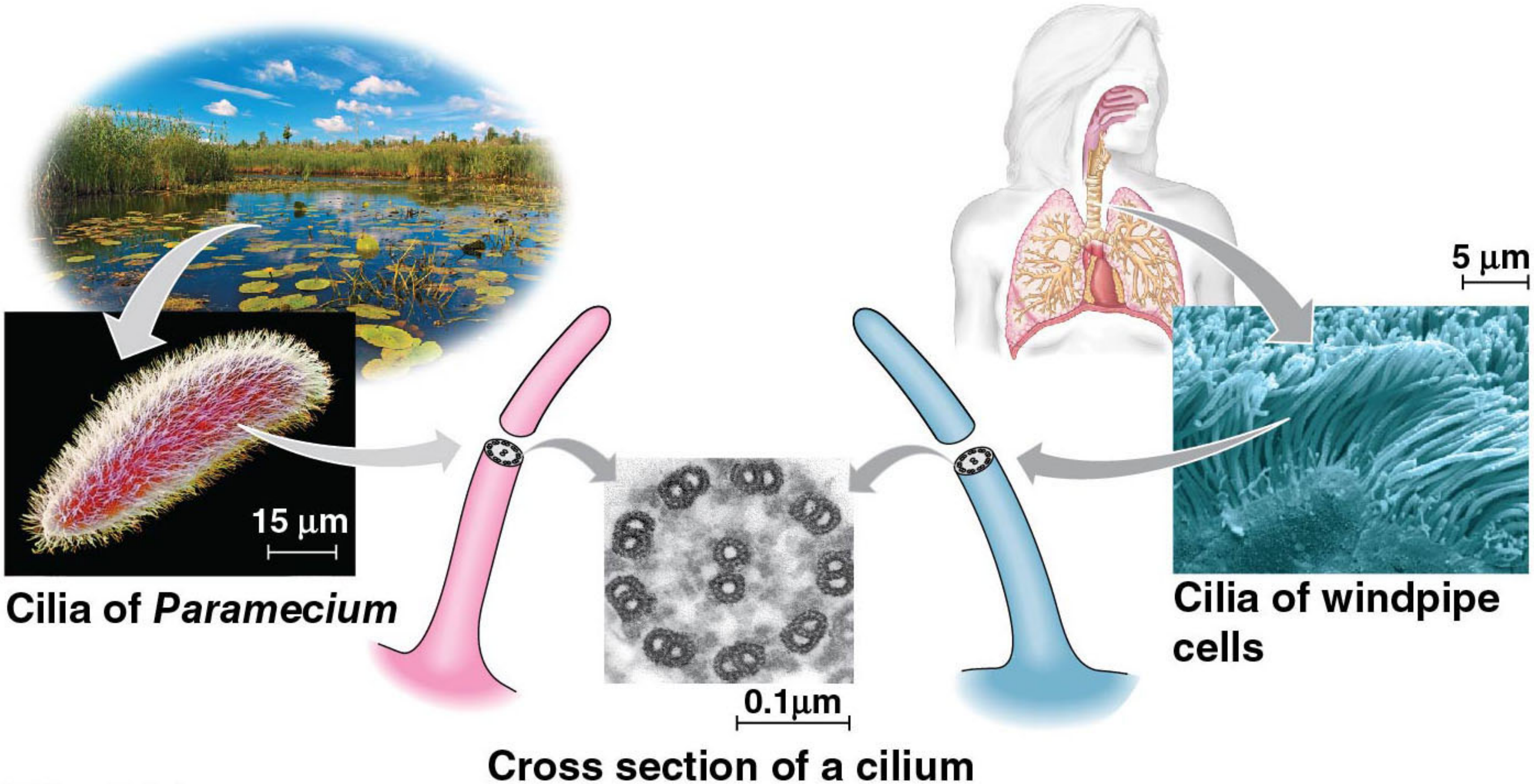
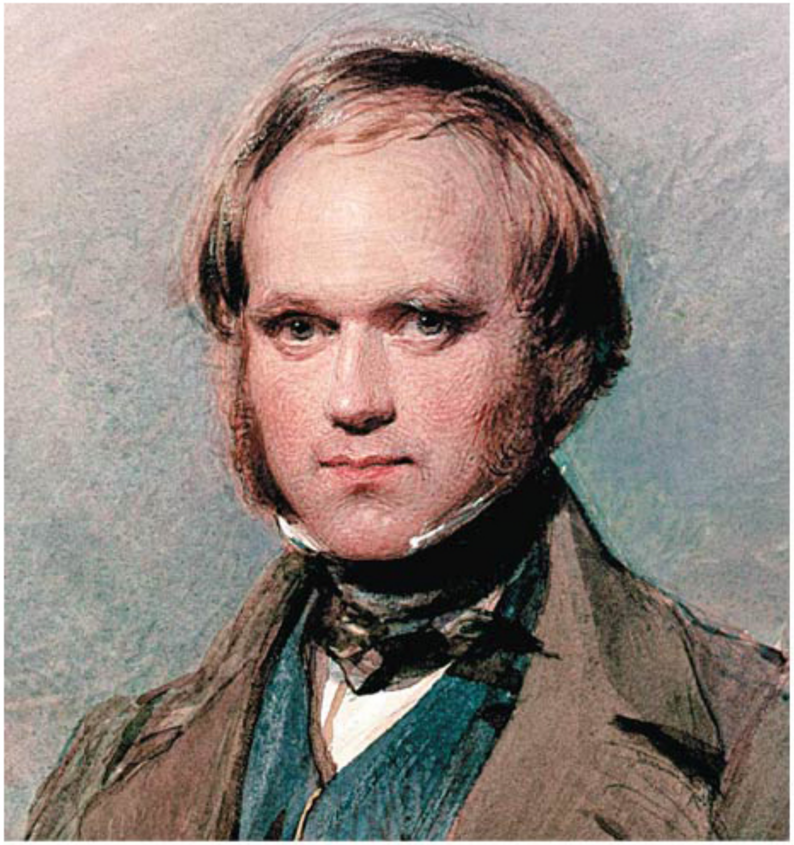

15 µm
Cilia of *Paramecium*
0.1µm
Cross section of a cilium
5 µm
Cilia of windpipe cells

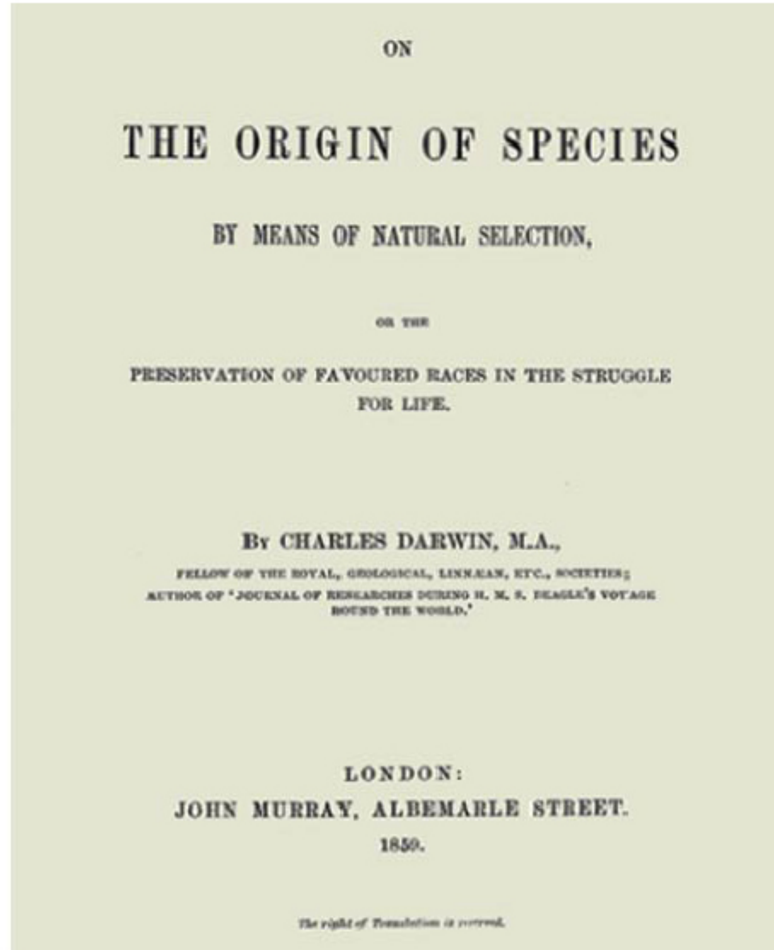
Figure 1.15

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

Figure 1.16





ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

Figure 1.17

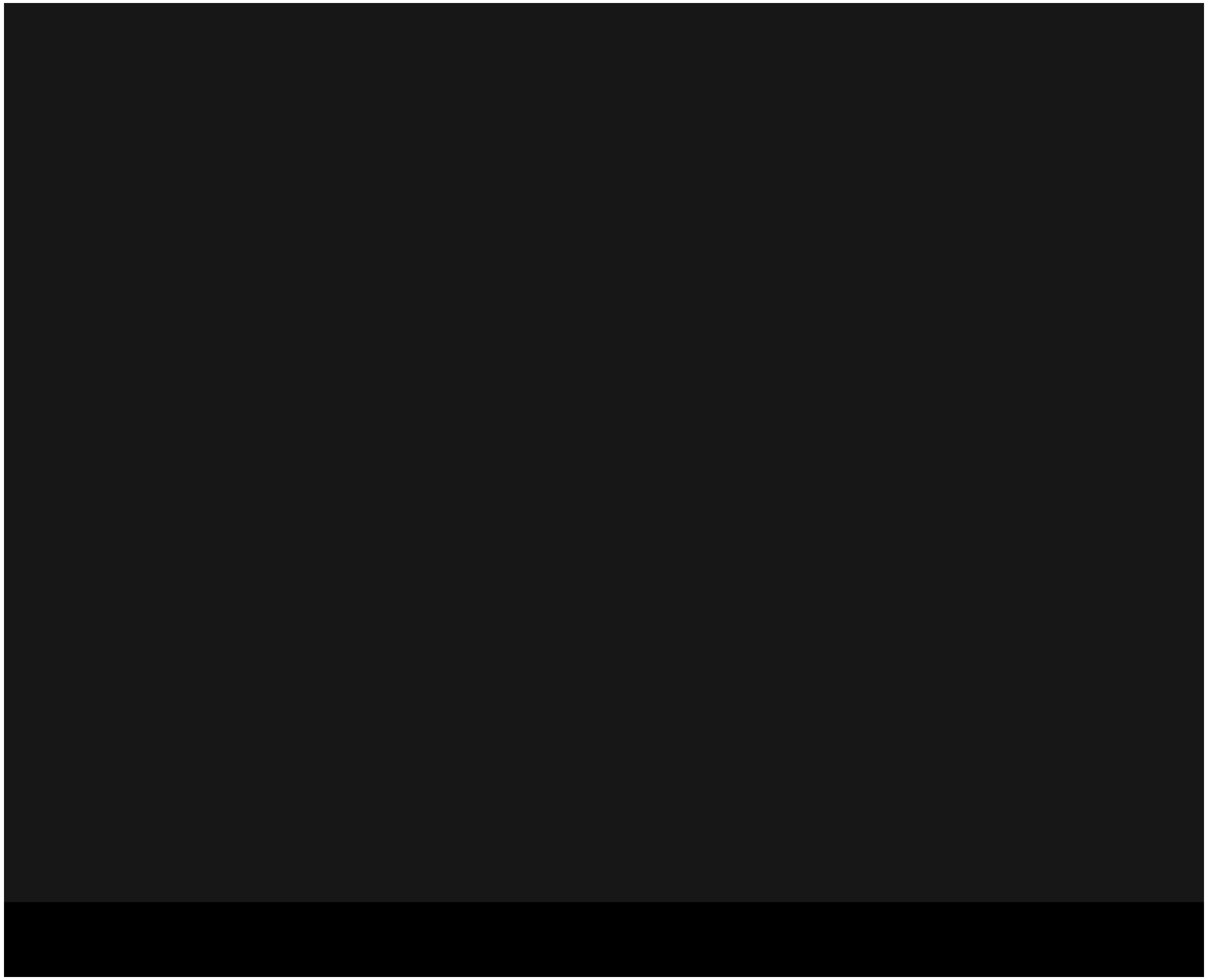
▼Red-tailed hawk (*Buteo borealis*)

▼American flamingo (*Phoenicopterus ruber*)

▲European robin (*Erithacus rubecula*)

▲Gentoo penguin (*Pygoscelis papua*)

Video: Evolution on the Galapagos Islands

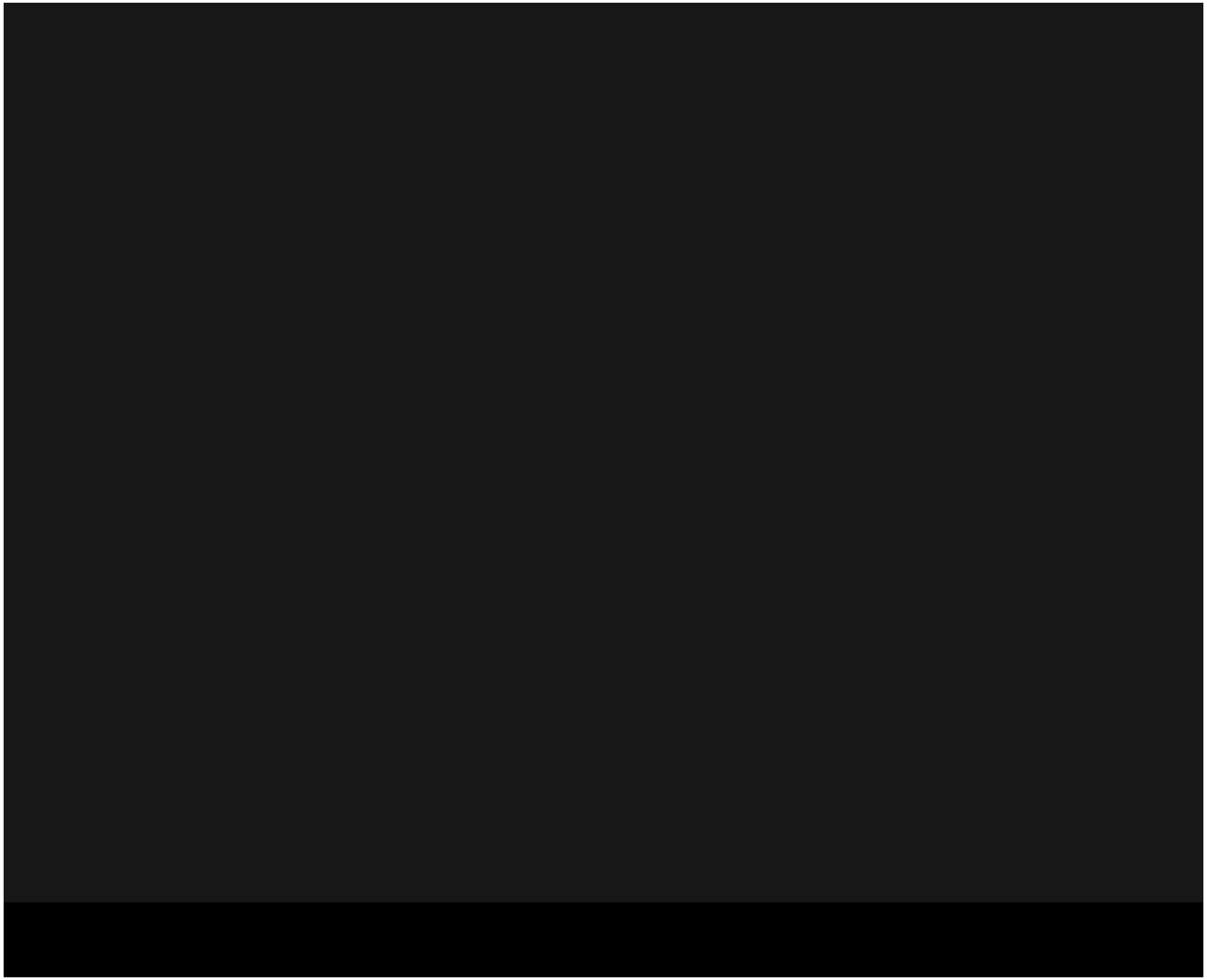


Video: Soaring Hawk

Video: Albatross Courtship Ritual

Video: Blue-footed Boobies Courtship Ritual

Video: Protecting the Galapagos Islands

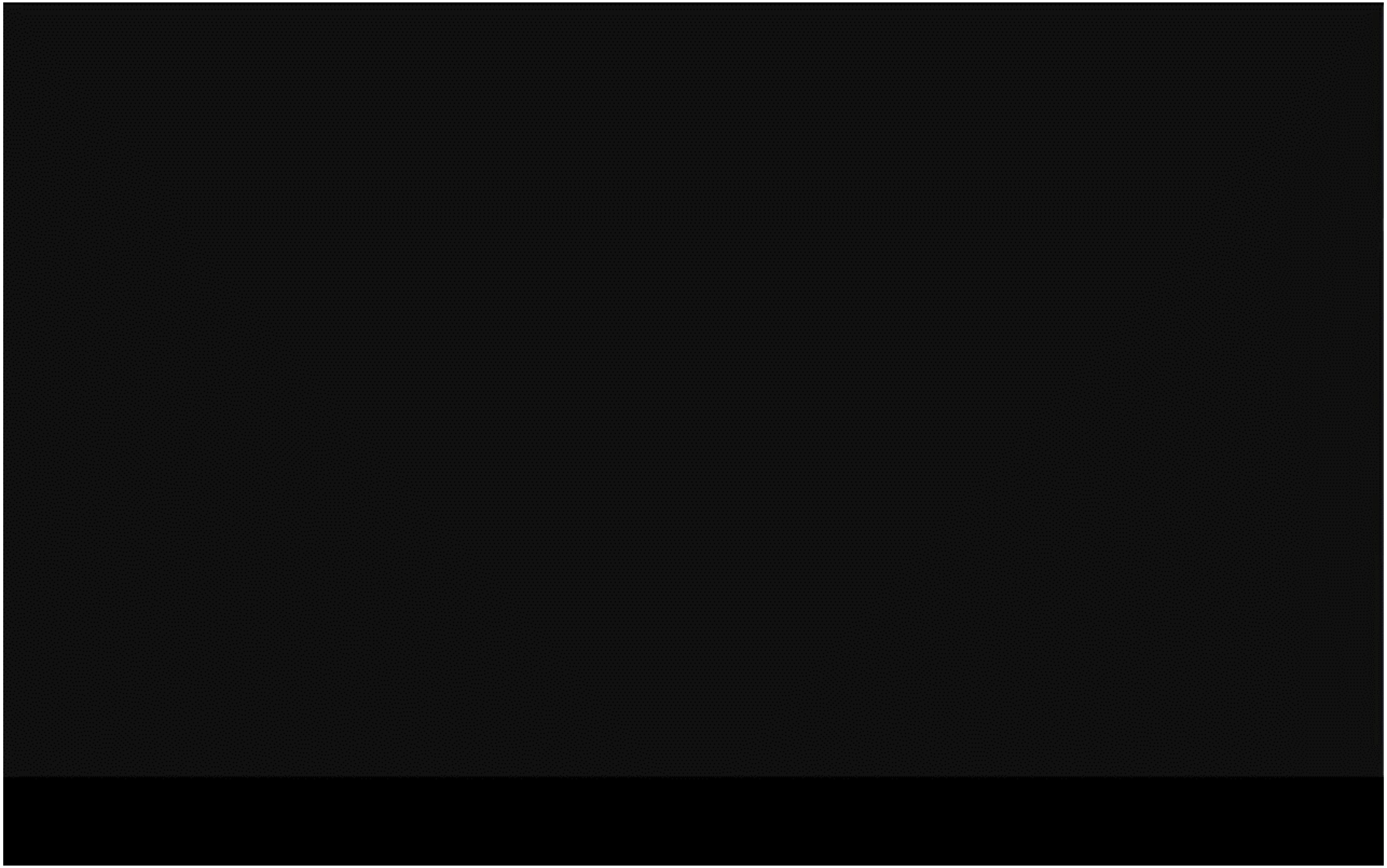


Video: Galapagos Marine Iguana

Video: Galapagos Sea Lion

Video: Galapagos Tortoise

Video: Galápagos Biodiversity

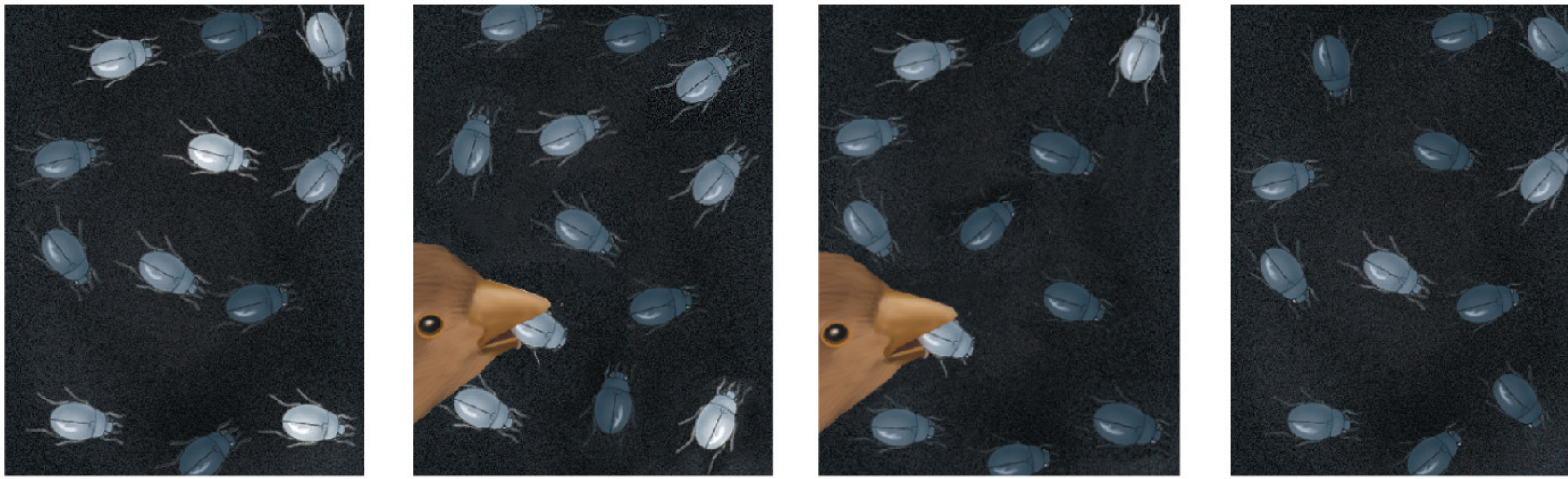


- Darwin observed that
  - Individuals in a population vary in their traits, many of which seem to be heritable
  - More offspring are produced than survive, and competition is inevitable
  - Species generally suit their environment

- Darwin reasoned that
  - Individuals with traits 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
- Evolution occurs as the unequal reproductive success of individuals

- The natural environment “selects” for the propagation of beneficial traits
- Darwin called this process **natural selection**

Figure 1.18



1 Population with varied inherited traits

2 Elimination of individuals with certain traits that make them more visible

3 Reproduction of survivors

4 Increased frequency of traits that enhance survival

- Natural selection results in the adaptation of organisms to the circumstances of their way of life and their environment
- For example, bat wings are an example of adaptation

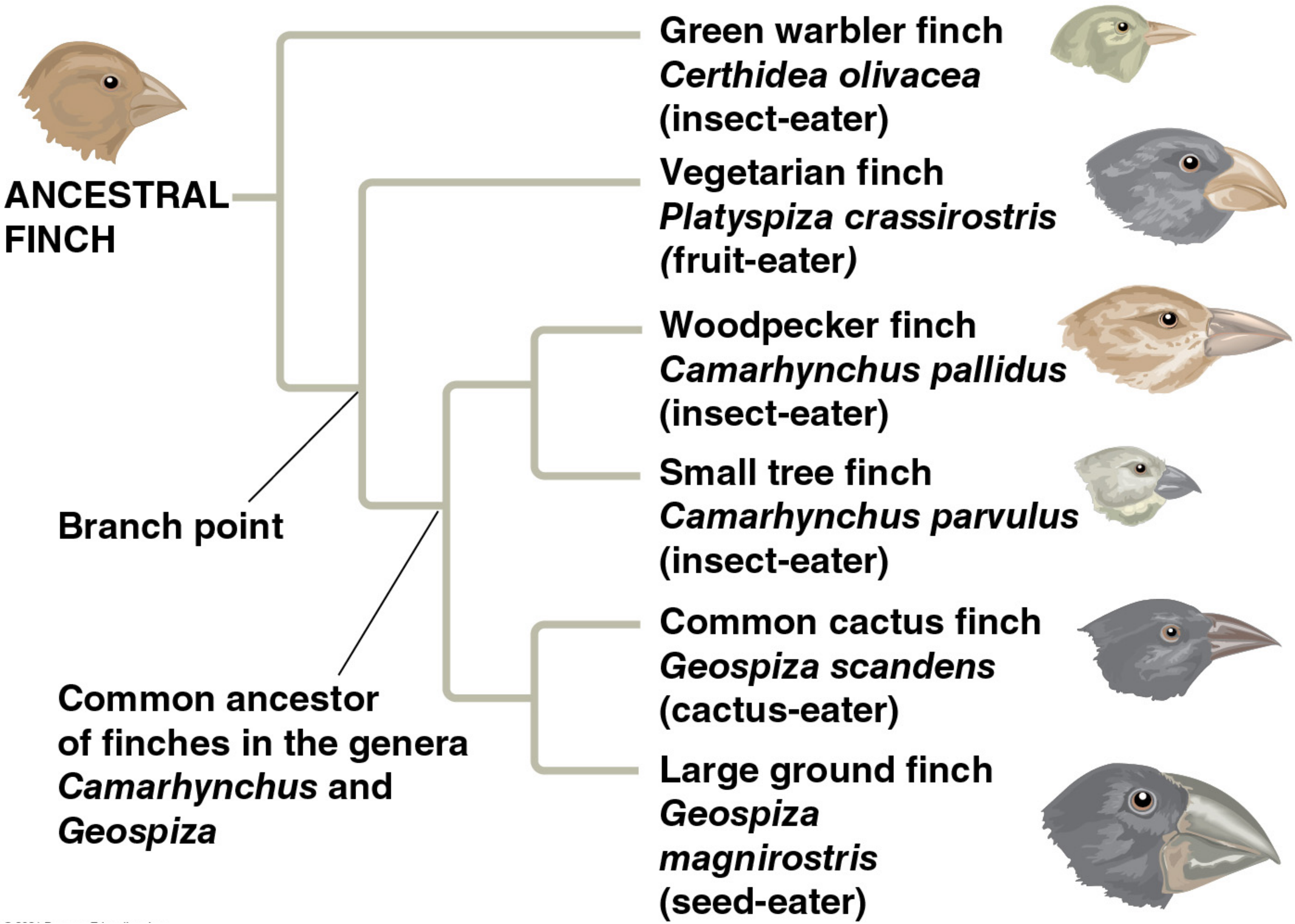
Figure 1.19

The Tree of Life

- The shared anatomy of mammalian limbs reflects the inheritance of the limb structure from a common ancestor
- Fossils and other evidence corroborate anatomical unity in support of mammalian descent with modification

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

Figure 1.20



ANCESTRAL FINCH
Branch point
Common ancestor of finches in the genera *Camarhynchus* and *Geospiza*
Green warbler finch
Certhidea olivacea
(insect-eater)
Vegetarian finch
Platyspiza crassirostris
(fruit-eater)
Woodpecker finch
Camarhynchus pallidus
(insect-eater)
Small tree finch
Camarhynchus parvulus
(insect-eater)
Common cactus finch
Geospiza scandens
(cactus-eater)
Large ground finch
Geospiza magnirostris
(seed-eater)

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

- The word **science** is derived from Latin and means "to know"
- **Inquiry** is the search for information and explanations of natural phenomena
- Scientists use a process of inquiry that includes making observations, forming logical *hypotheses*, and testing them

Exploration and Observation

- Biology begins with careful observation
- Observations can reveal valuable information about the natural world
- Biologists also rely heavily on the published contributions of fellow scientists
- They build on the foundation of existing knowledge
- Identifying relevant publications is easier than in the past, thanks to indexed and searchable electronic databases

Gathering and Analyzing Data

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

Figure 1.21

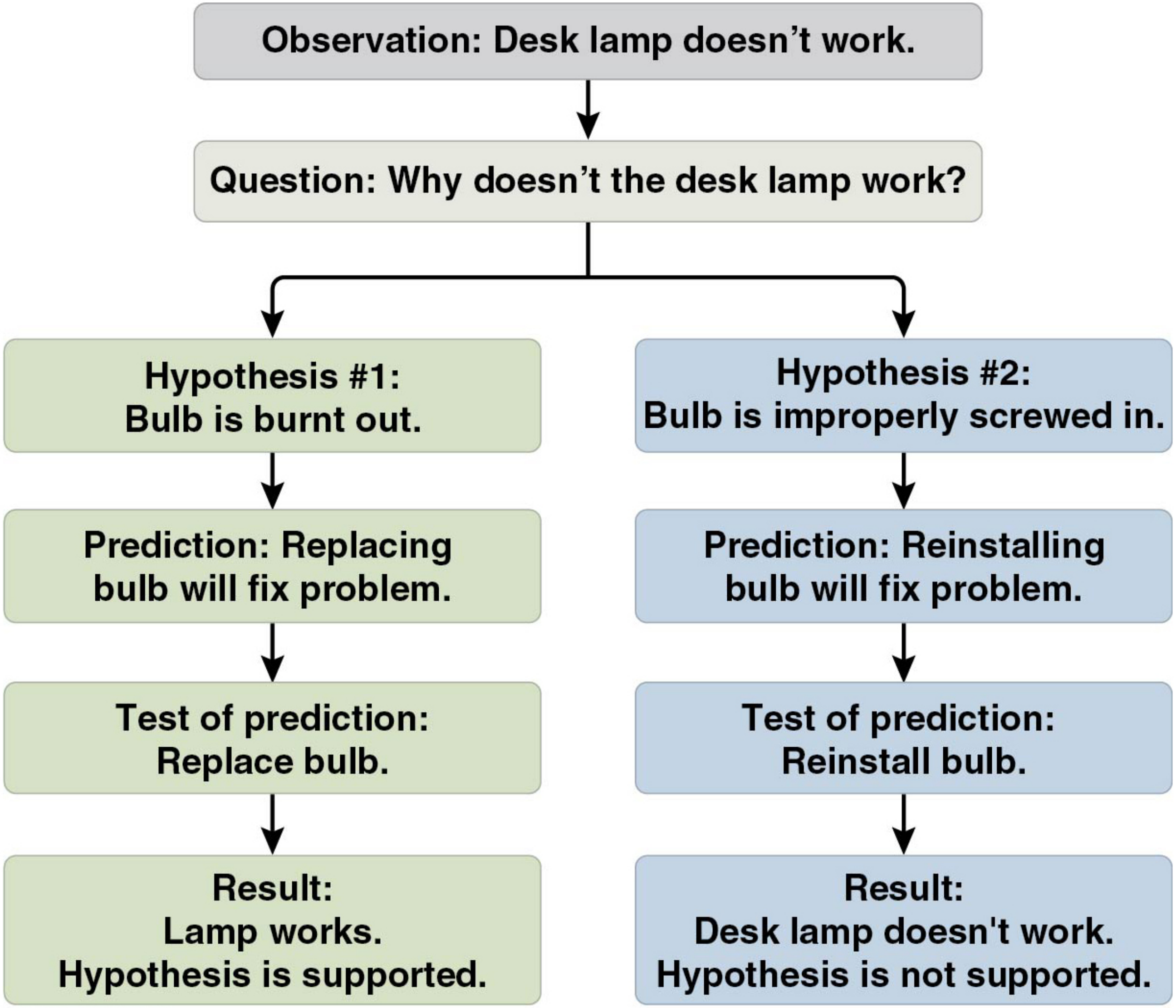
- **Inductive reasoning** derives generalizations from a large number of specific observations
- Careful observations and data analyses, along with generalizations reached by induction, are fundamental to our understanding of nature

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

- For example:
  - Observation: Desk lamp doesn’t work
  - Question: Why does’t the desk lamp work?
  - Hypothesis 1: The bulb is burnt out
  - Hypothesis 2: The bulb is not screwed in properly
- Both these hypotheses are testable

Figure 1.22


Observation: Desk lamp doesn’t work.
Question: Why doesn’t the desk lamp work?
Hypothesis #1:
Bulb is burnt out.
Hypothesis #2:
Bulb is improperly screwed in.
Prediction: Replacing bulb will fix problem.
Prediction: Reinstalling bulb will fix problem.
Test of prediction:
Replace bulb.
Test of prediction:
Reinstall bulb.
Result:
Lamp works.
Hypothesis is supported.
Result:
Desk lamp doesn't work.
Hypothesis is not supported.

Deductive Reasoning

- **Deductive reasoning** uses general premises to make specific predictions
- Initial observations may give rise to multiple hypotheses
- We can never prove that a hypothesis is true, but testing it in many ways with different sorts of data can significantly increase our confidence in it

Questions That Can and Cannot Be Addressed by Science

- A hypothesis must be testable
  - For example, a hypothesis that ghosts fooled with the desk lamp cannot be tested
- Supernatural and religious explanations are outside the bounds of science

Animation: Introduction to Experimental Design

Cell Theory

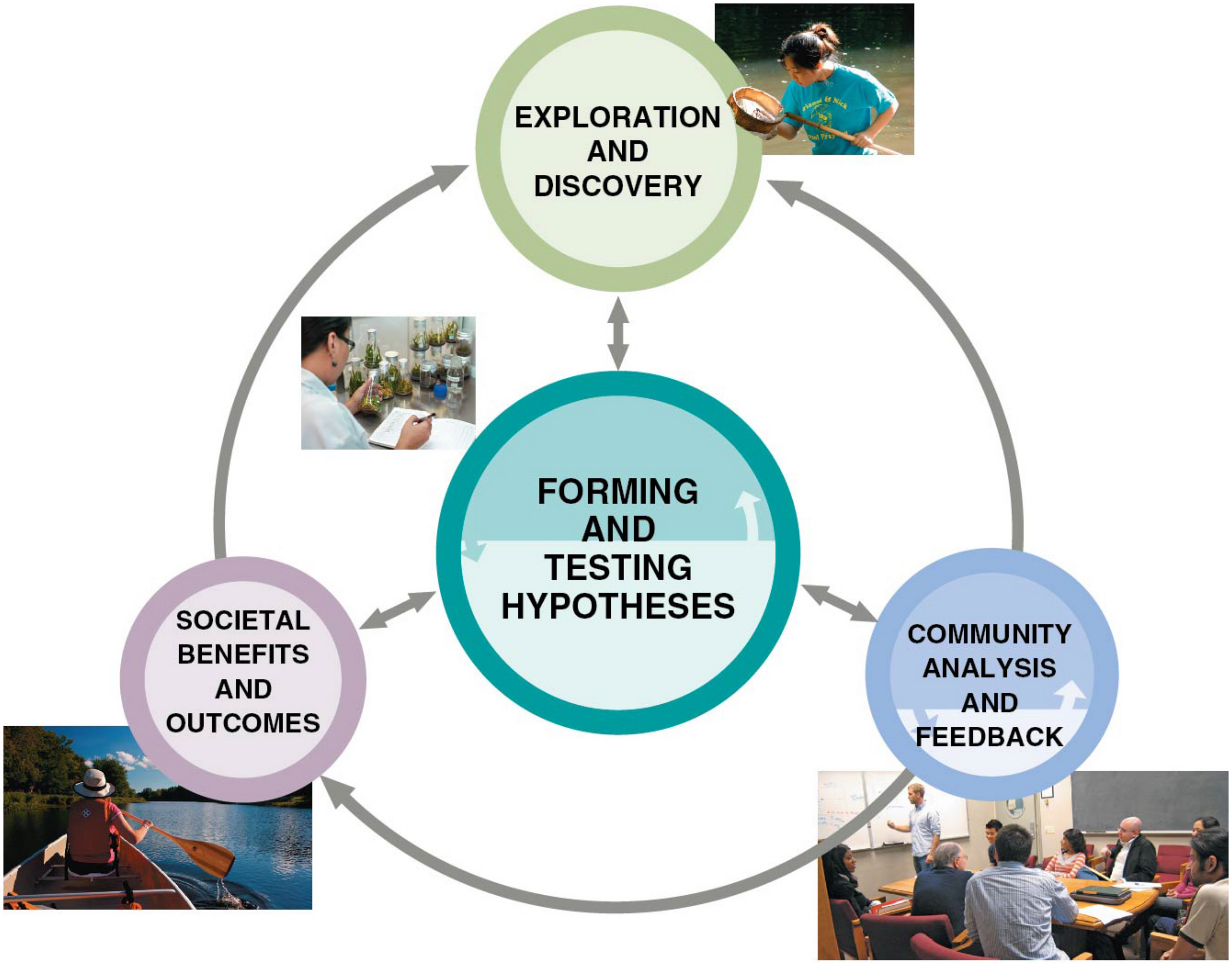
Where do cells come from? Scientists in the 1800s proposed an answer to this question by stating that all organisms are made of cells, and all cells arise from preexisting cells. This ***hypothesis***, later to become the ***cell theory***, was a direct challenge to an alternate hypothesis called ***spontaneous generation***.

Scientists design experiments to test the validity of hypotheses.

The Flexibility of the Scientific Process

- The *scientific method* is an idealized process of inquiry
- However, very few scientific inquiries adhere rigidly to this approach
- Backtracking may be necessary partway through the process
- In other cases, observations may be too puzzling to prompt well-defined questions, until further studies are complete

Figure 1.23

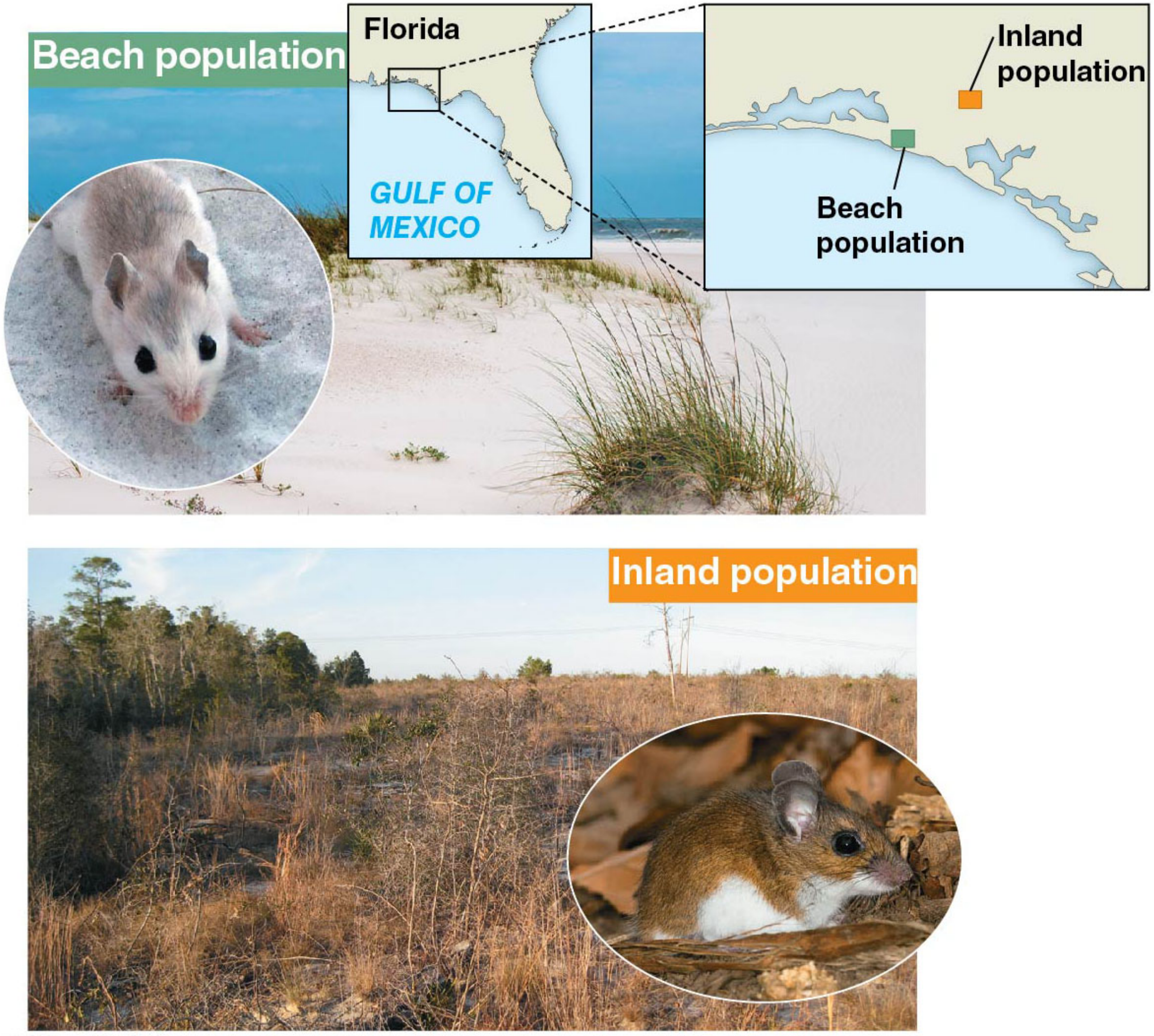


EXPLORATION AND DISCOVERY
FORMING AND TESTING HYPOTHESES
SOCIETAL BENEFITS AND OUTCOMES
COMMUNITY ANALYSIS AND FEEDBACK

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

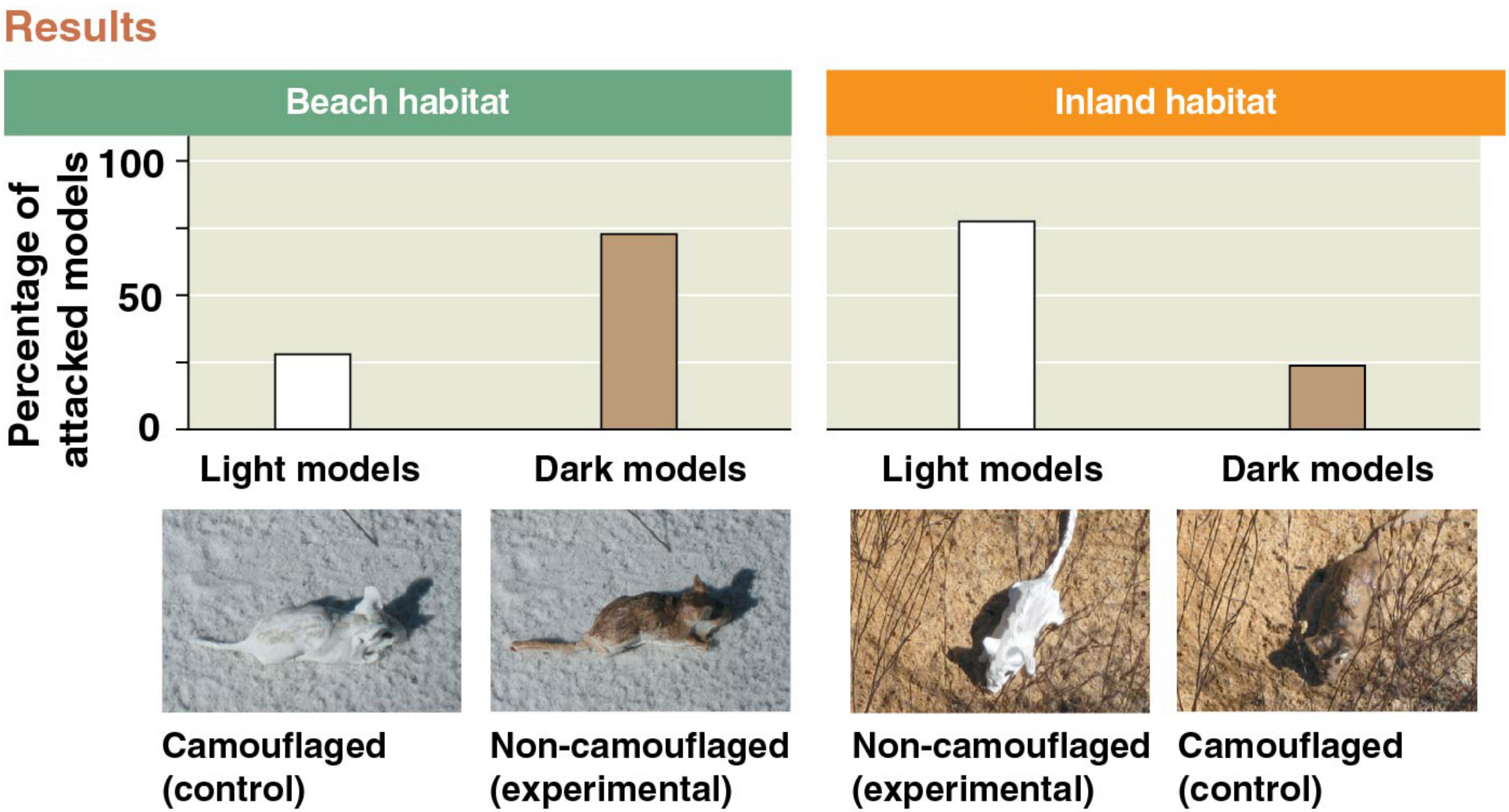
Figure 1.24


Beach population
Florida
GULF OF MEXICO
Inland population
Beach population
Inland population

- The two types of mice match the coloration of their habitats
- Natural predators of these mice are all visual hunters
- Francis Bertody Sumner hypothesized that the color patterns had evolved as adaptations to protect the mice from predators
- In 2010, Hopi Hoekstra and a group of students tested this hypothesis

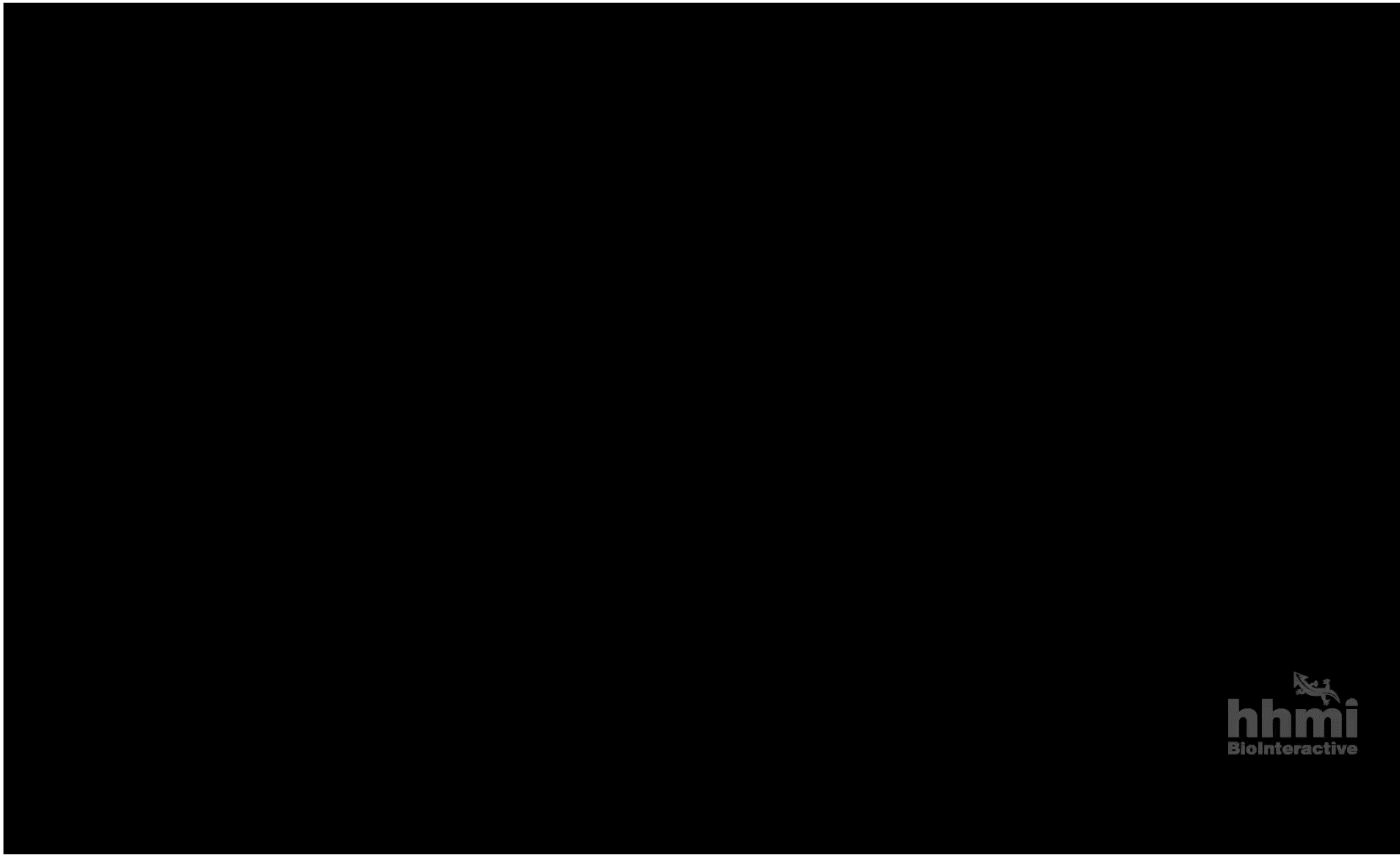
- The researchers predicted that mice that did not match their habitat would be preyed on more heavily than mice that did match the surroundings
- They built models of mice, painted them to match one of the surroundings, and placed equal numbers of each type of model in each habitat
- They then recorded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

Figure 1.25



Data from S. N. Vignieri, J. G. Larson, and H. E. Hoekstra, The selective advantage of crypsis in mice, *Evolution* 64:2153–2158 (2010).

Video: The Making of the Fittest: Natural Selection and Adaptation (Rock Pocket Mouse)



Variables and Controls in Experiments

- In a **controlled experiment**, an experimental group (the non-camouflaged mice in this case) is compared with a control group (the camouflaged mice)
- Experimental **variables** are features or quantities that vary in an experiment
  - The **independent variable** is the one that is manipulated by the researchers
  - The **dependent variable** is the one predicted to be affected in response

Theories in Science

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

CONCEPT 1.4: Science benefits from a cooperative approach and diverse viewpoints

- 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
- Research papers are not published until vetted by colleagues in the "peer review" process

Building on the Work of Others

- Scientists check each other's claims by performing similar experiments
- If experimental results are not repeatable, the original claim will have to be revised
- It is not unusual for different scientists to work on the same research question

- Scientists cooperate by sharing data about **model organisms** (for example, the fruit fly *Drosophila melanogaster*)
- There are several other popular model organisms as well
- Biologists approach interesting questions from different angles

Science, Technology, and Society

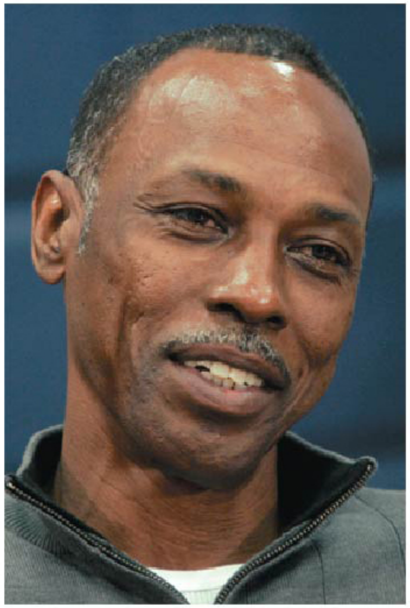
- The goal of science is to understand natural phenomena
- The goal of **technology** is to *apply* scientific knowledge for some specific purpose
- Science and technology are interdependent

- The combination of science and technology can have 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
- Debates on technology center more on "*should* we do it" than "*can* we do it"

- Ethical issues that arise from new technology can have as much to do with politics, economics, and cultural values as with science and technology

Figure 1.26

Lynn DeJac



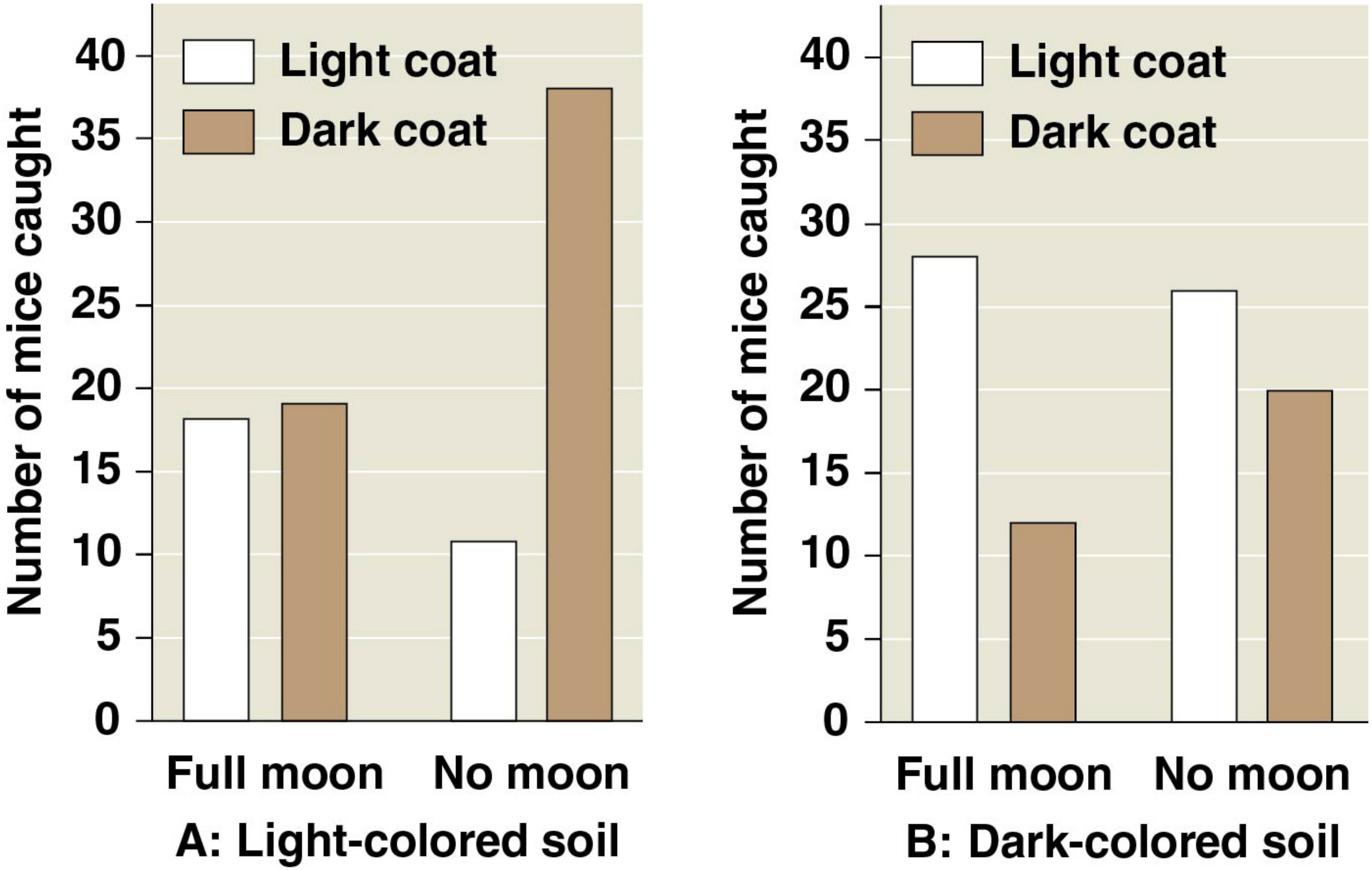
John White

Michael Morton

Clemente Aguirre-Jarquin

The Value of Diverse Viewpoints in Science

- Many important inventions have occurred where a mix of different cultures ignited new ideas
  - For example, the printing press relied on innovations from China (paper and ink) and Europe (mass production in mills)
- Science benefits from a diversity of backgrounds and viewpoints among its practitioners
- The more voices heard, the more robust, valuable, and productive the scientific interchange



Data from D. W. Kaufman, Adaptive coloration in *Peromyscus polionotus*: Experimental selection by owls, *Journal of mammalogy* 55:271–283 (1974).

Figure 1.UN03

Figure 1.UN04

Figure 1.UN05

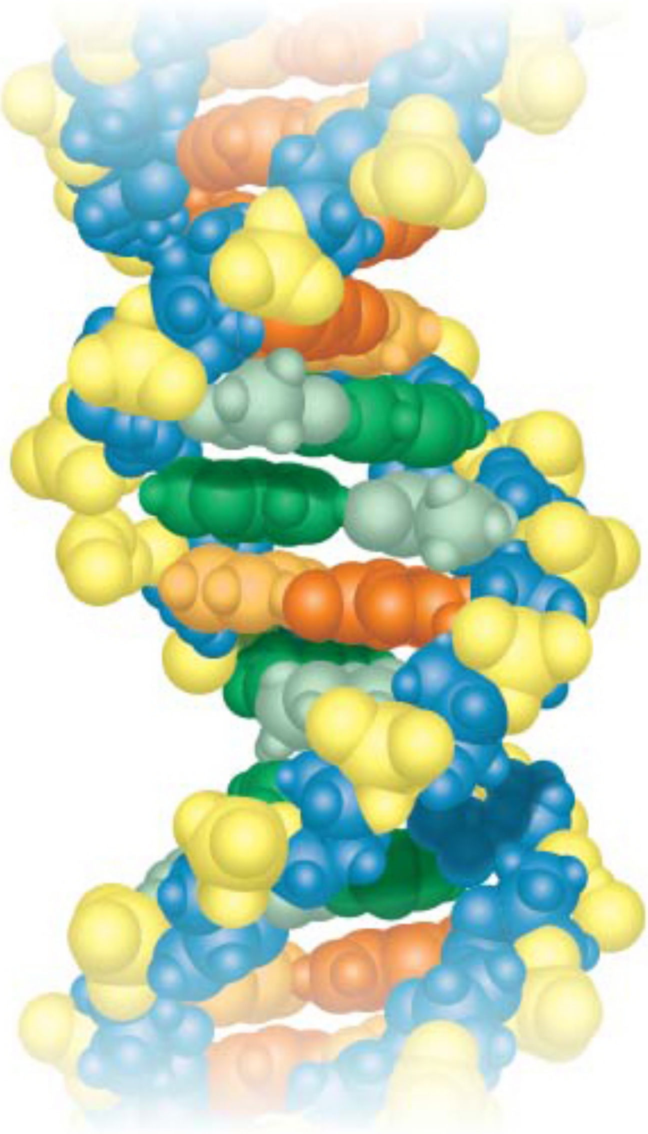


Figure 1.UN06

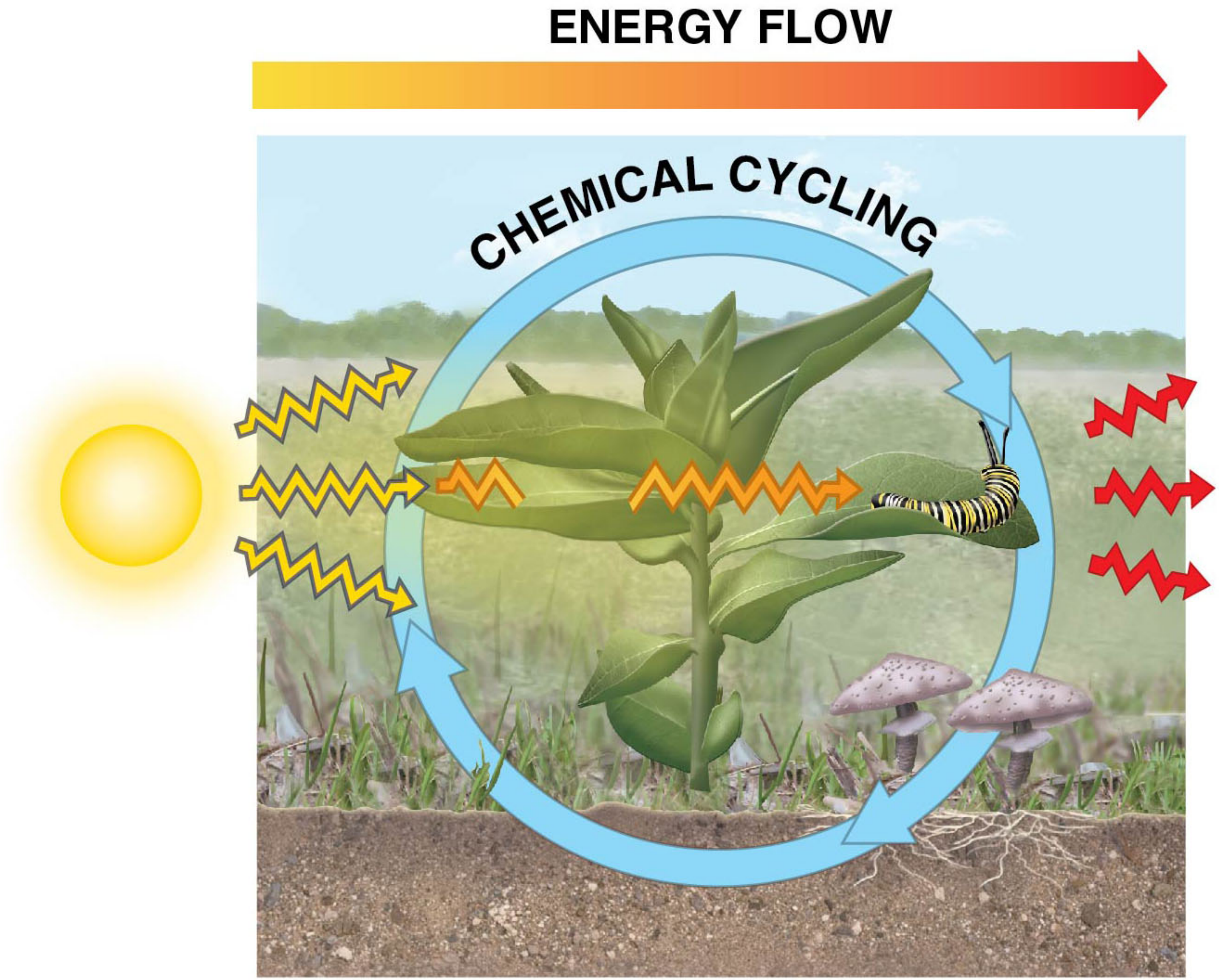
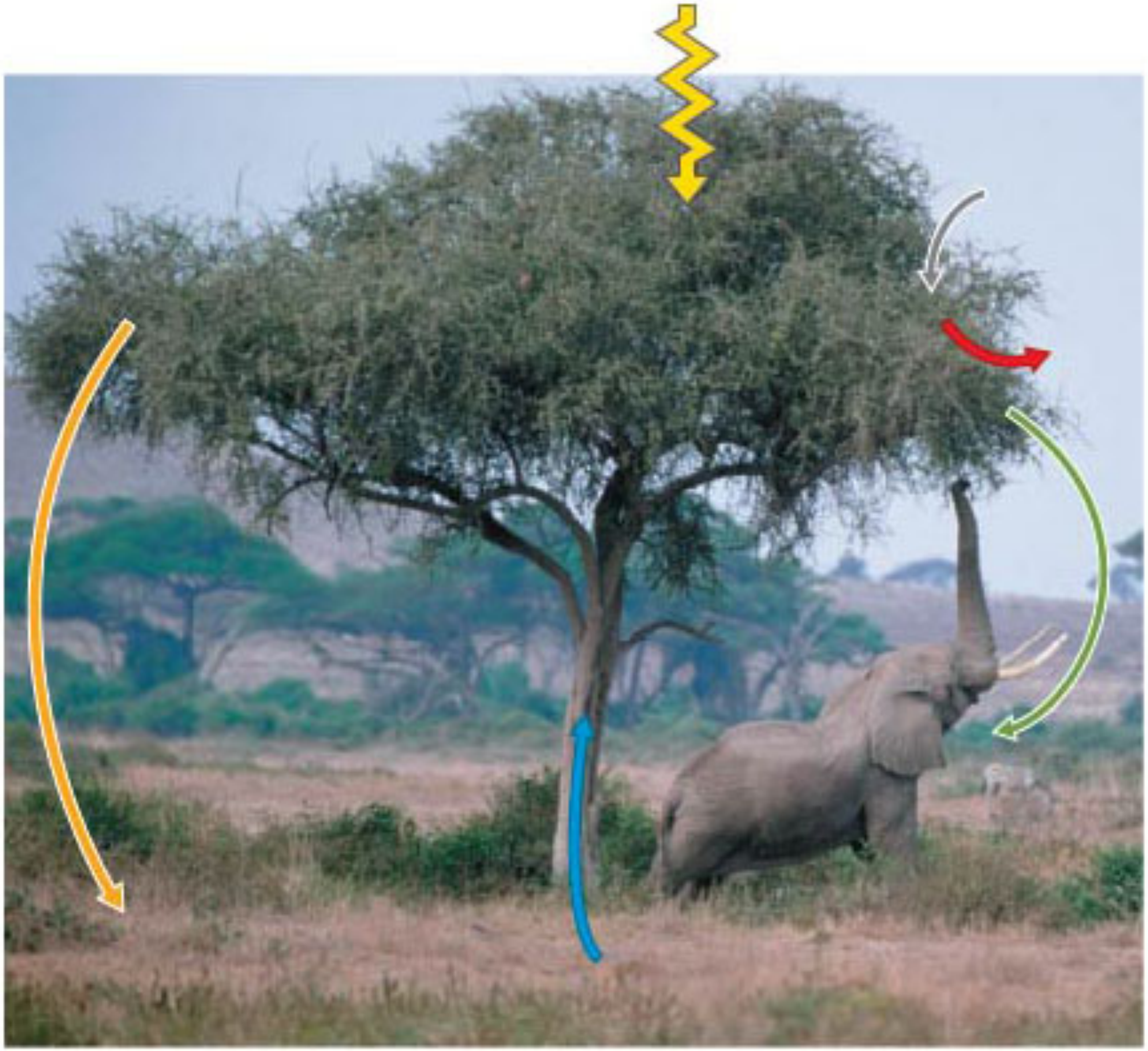


Figure 1.UN07



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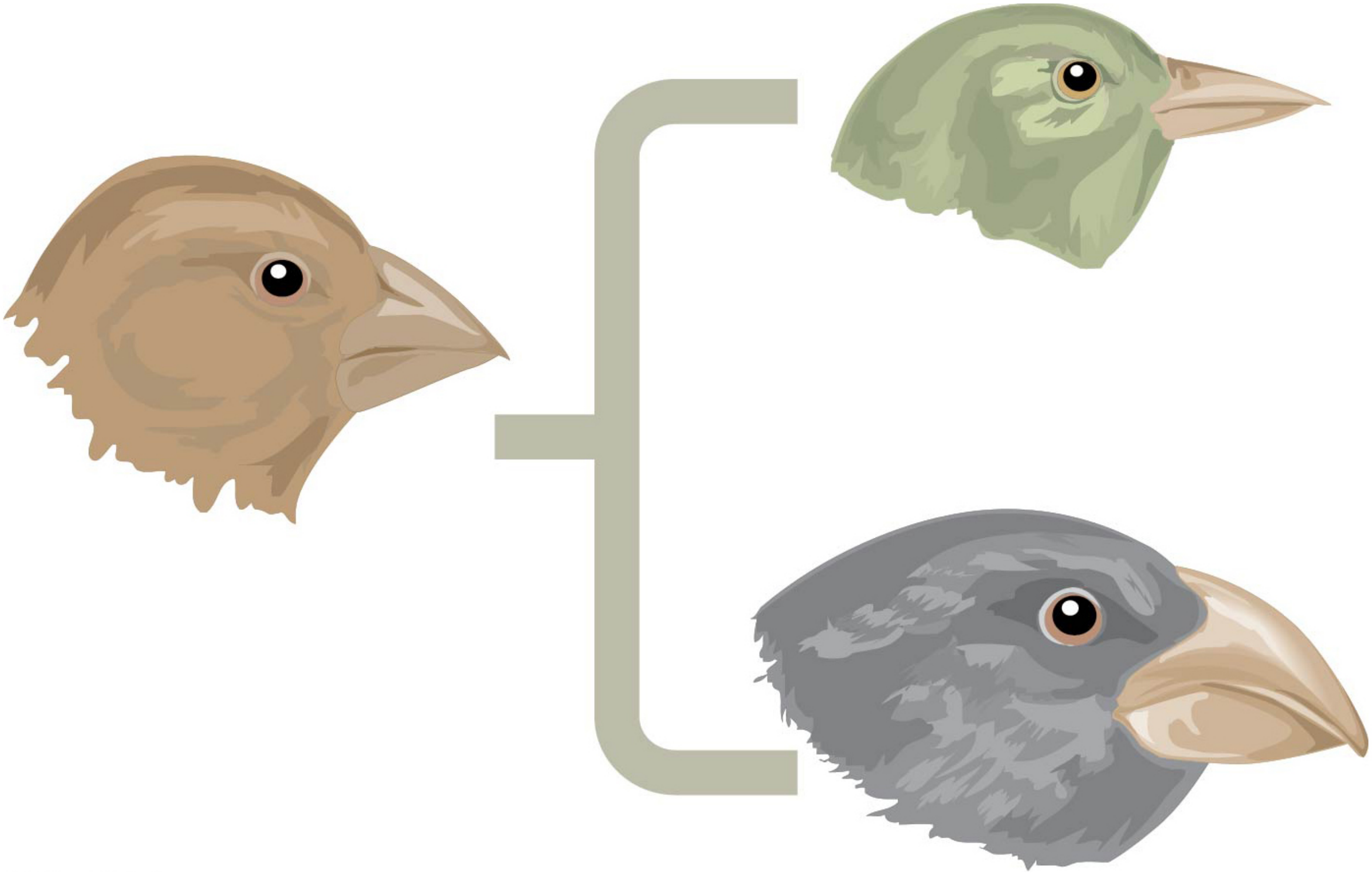


Figure 1.UN09

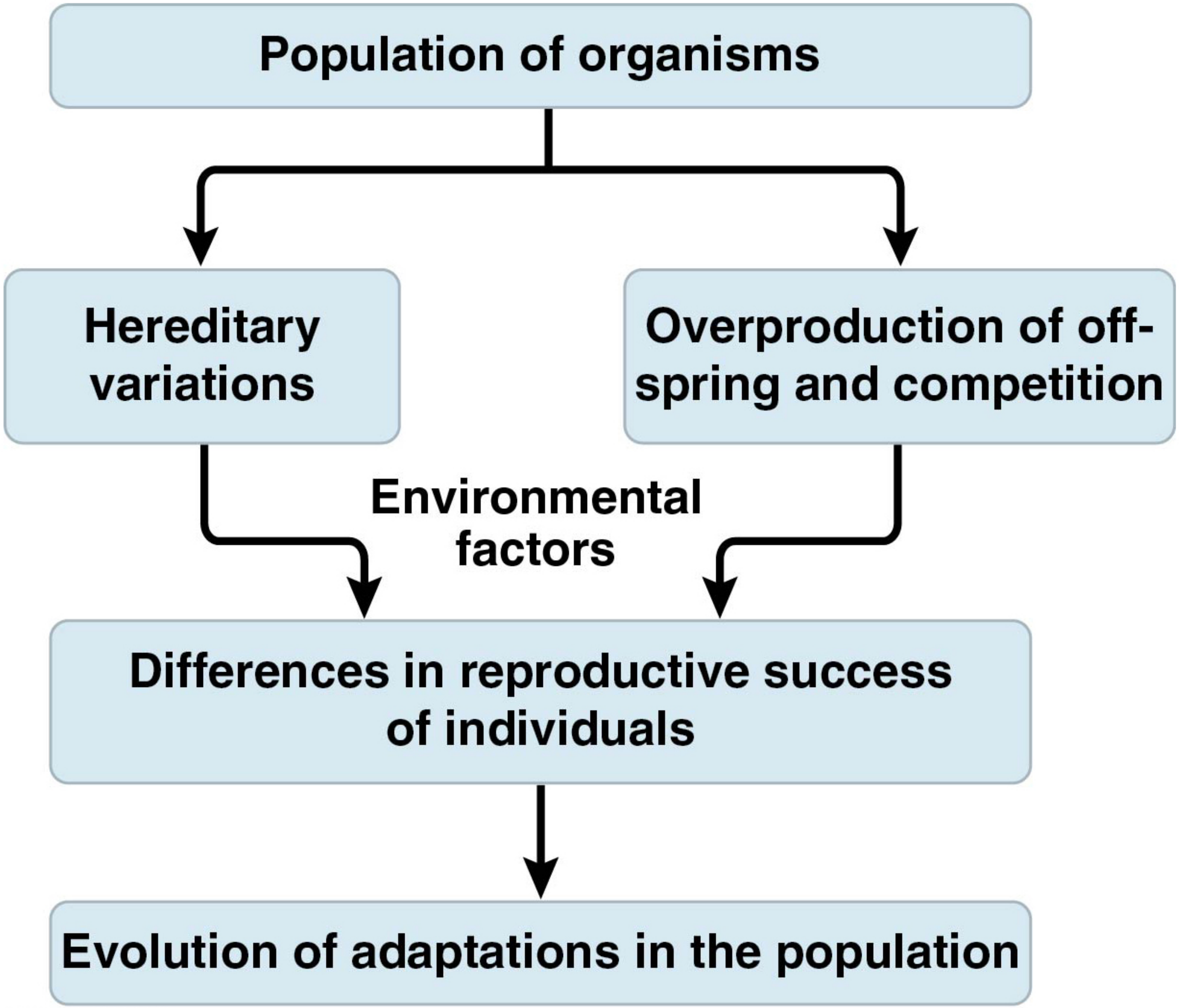
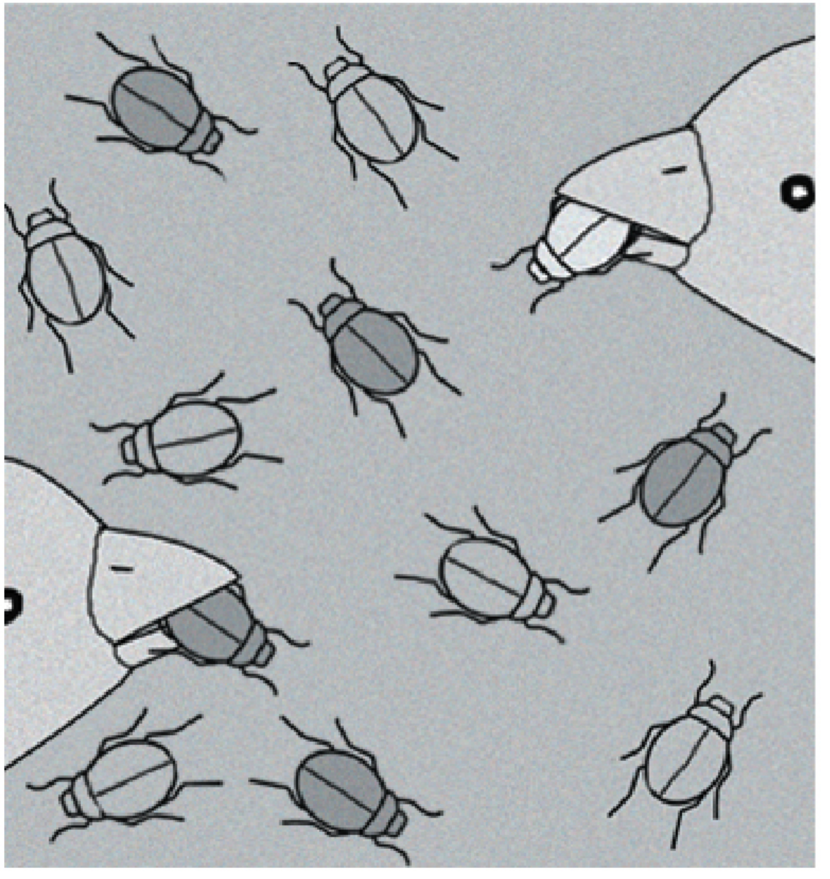


Figure 1.UN10



5 **Environmental change resulting in survival of organisms with different traits**

Figure 1.ans-02