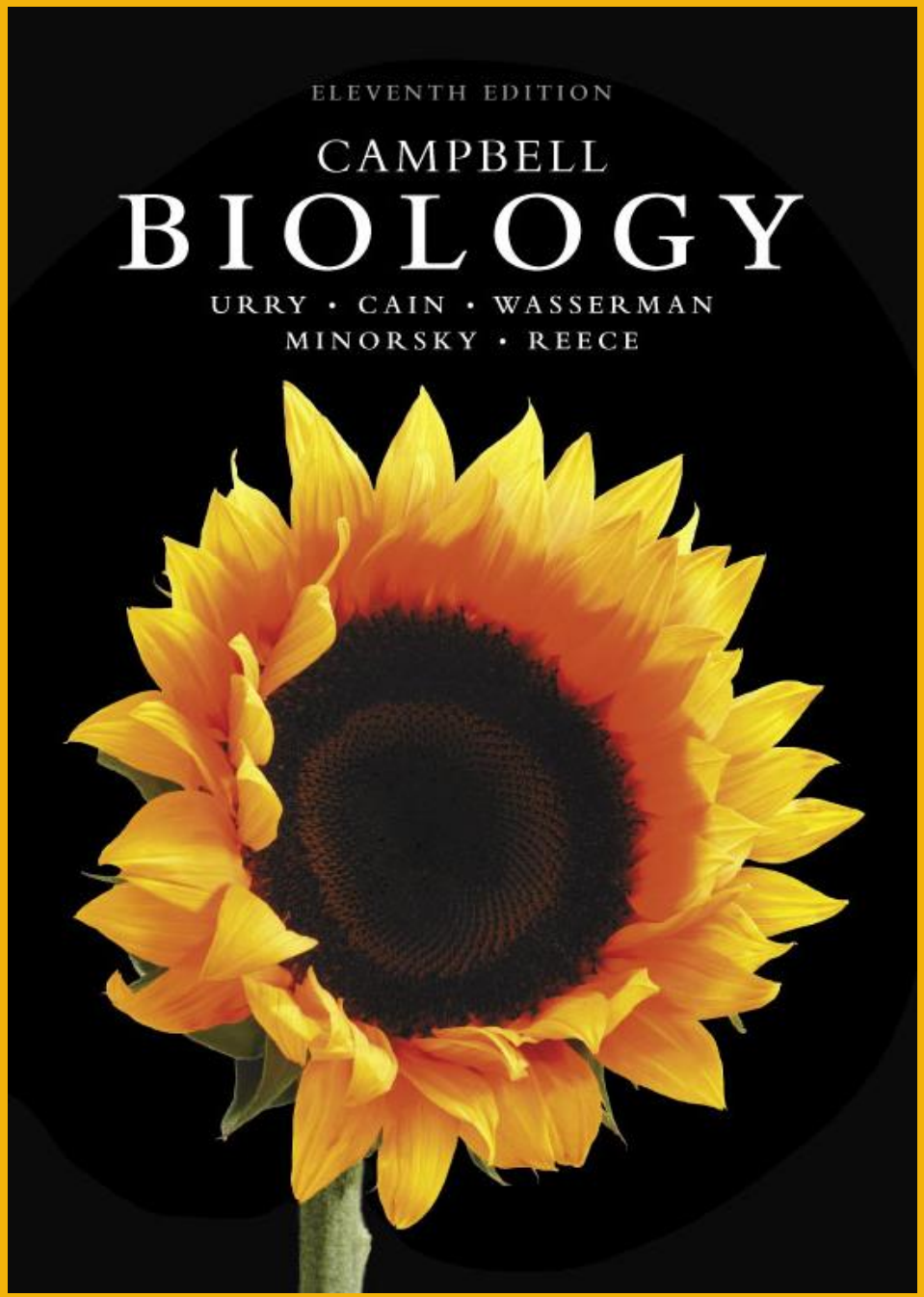


Chapter 1

Evolution, the Themes of Biology, and Scientific Inquiry

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Inquiring About Life

- An organism's adaptations to its environment are the result of evolution
  - For example, the color of the beach mouse has come to be well matched, or adapted, to its local background
- Evolution is the process of change that has transformed life on Earth

Figure 1.1

Figure 1.1a

An inland mouse of the species *Peromyscus polionotus*

- **Biology** is the scientific study of life
- Biologists ask questions, such as: How does a single cell develop into an organism?
- Biology is a quest, an ongoing inquiry about the nature of life
- Life defies a simple, one-sentence definition
- Life is recognized by what living things do

Figure 1.2

▼ Order

▲ Evolutionary adaptation

▲ Regulation

▲ Energy processing

▲ Growth and development

▲ Response to the environment

▼ Reproduction

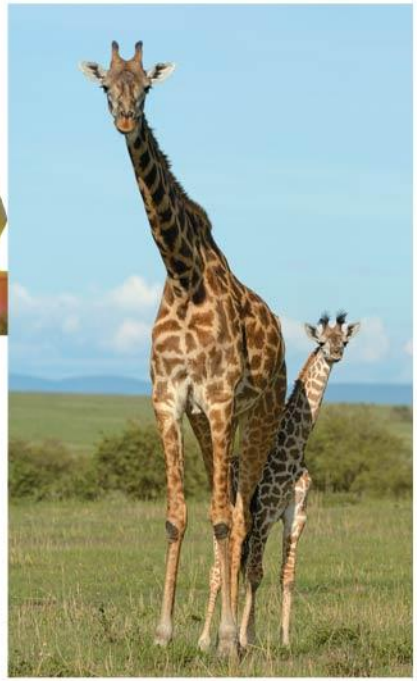
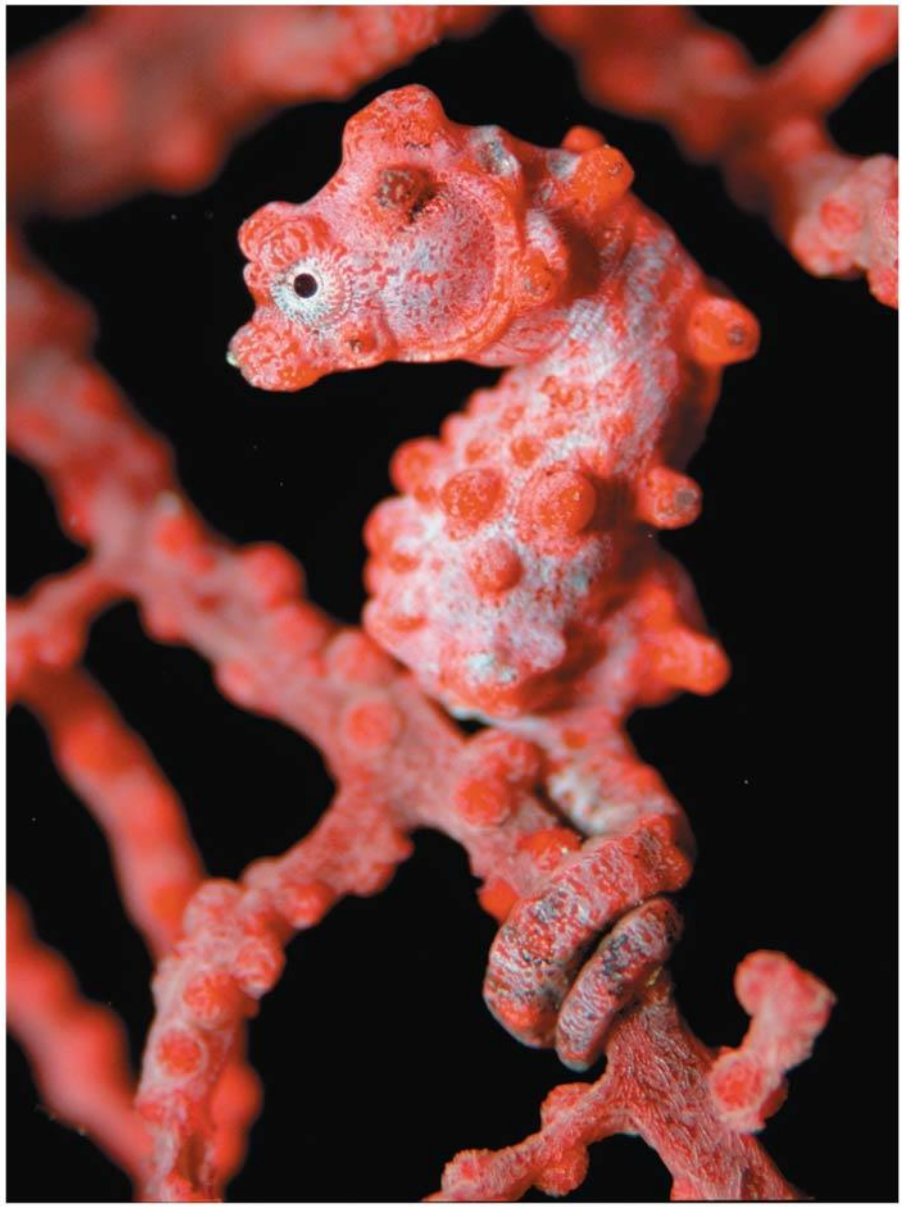


Figure 1.2a

Order

Figure 1.2b

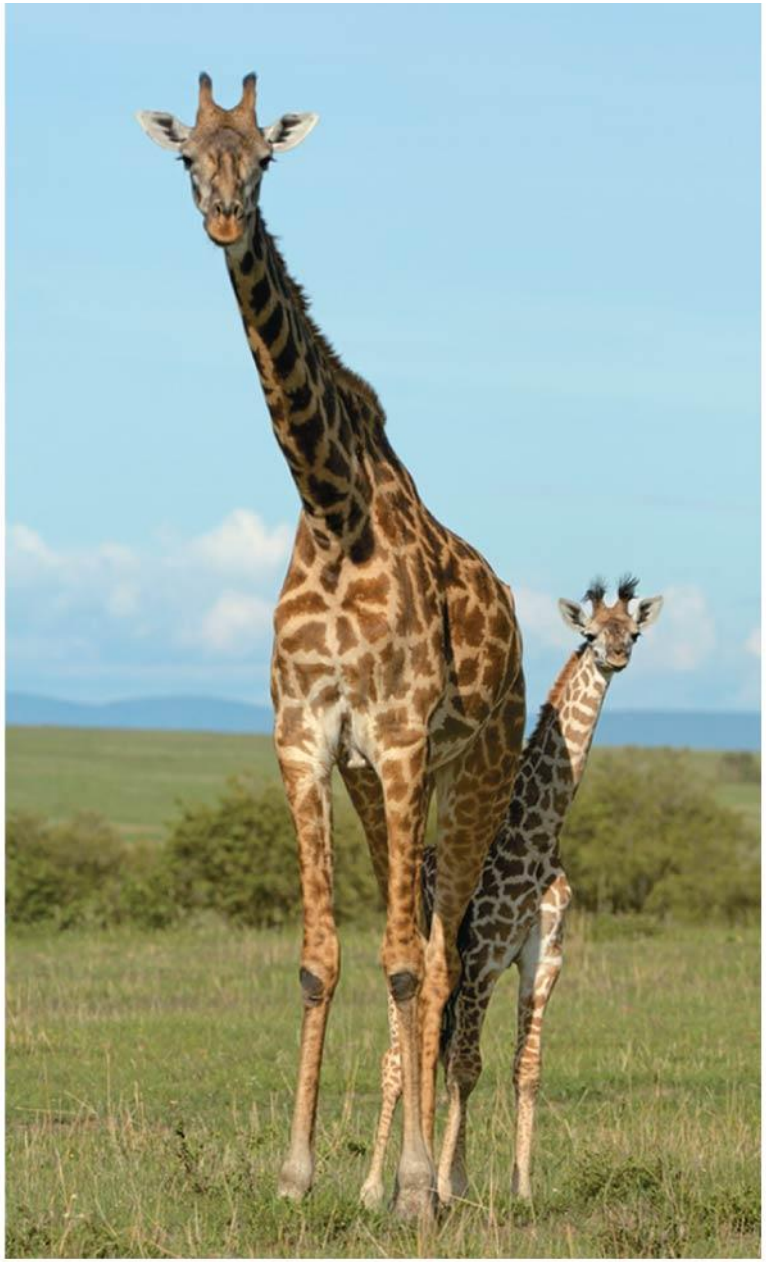


Evolutionary adaptation

Figure 1.2c

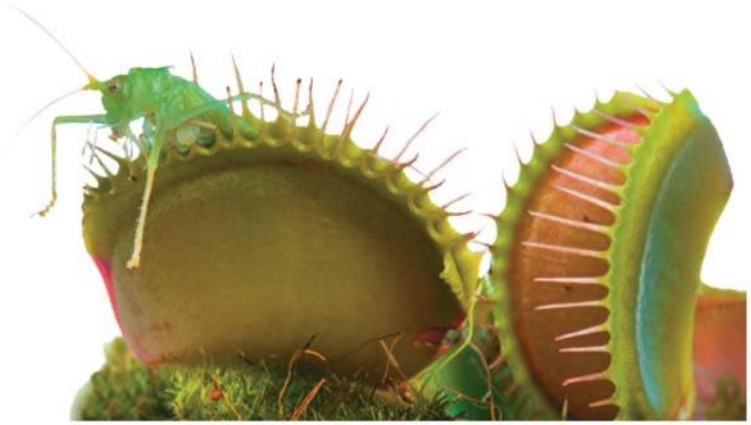
Regulation

Figure 1.2d



Reproduction

Figure 1.2e



Response to the environment

Figure 1.2f

Growth and development

Figure 1.2g

Energy processing

Video: Seahorse Camouflage

Concept 1.1: 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

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

Figure 1.3

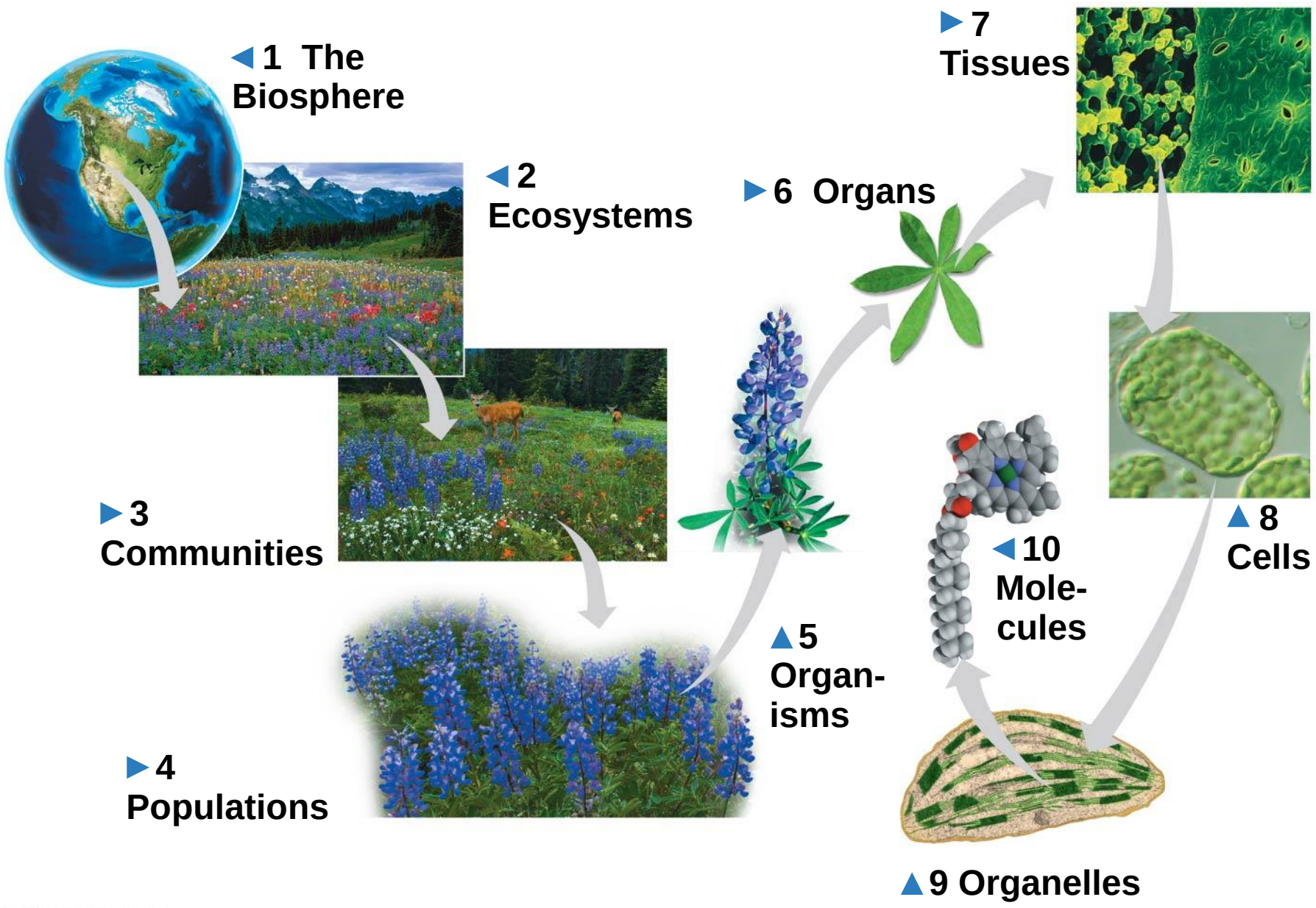


Figure 1.3a

The Biosphere

Figure 1.3b

Ecosystems

Figure 1.3c

Communities

Figure 1.3d

Populations

Figure 1.3e

Organisms

Figure 1.3f

Organs

Figure 1.3g

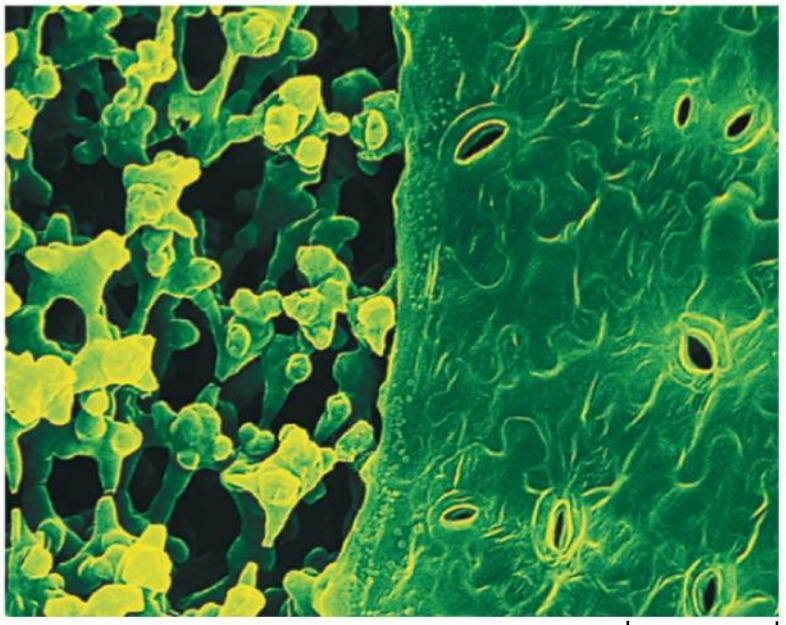
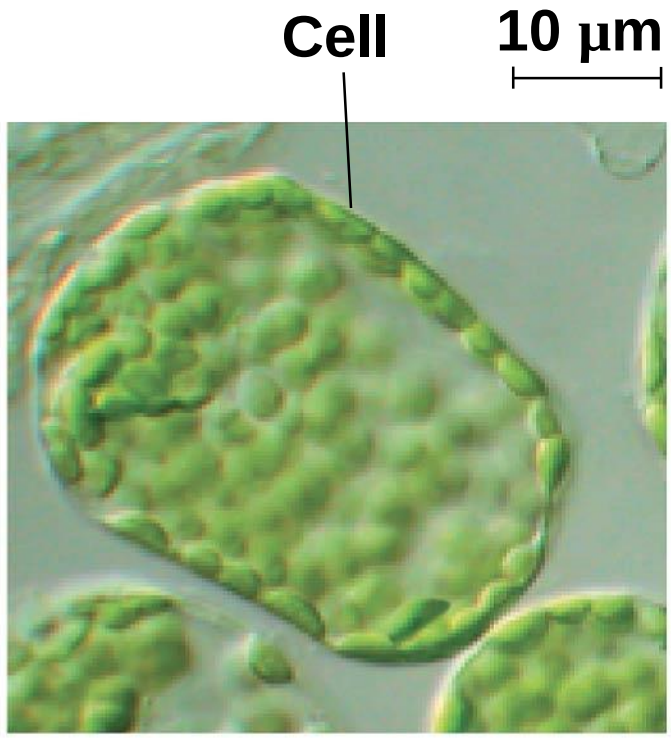
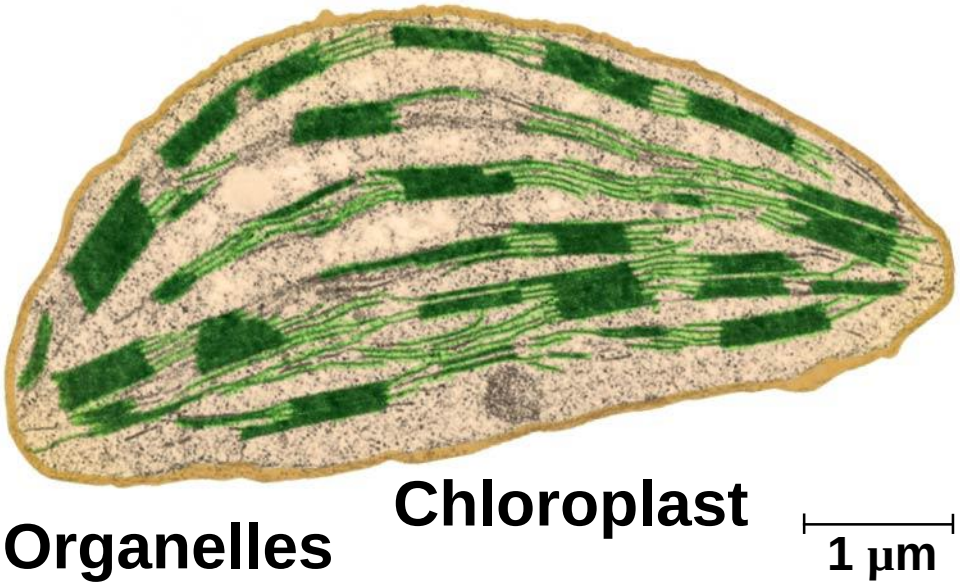


Figure 1.3h



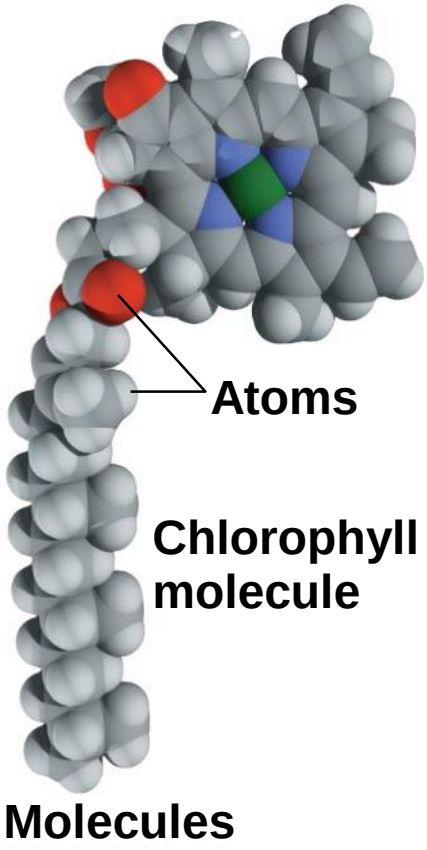
Cells

Figure 1.3i



Organelles

Figure 1.3j



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 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
- 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

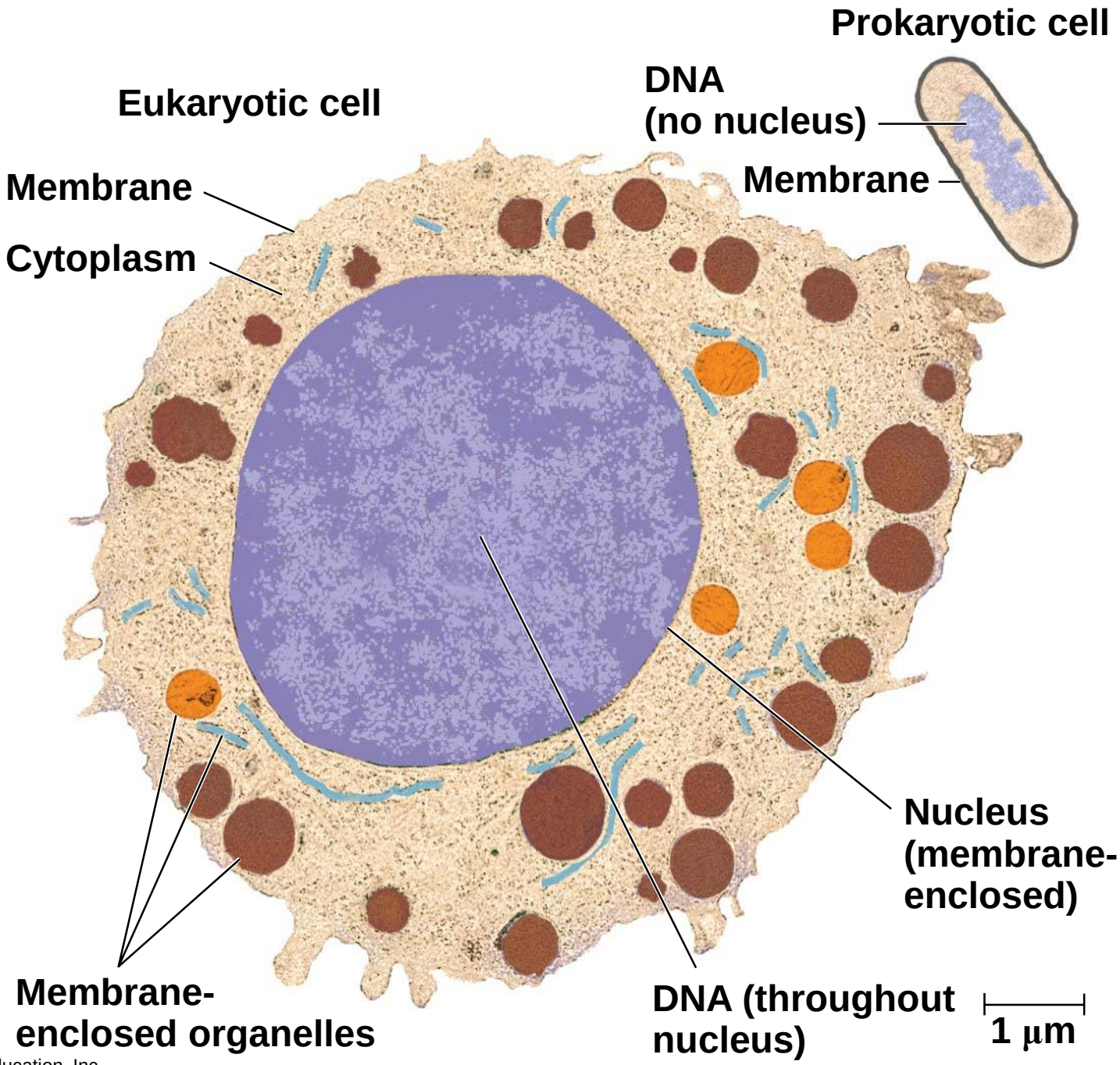


Figure 1.4a

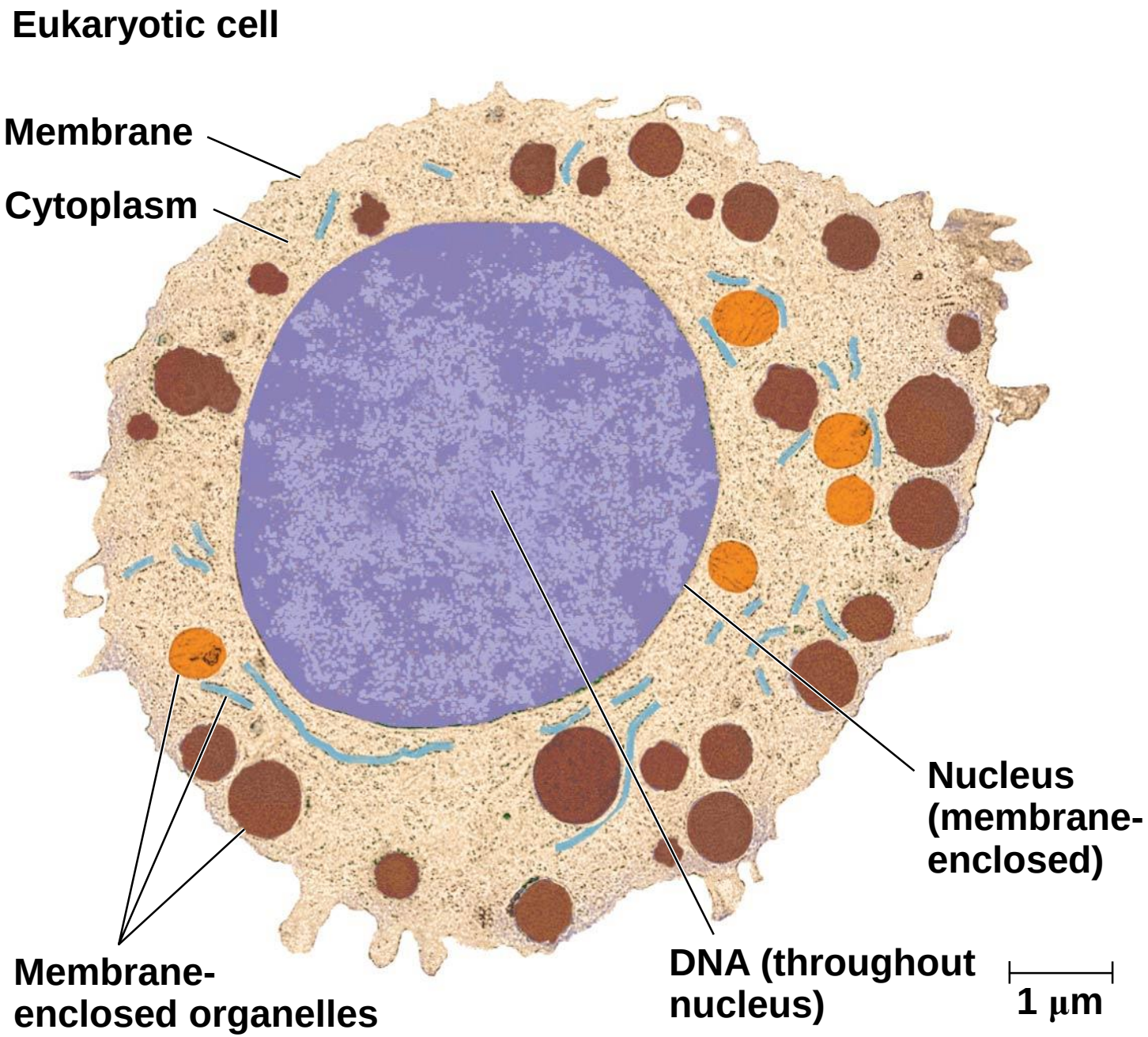
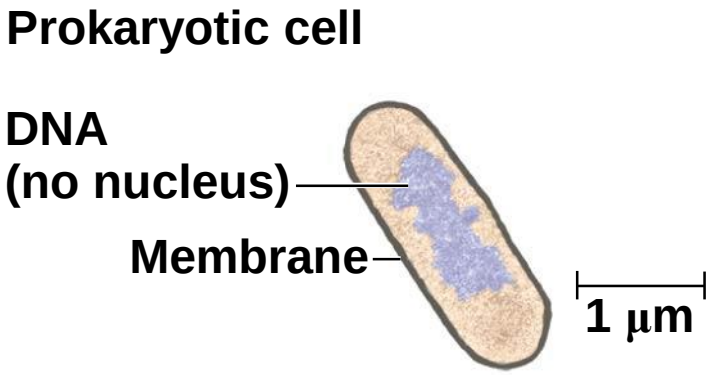


Figure 1.4b



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

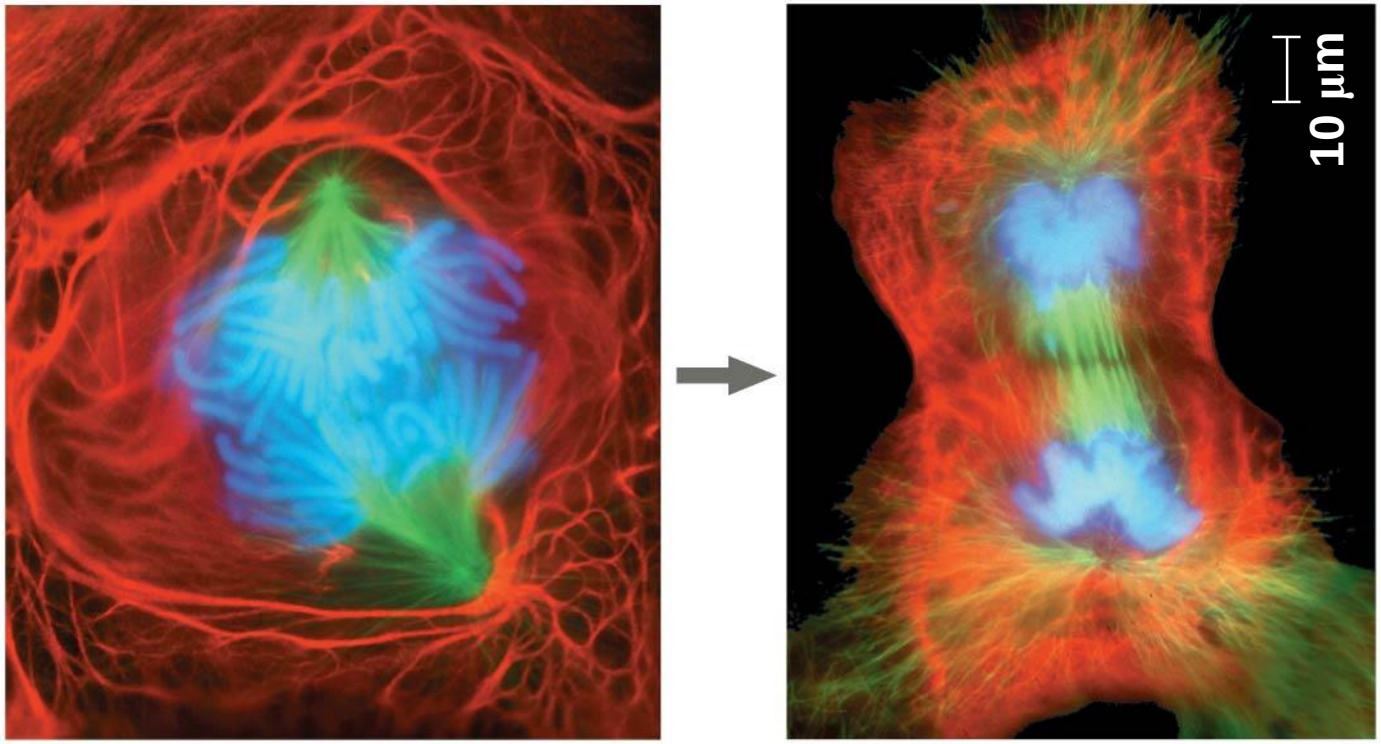


Figure 1.5a

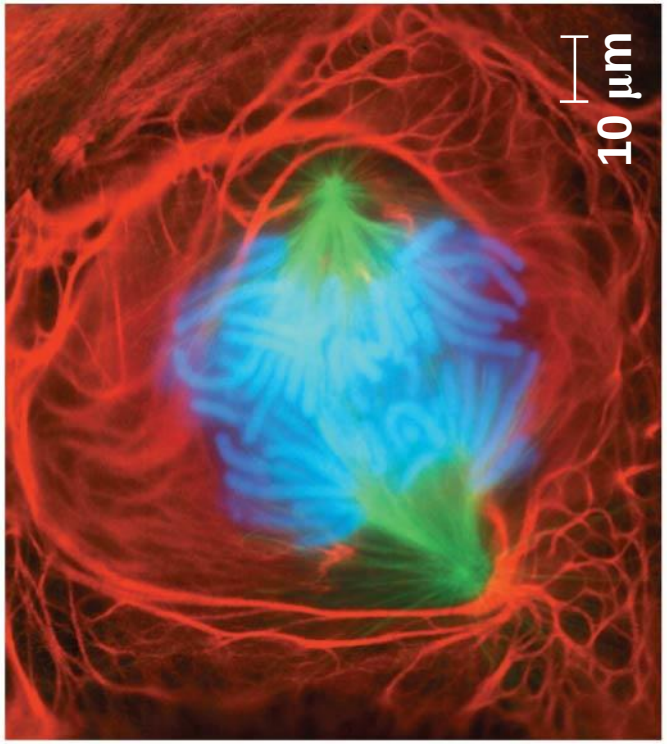
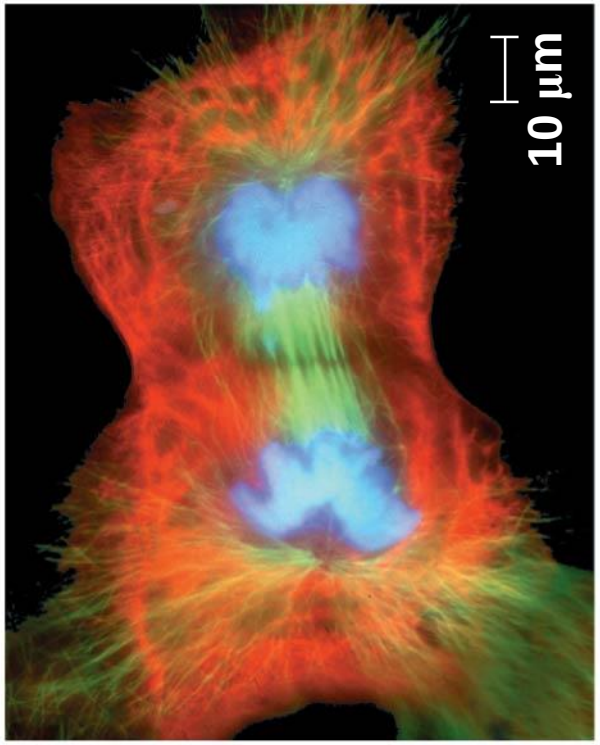


Figure 1.5b



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

Figure 1.6

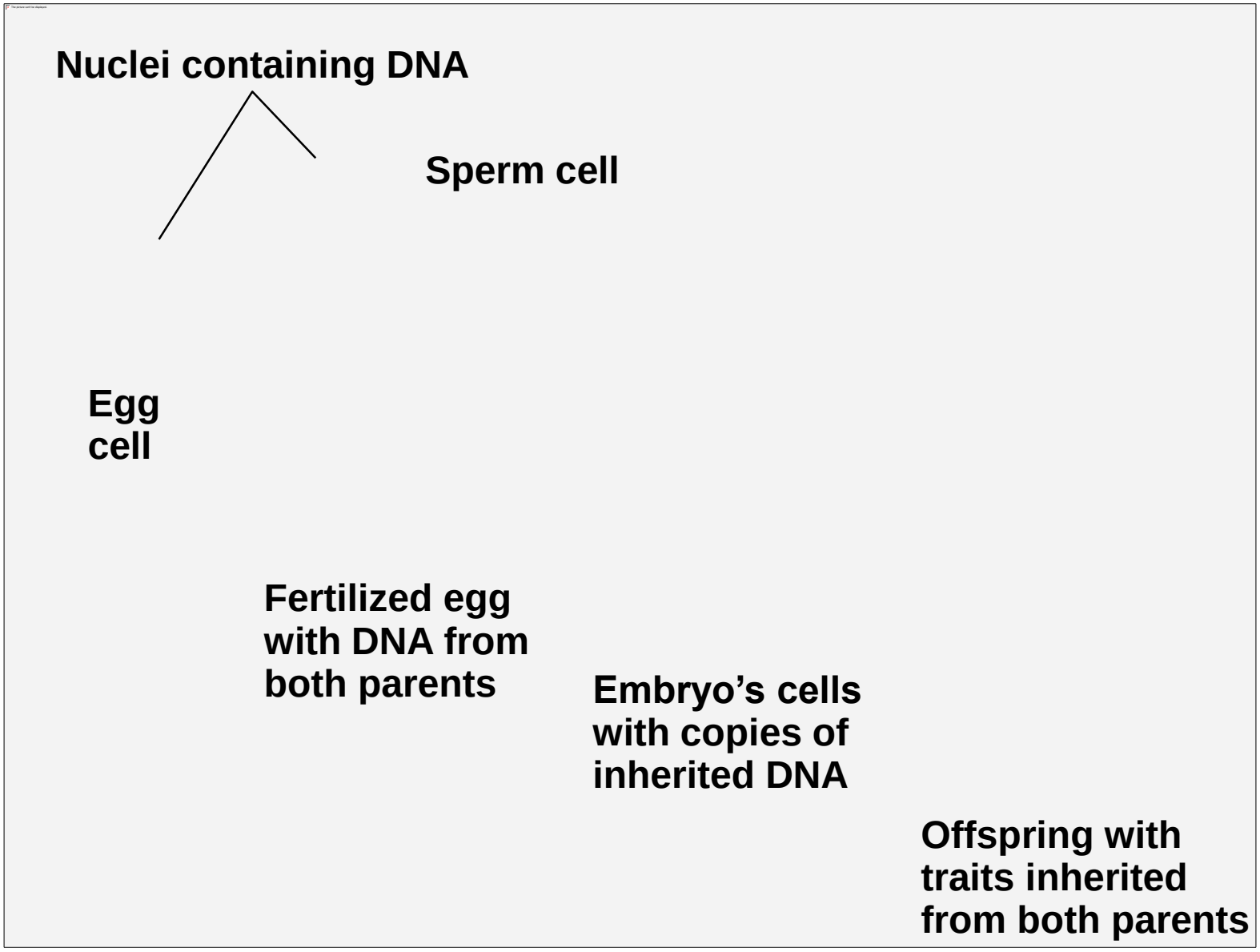
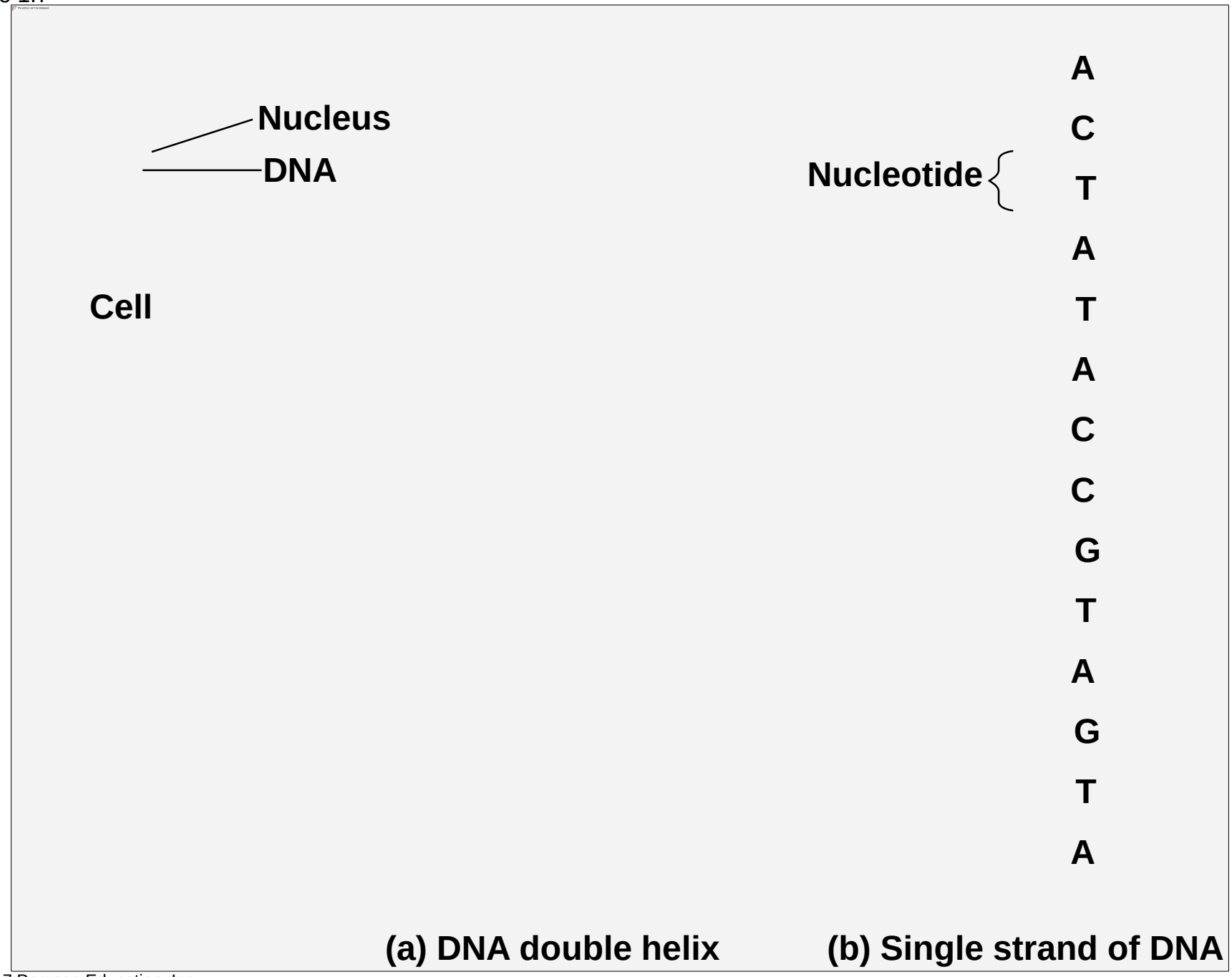


Figure 1.6a

- 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

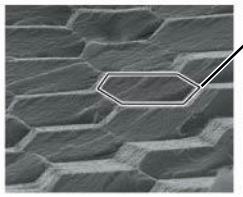
Figure 1.7



- 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.



(b) A lens cell uses information in DNA to make crystallin.

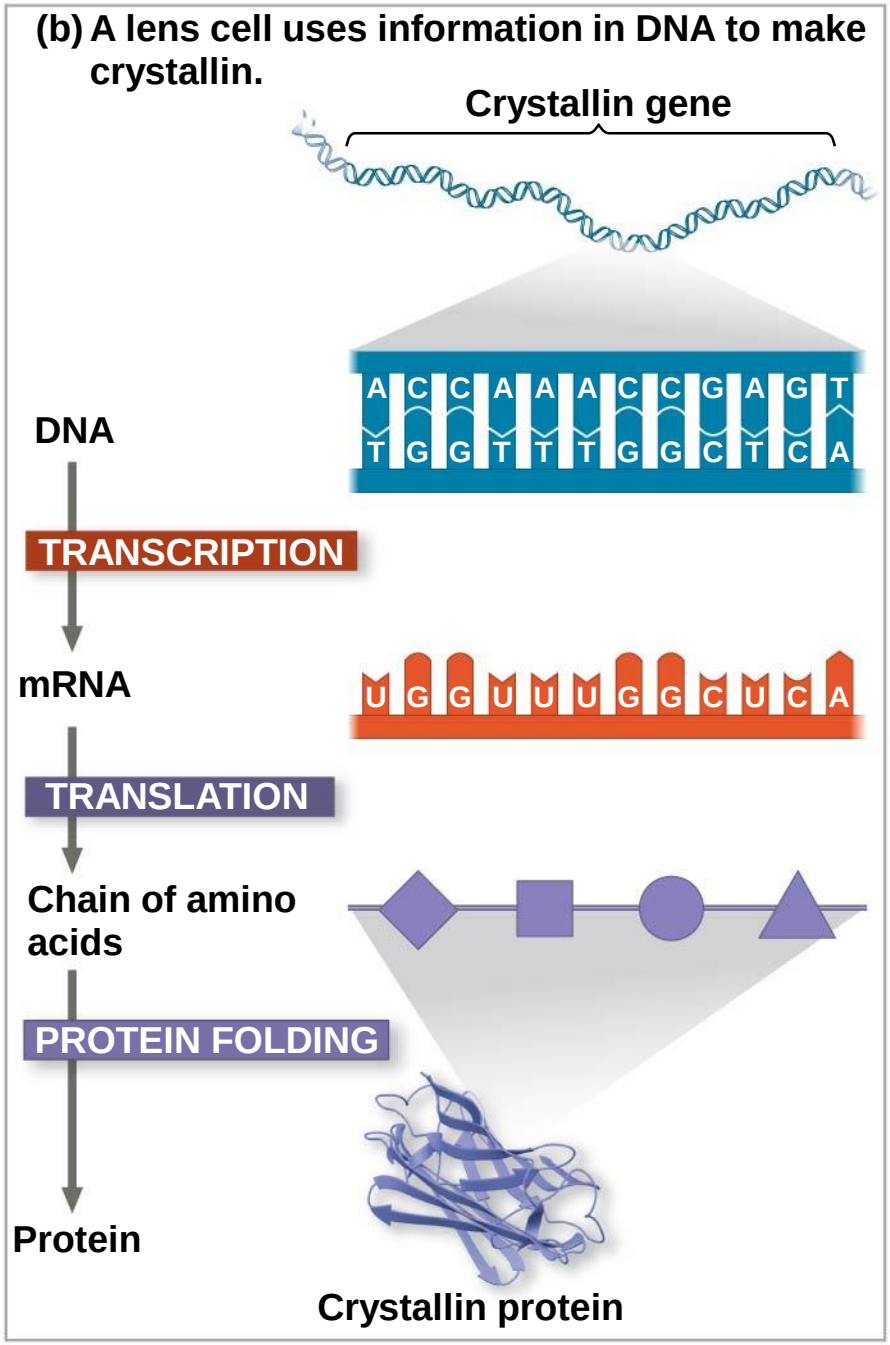


Figure 1.8a

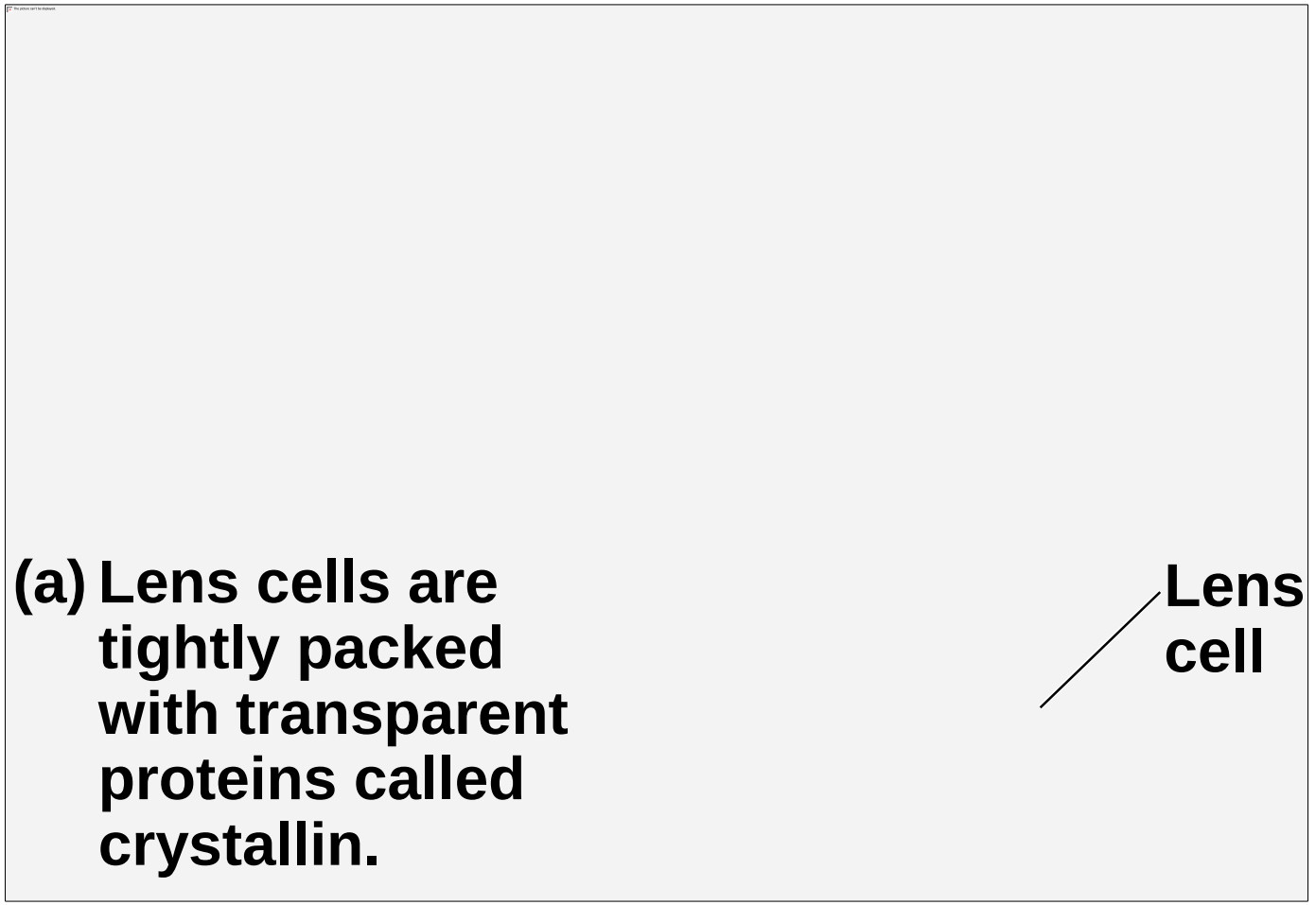


Figure 1.8aa

Figure 1.8ab

Figure 1.8b

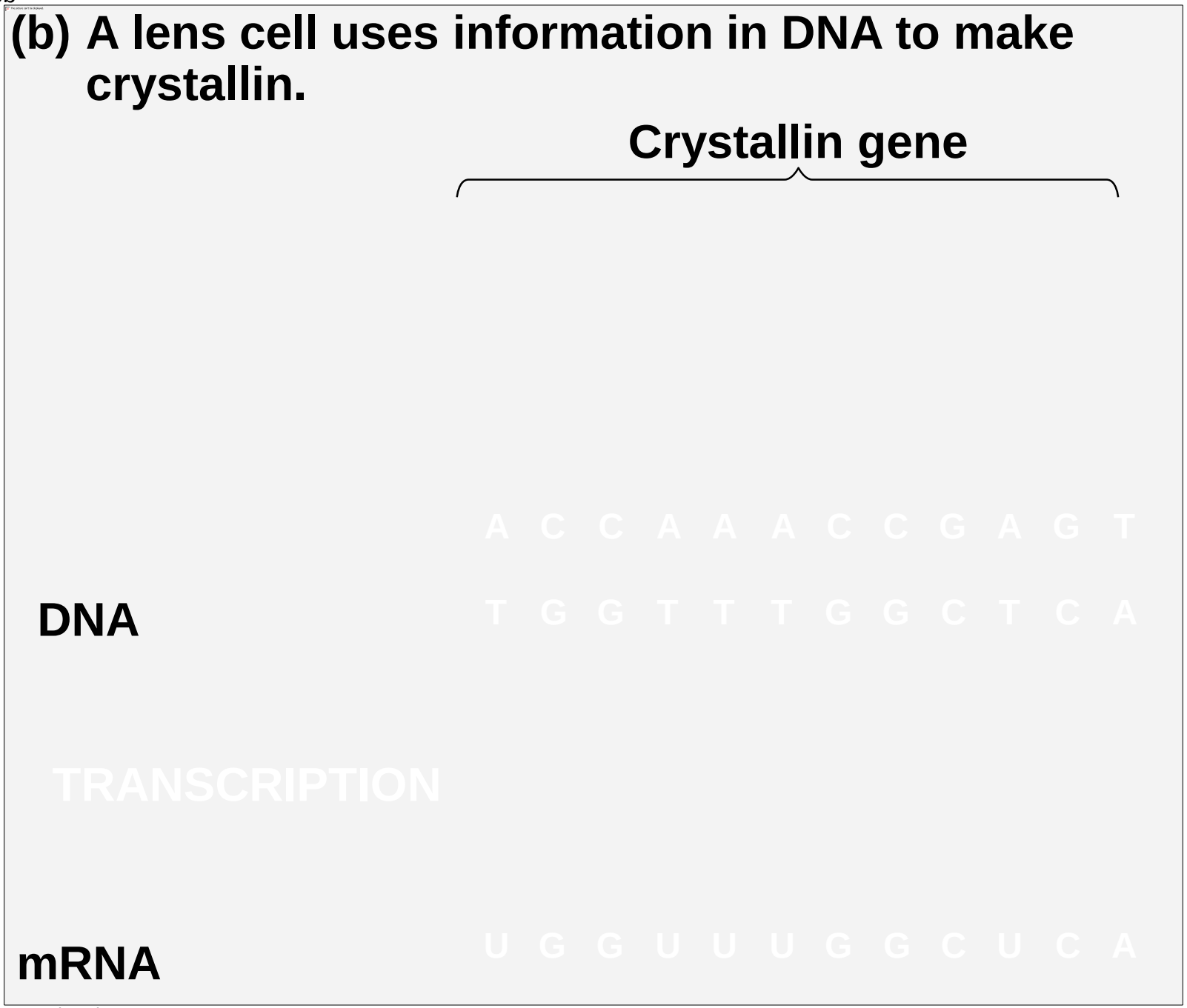
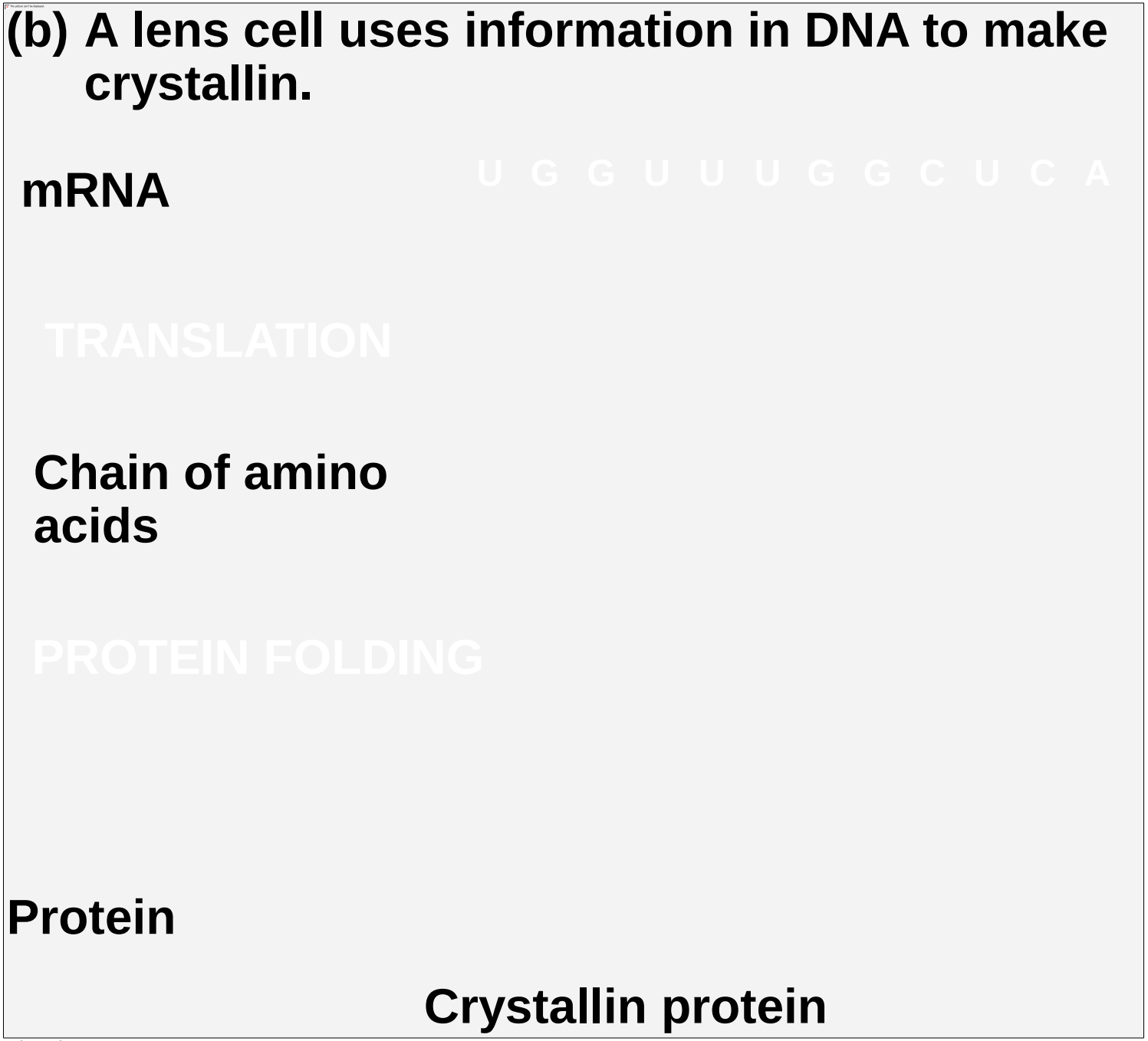


Figure 1.8c



Genomics: Large-Scale Analysis of DNA Sequences

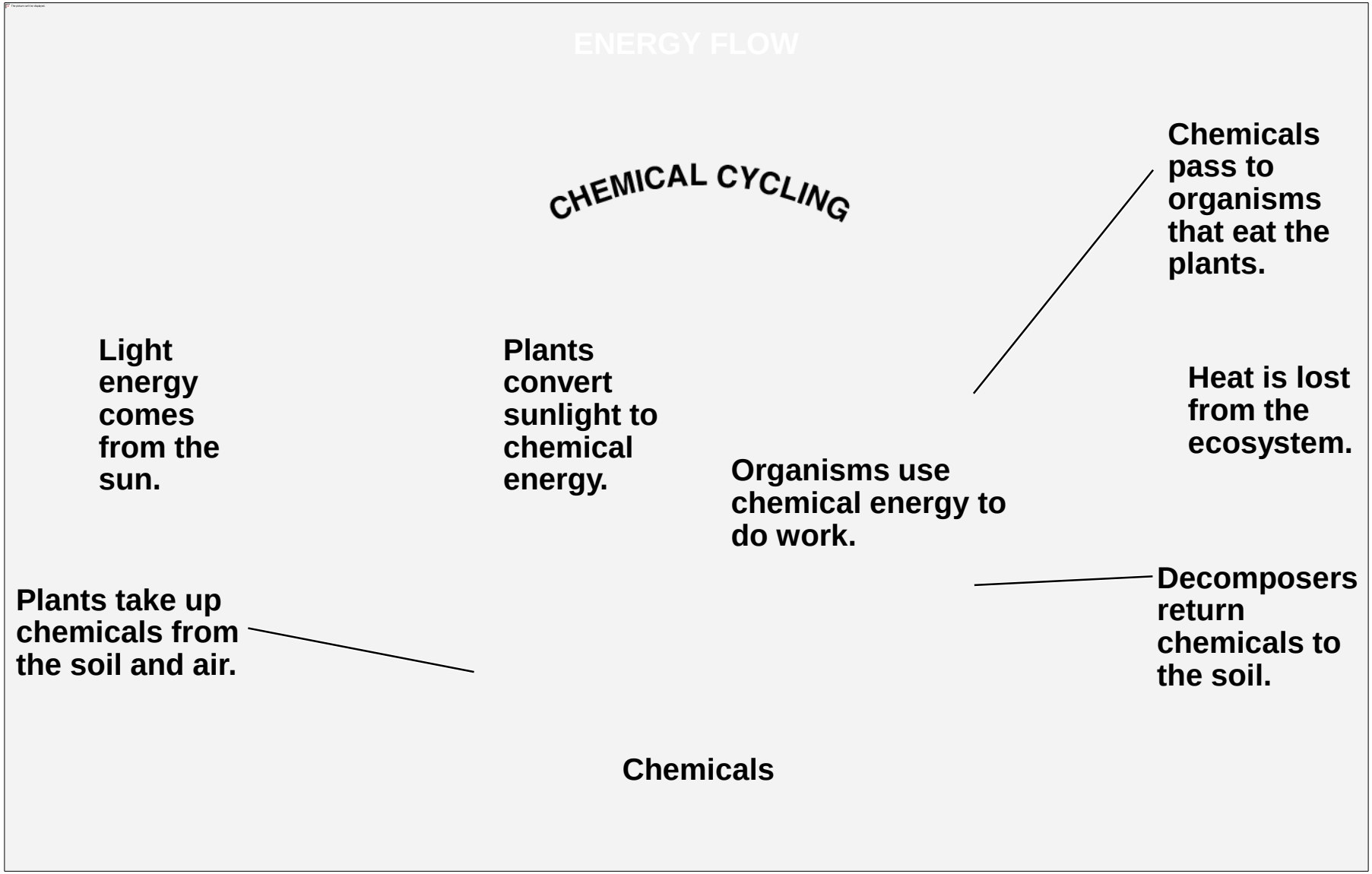
- An organism's **genome** is its entire "library" of genetic instructions
- **Genomics** is the study of sets of genes in one or more species
- **Proteomics** is the study of whole sets of proteins and their properties
- The entire set of proteins expressed by a given cell, tissue, or organ is called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



- 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

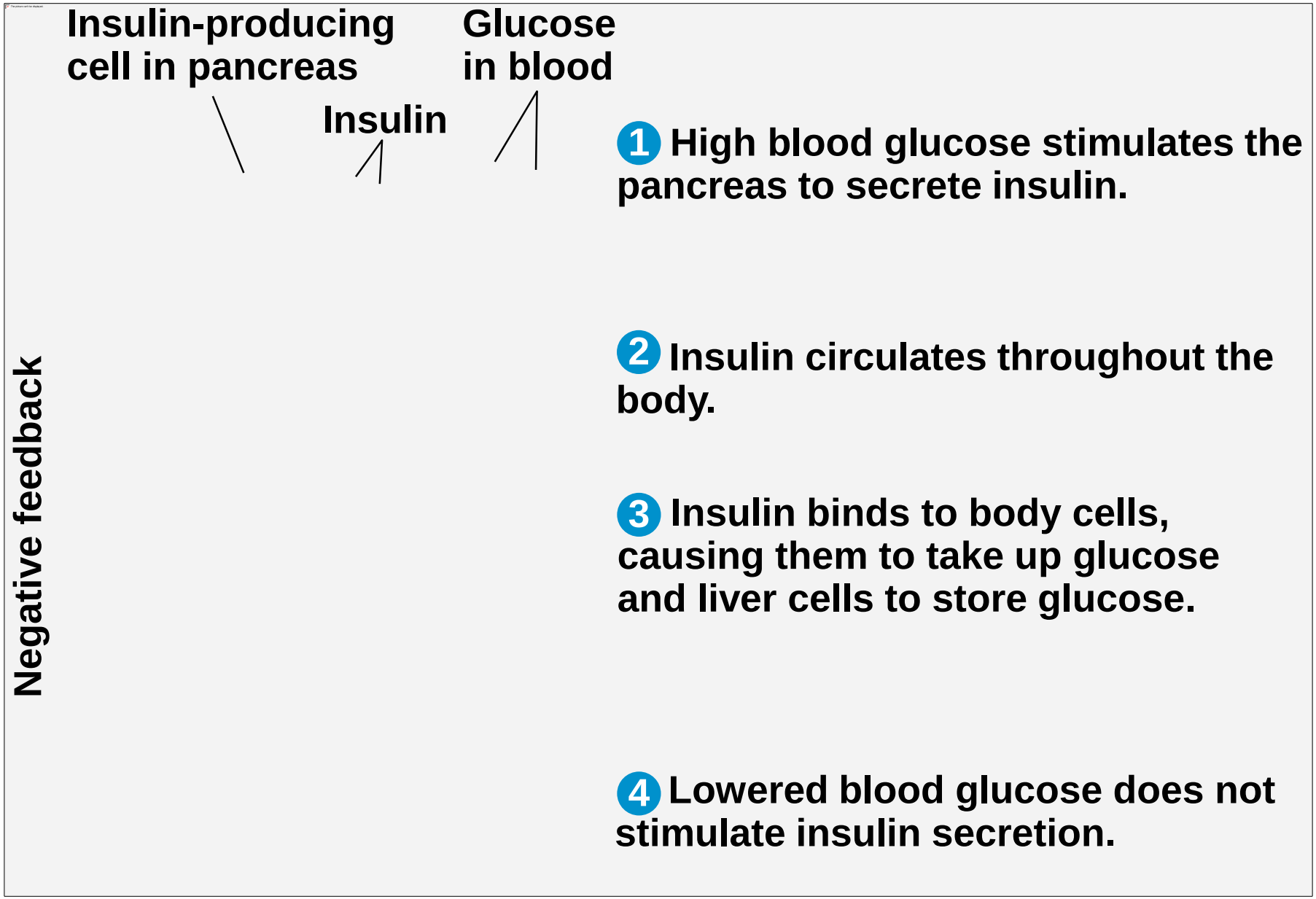
- Interactions between the components of the system ensure smooth integration of all the parts
- This holds true equally well for components of an ecosystem and the molecules in a cell

Molecules: Interactions Within Organisms

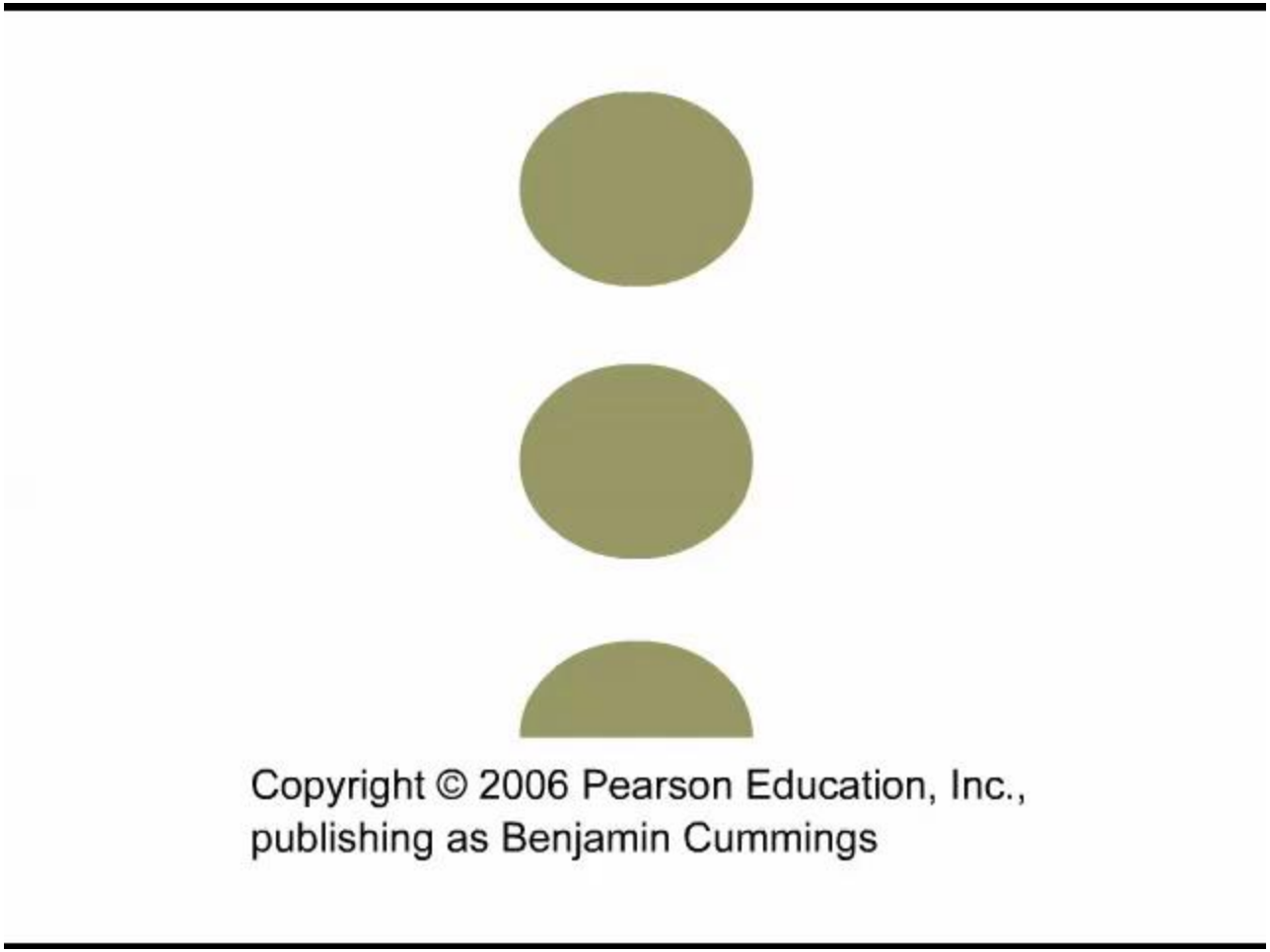
- Interactions between components—organs, tissues, cells, and molecules—that make up living organisms are crucial to their smooth operation
- Many biological processes can self-regulate through a mechanism called feedback

- 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

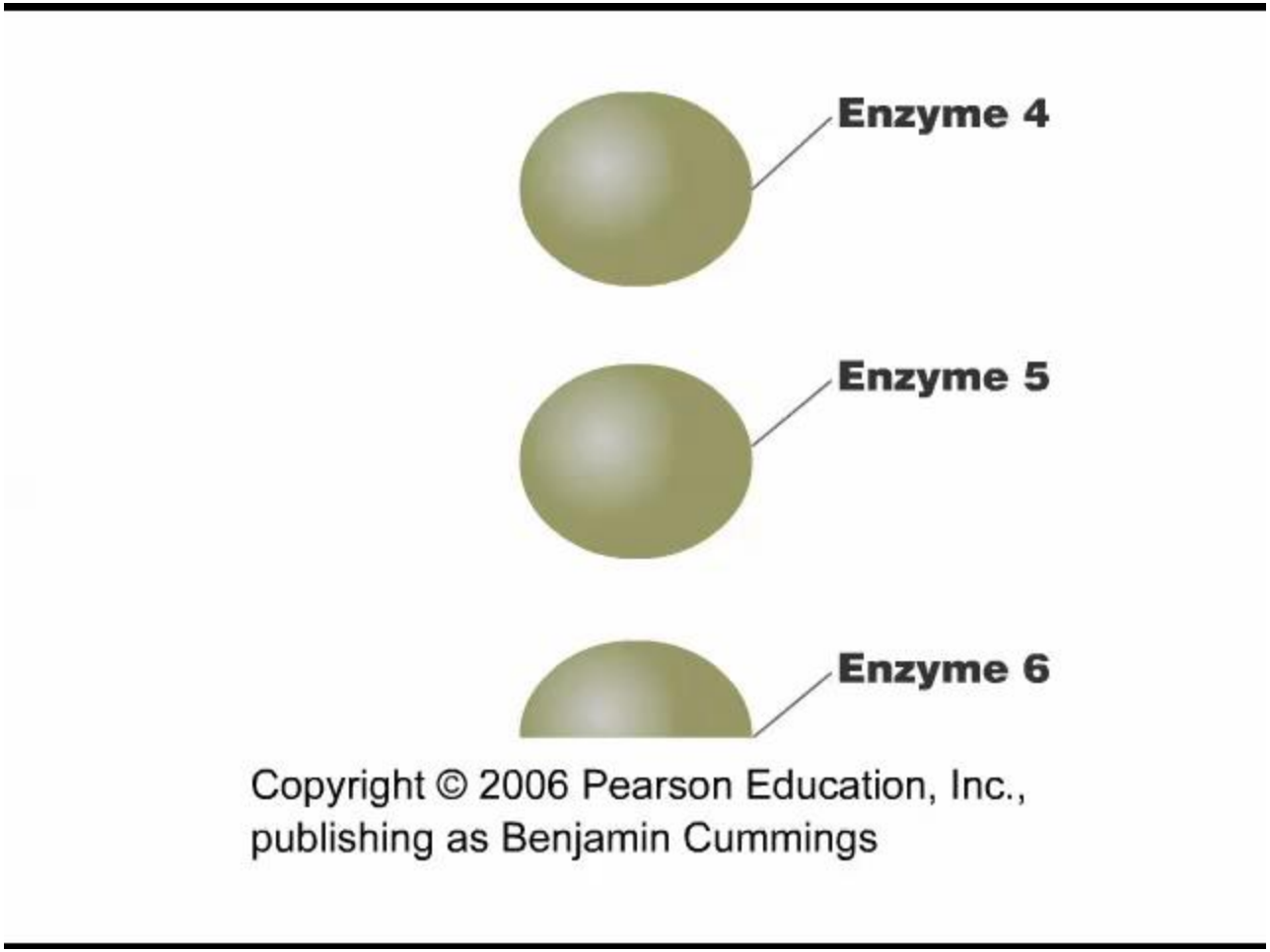
Figure 1.10



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

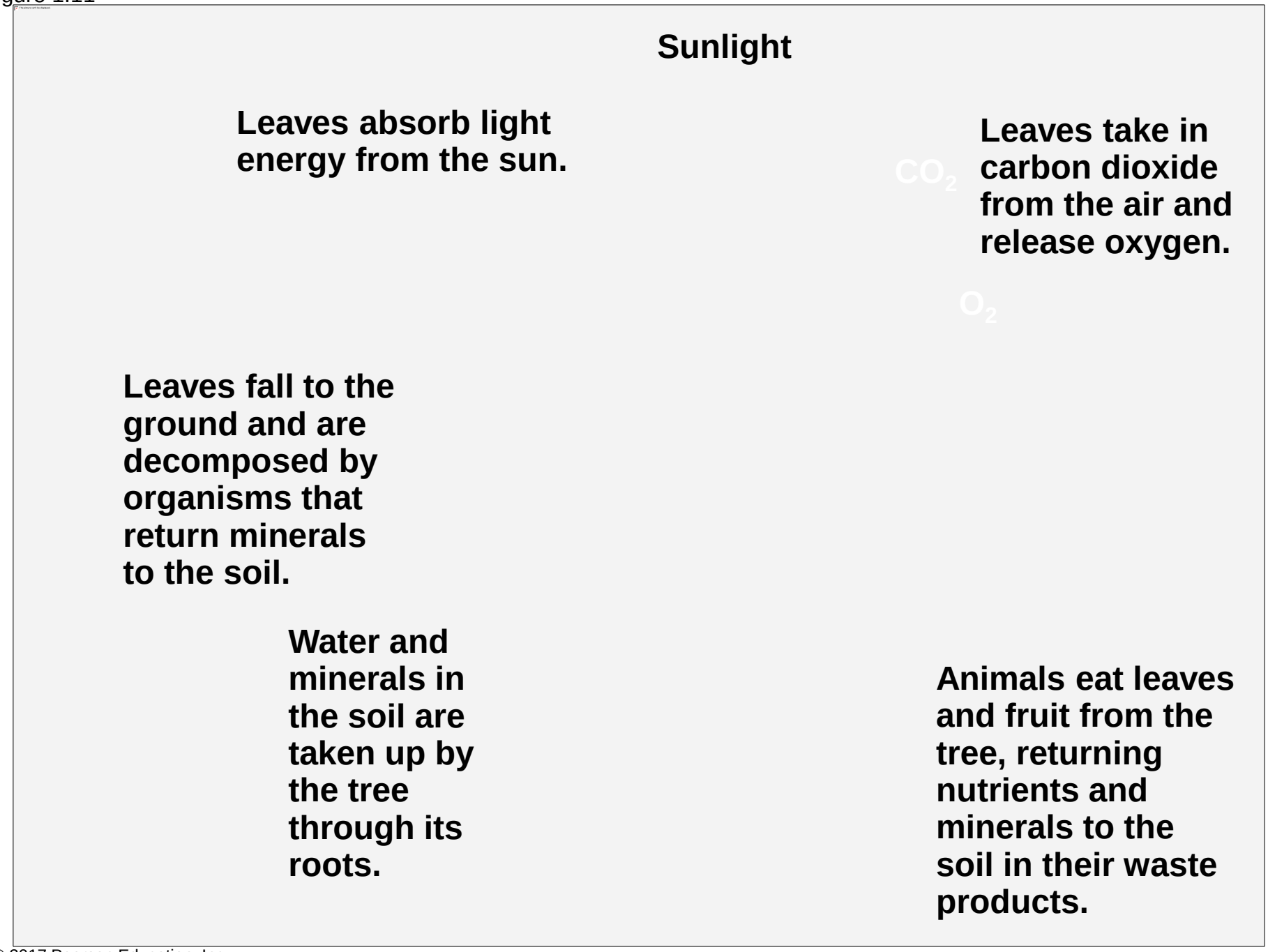


Figure 1.11a

- 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
- 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

- 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
- 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*, 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

- The most numerous and diverse eukaryotes are the protists
- 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

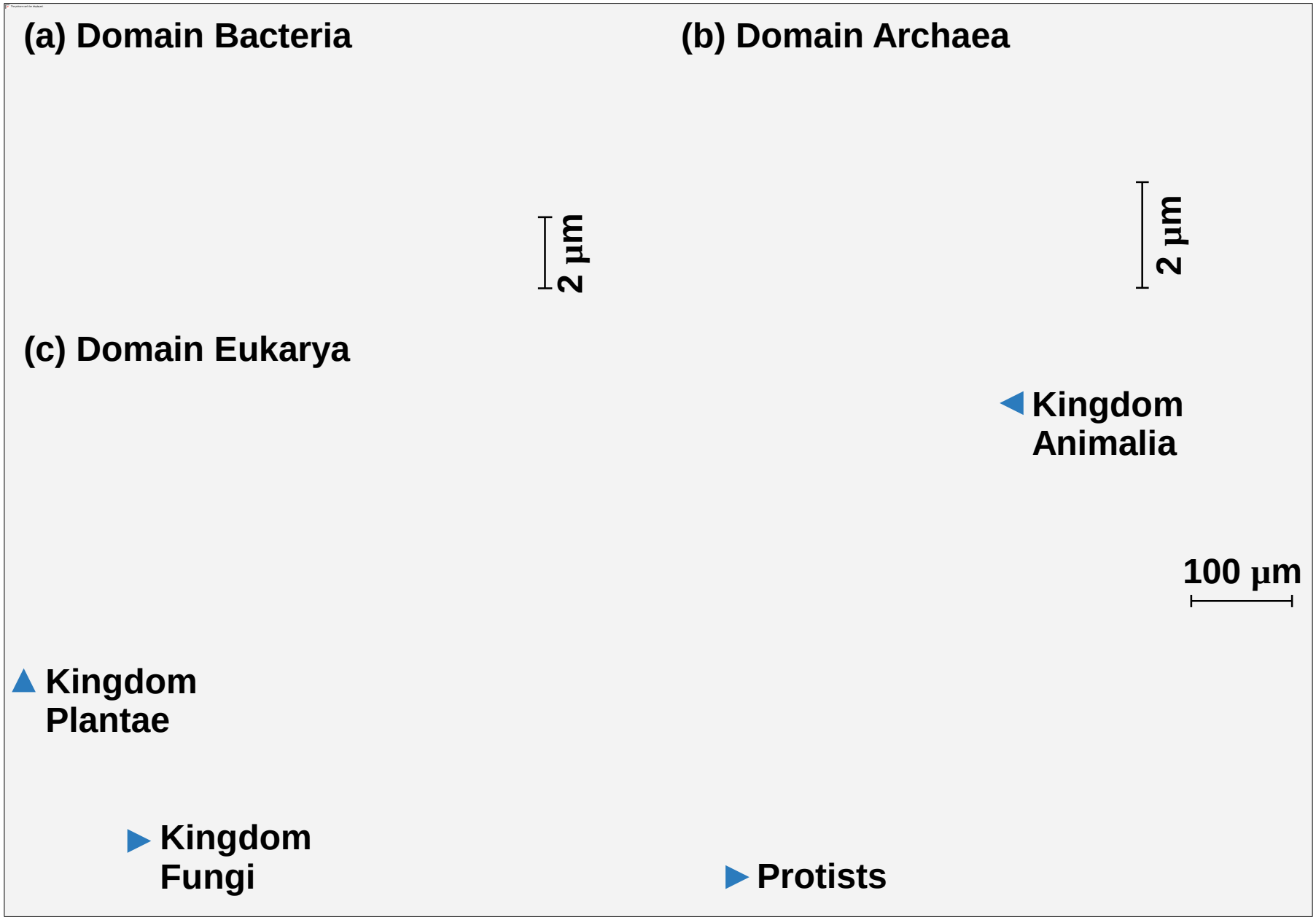


Figure 1.13a

Figure 1.13b

Figure 1.13c

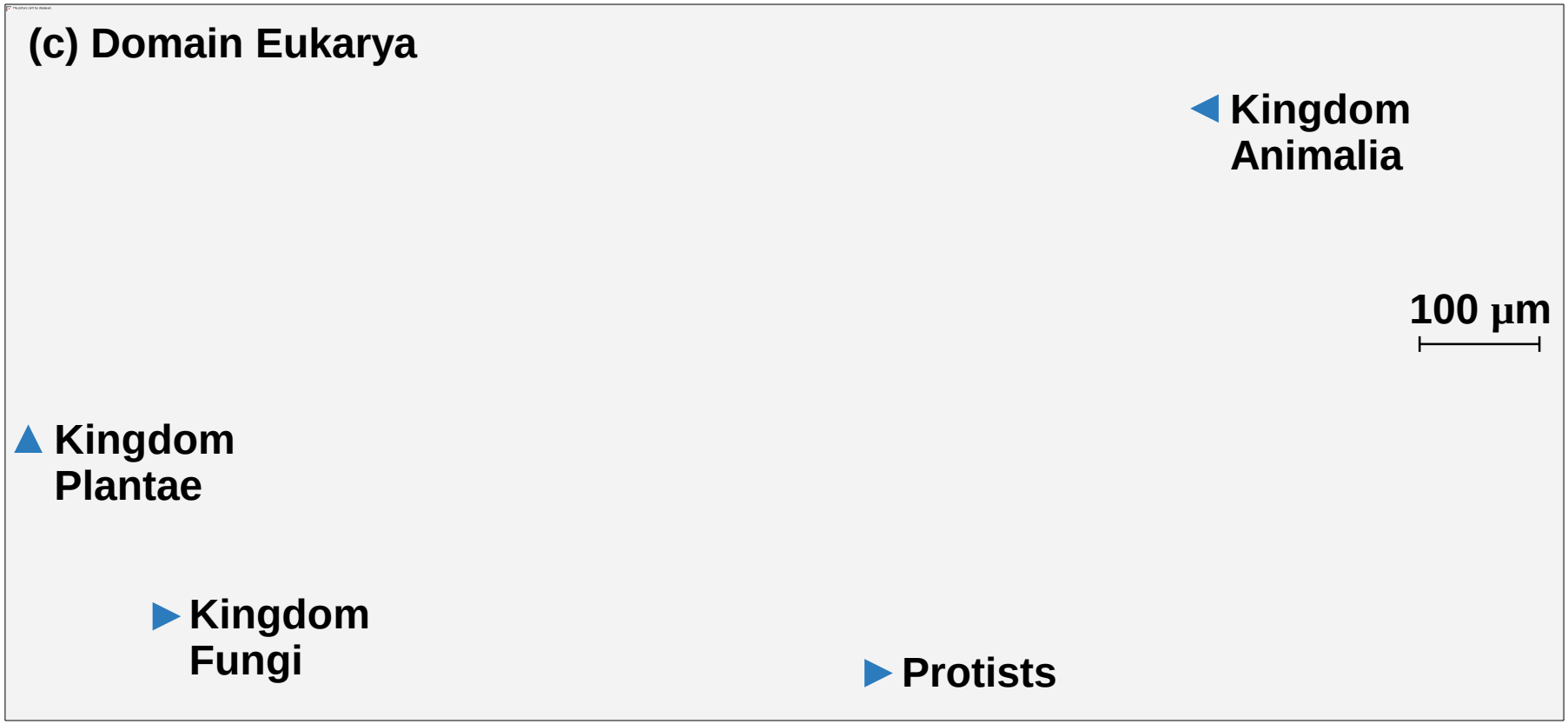


Figure 1.13ca

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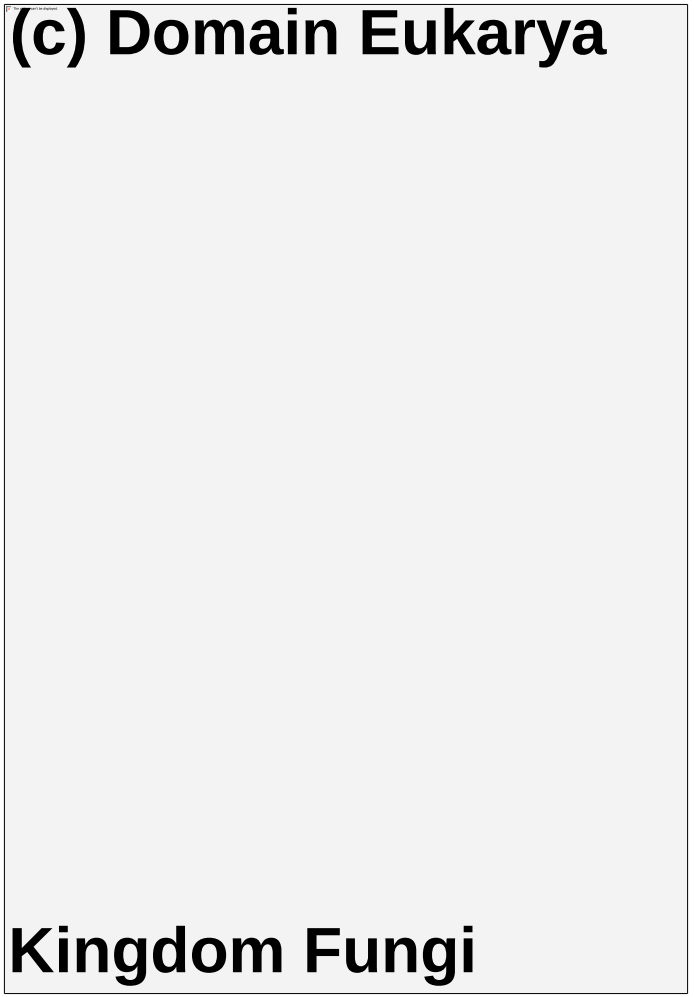
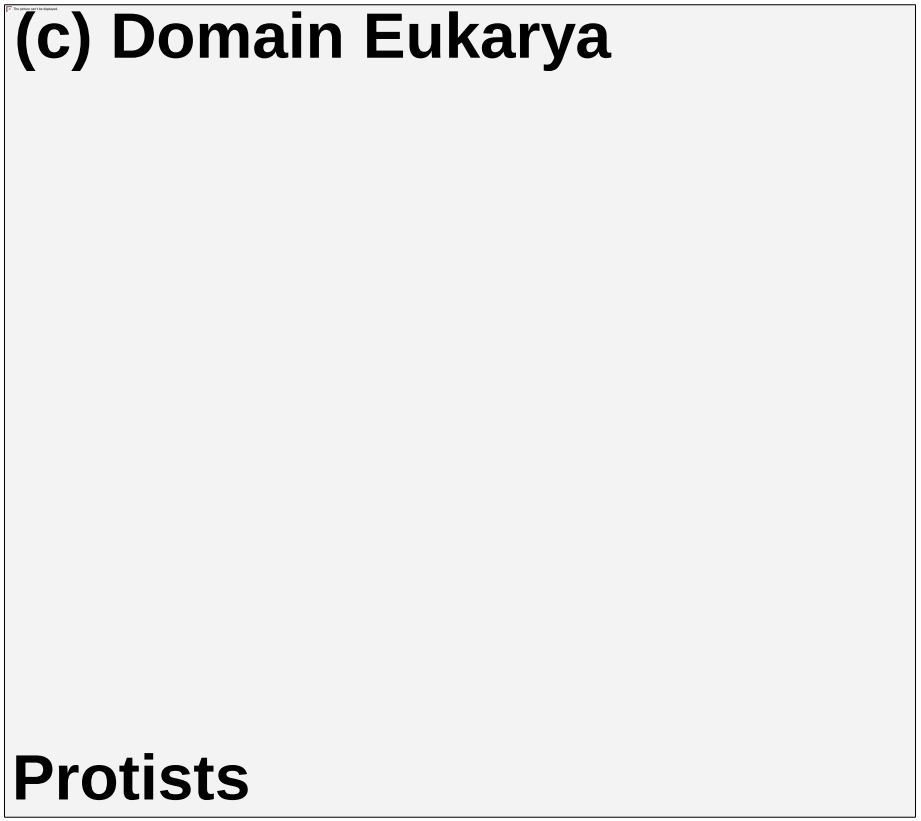


Figure 1.13cc

Figure 1.13cd



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
- 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

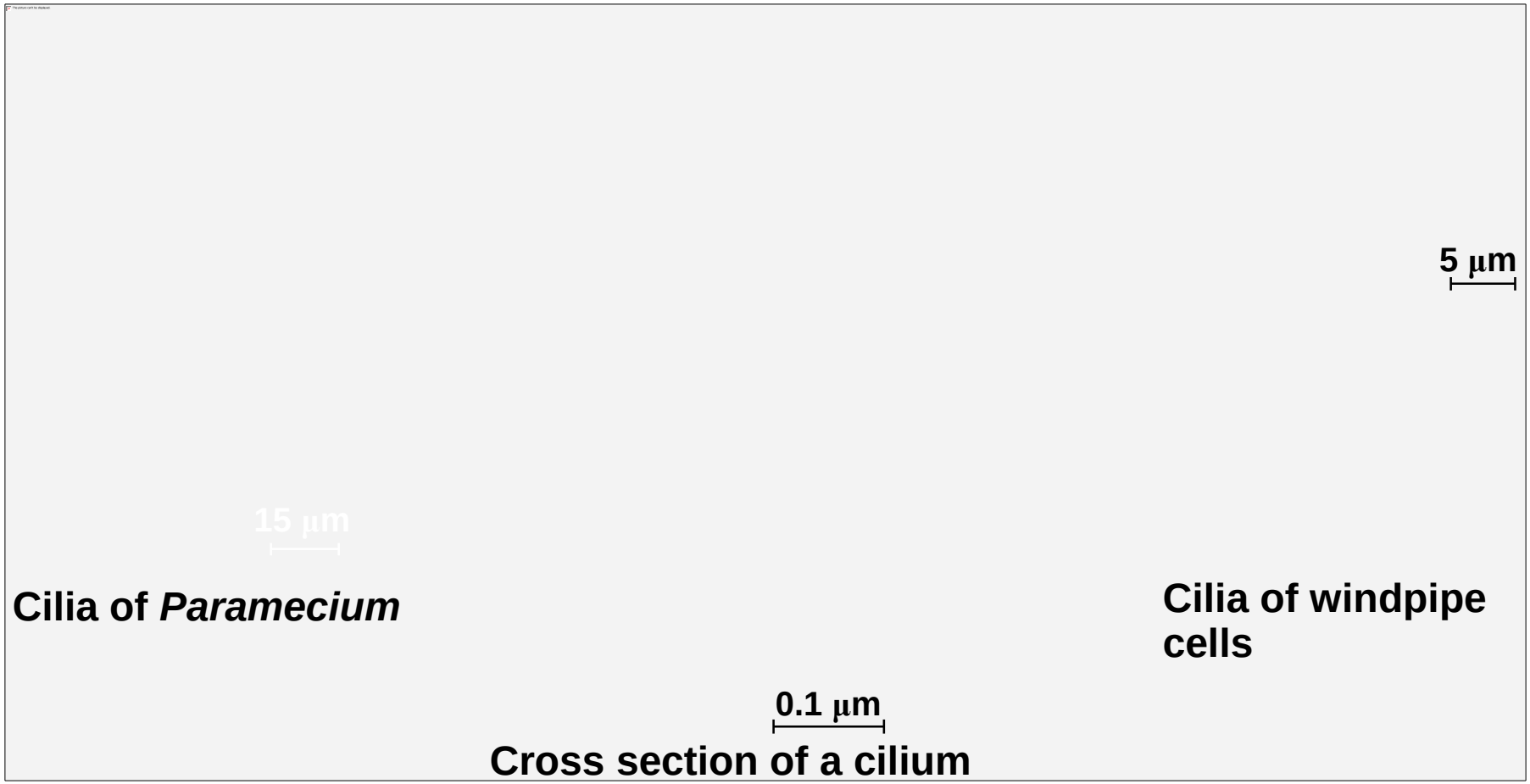


Figure 1.14a

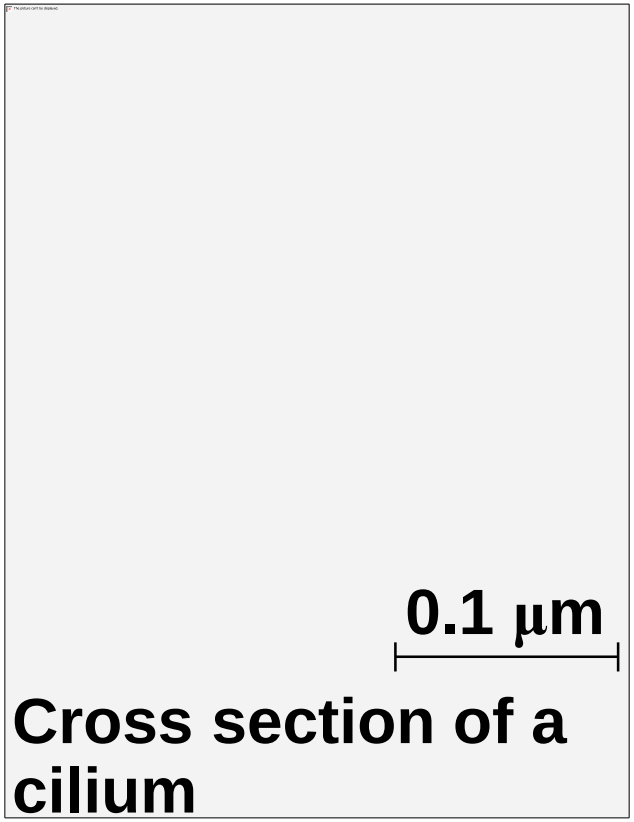


Figure 1.14b

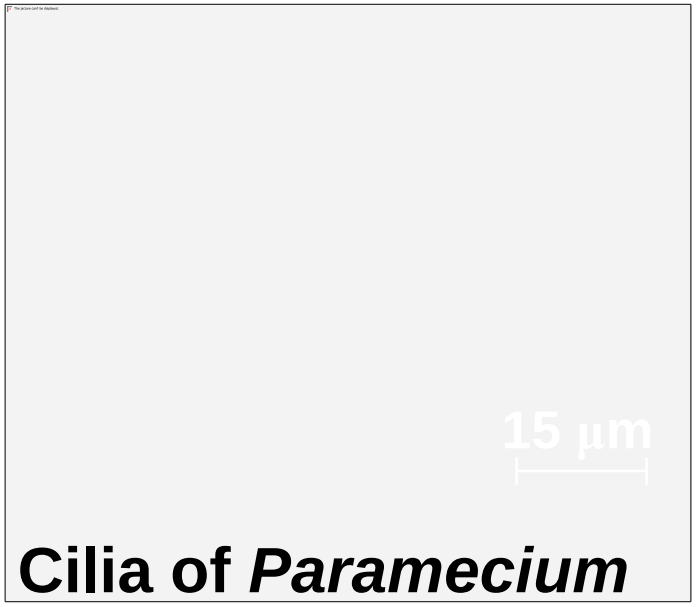


Figure 1.14c

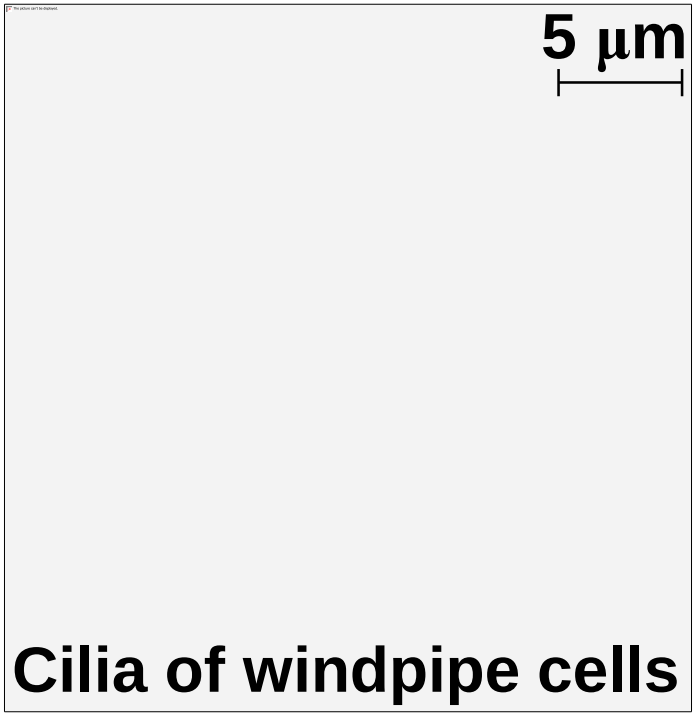


Figure 1.15

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

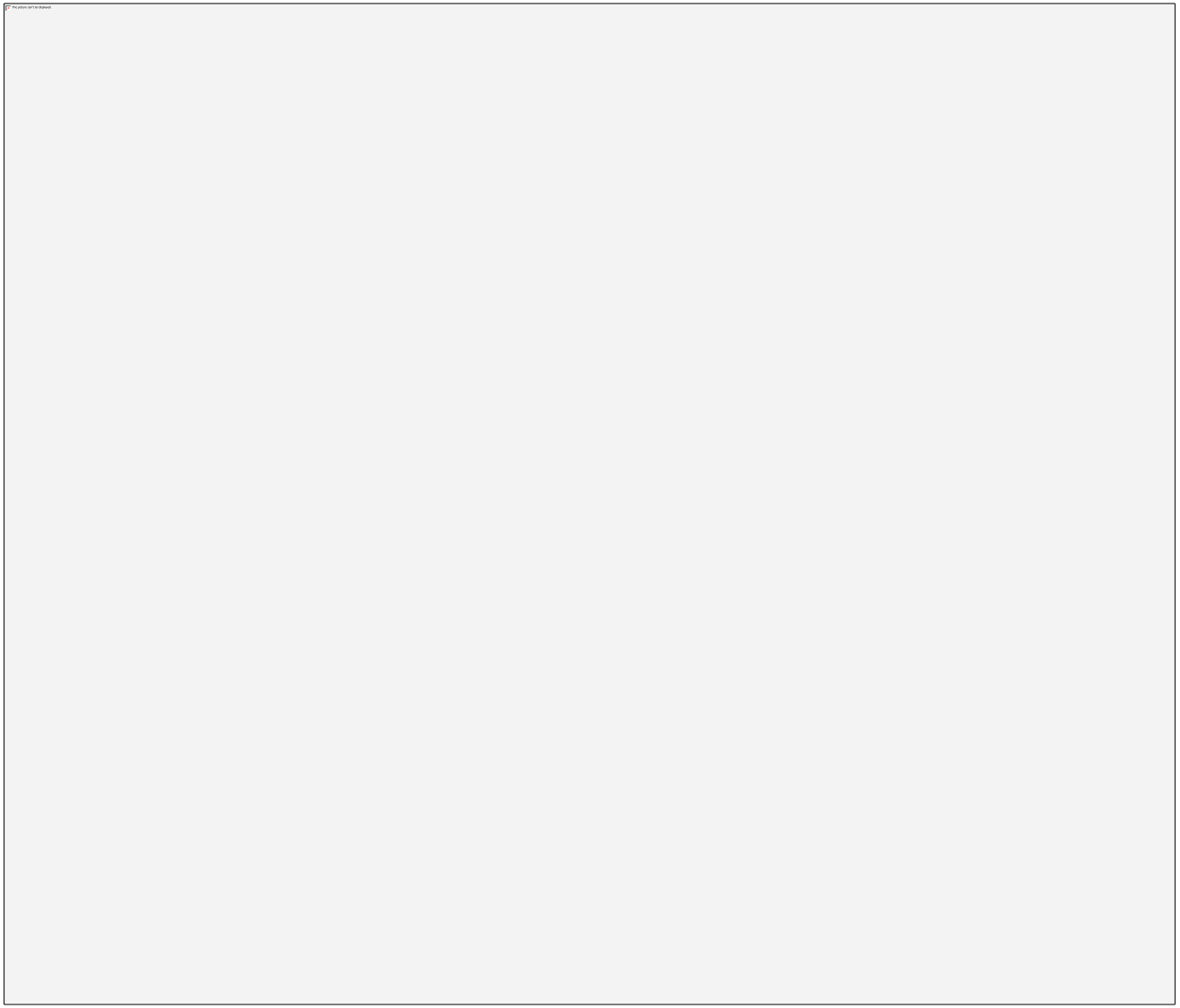


Figure 1.16a

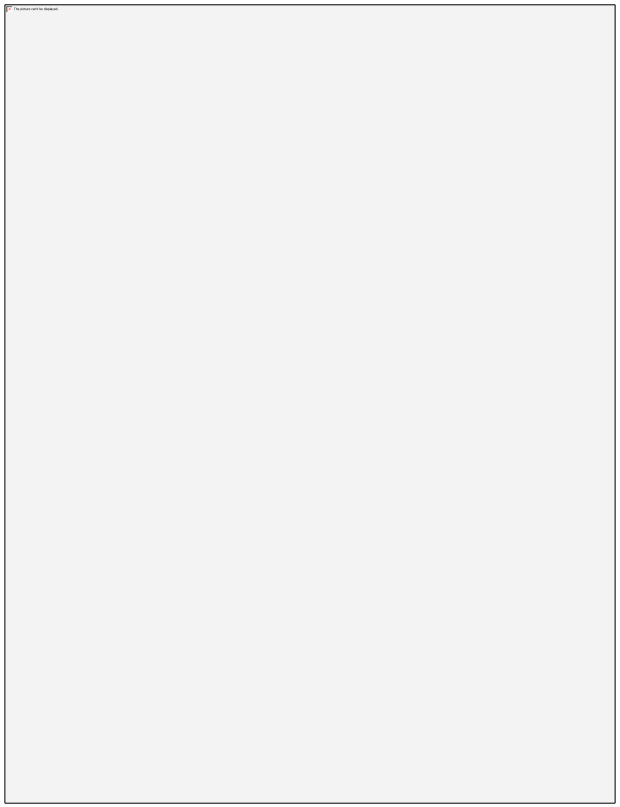


Figure 1.16b

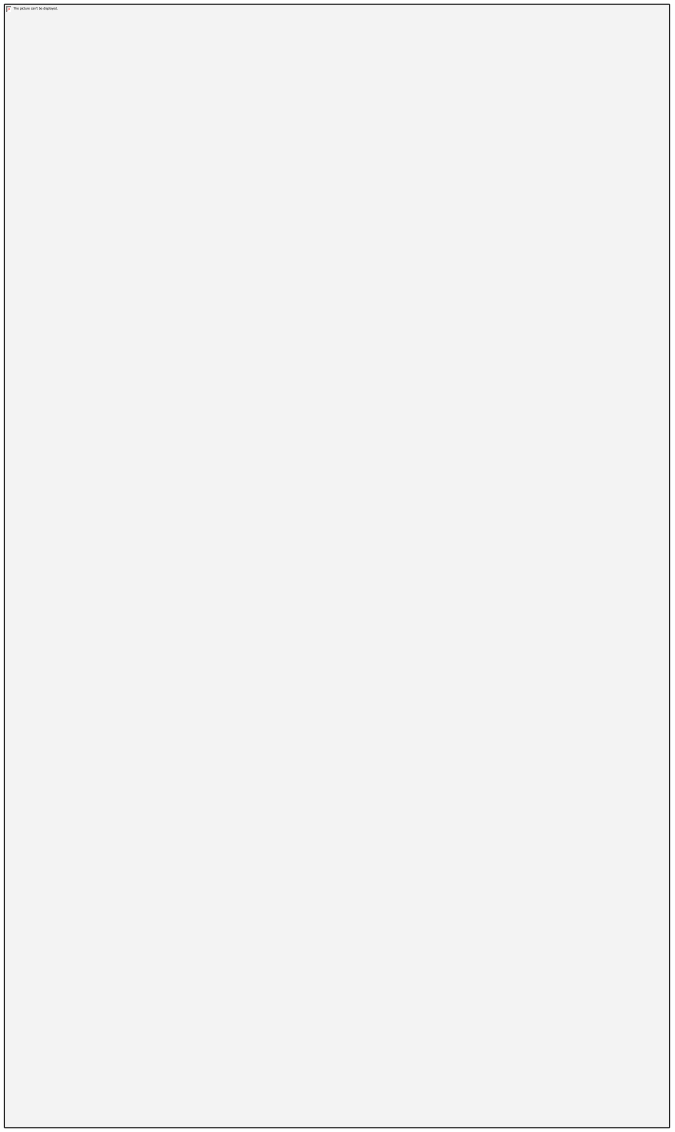


Figure 1.17

Figure 1.17a

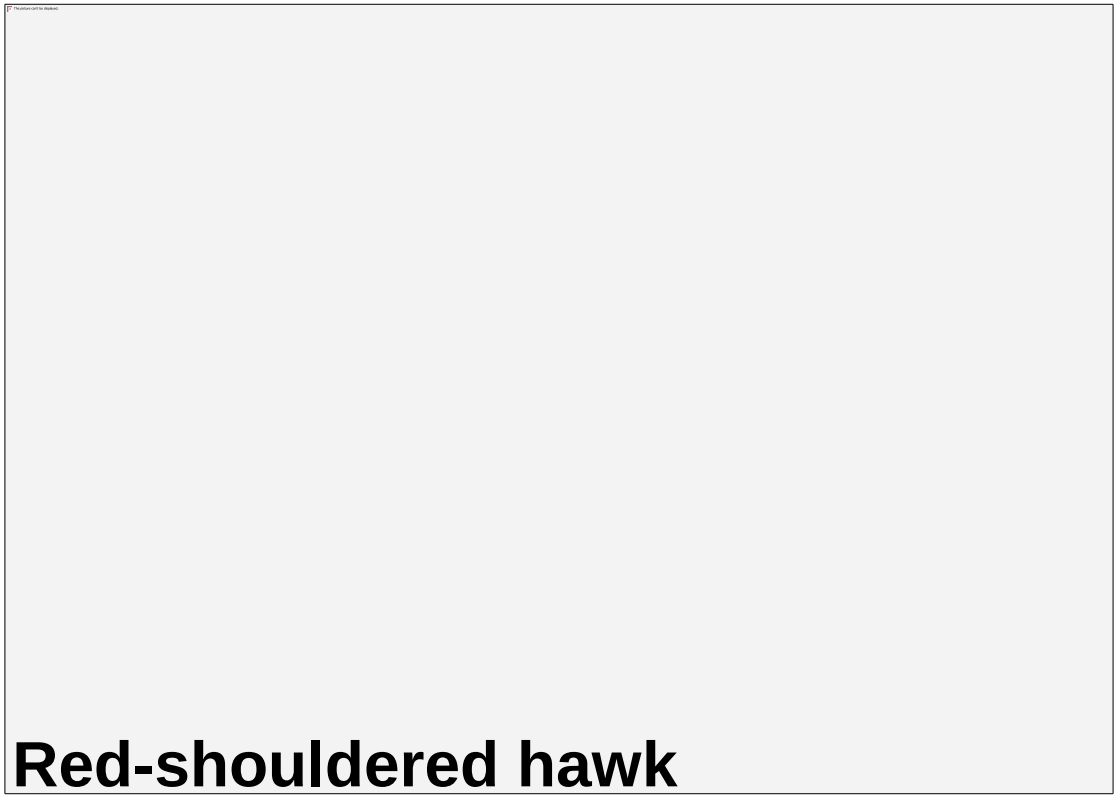


Figure 1.17b

European robin

Figure 1.17c

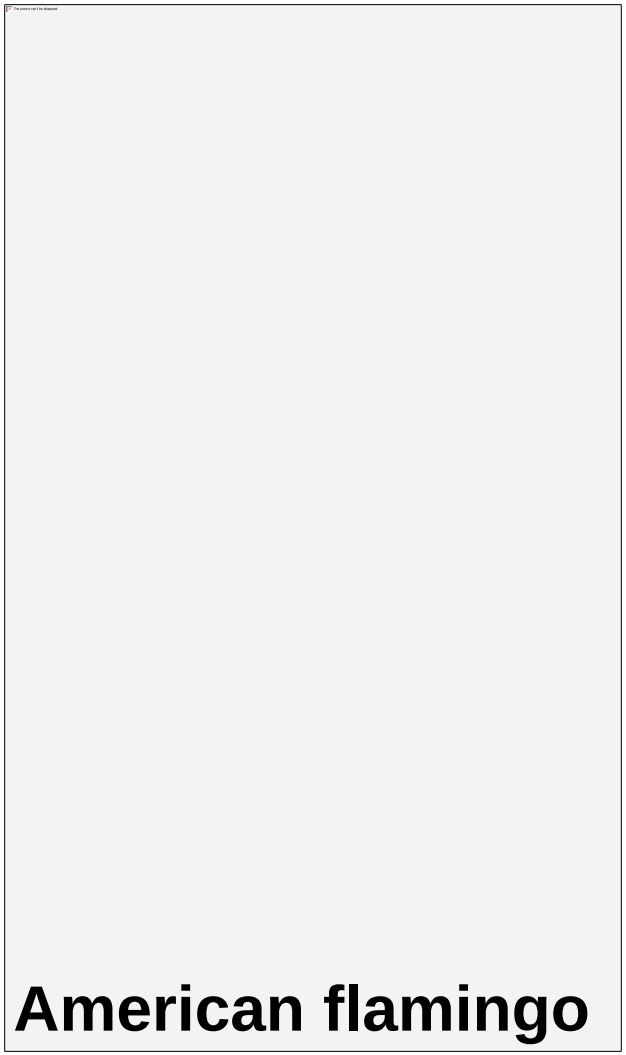
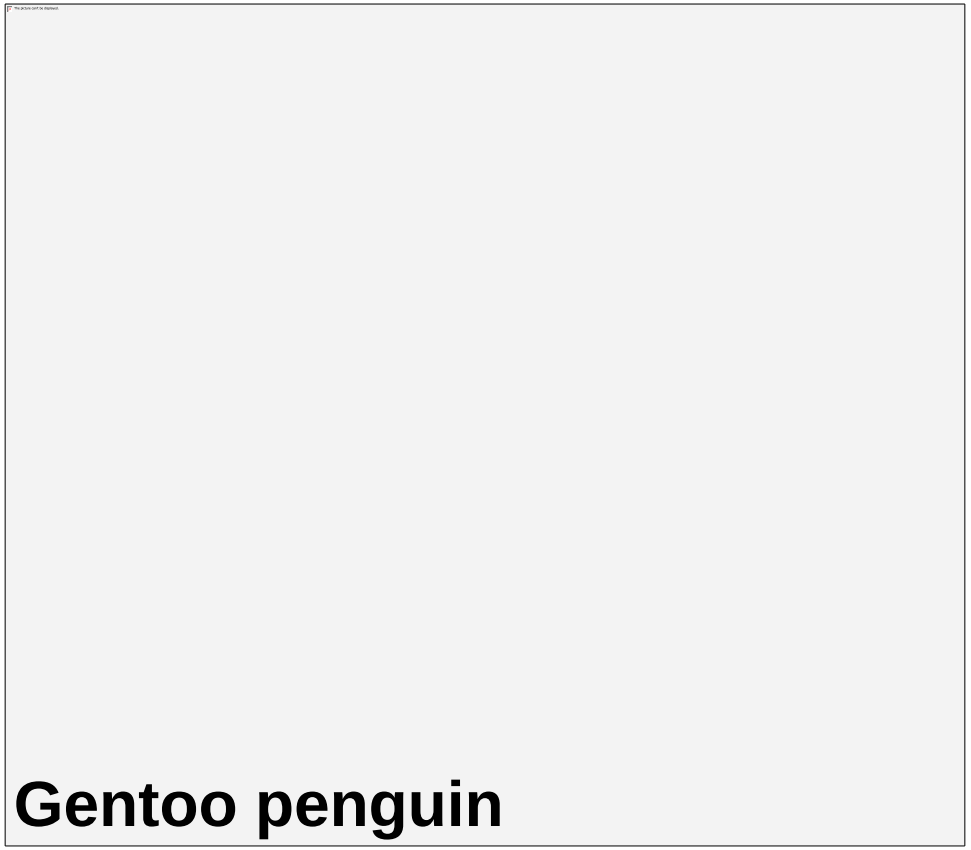


Figure 1.17d



Video: Soaring Hawk

Video: Albatross Courtship Ritual

Video: Blue-footed Boobies Courtship Ritual

Video: Galápagos Islands Overview

Video: Galápagos Marine Iguana

Video: Galápagos Sea Lion

Video: Galápagos Tortoise

- 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 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

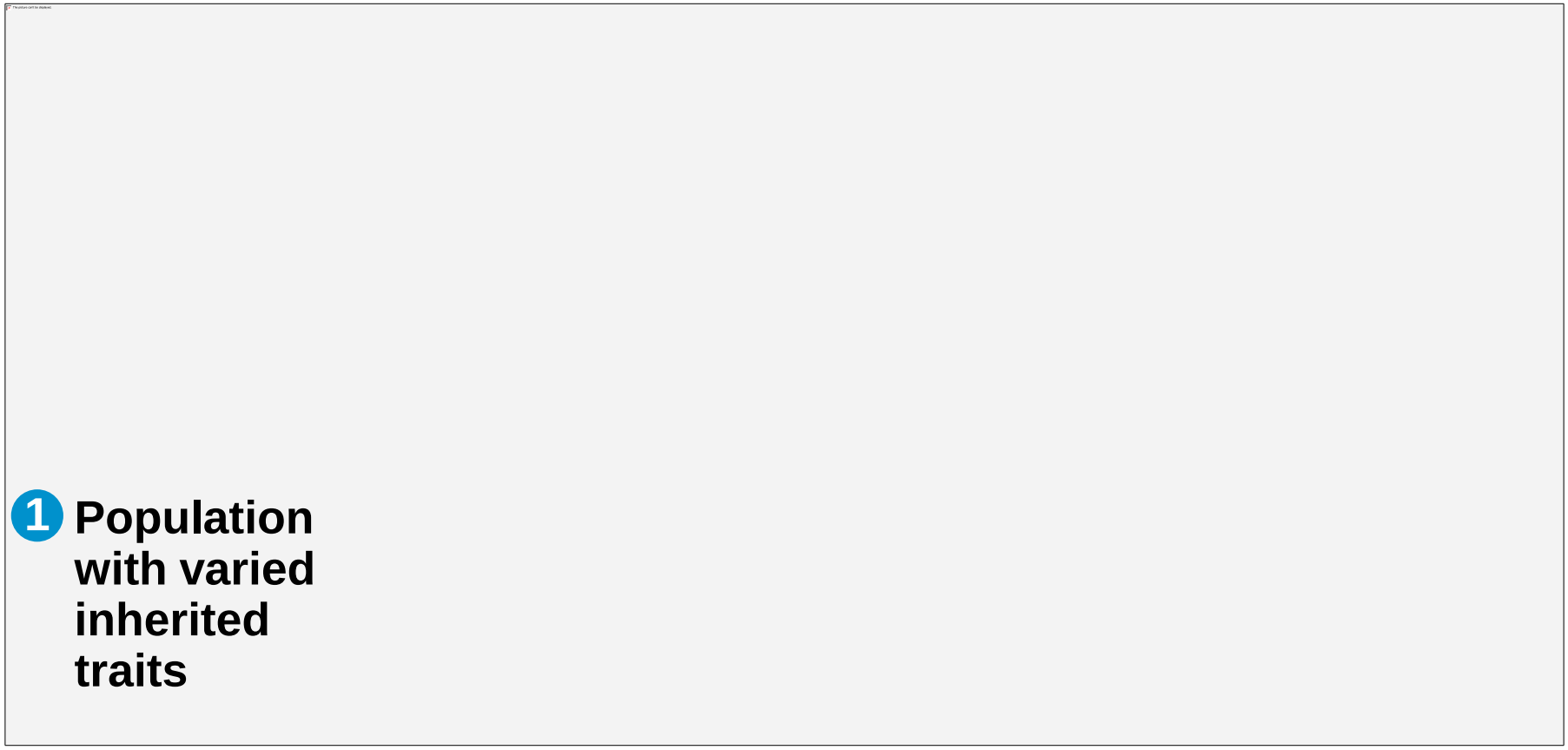
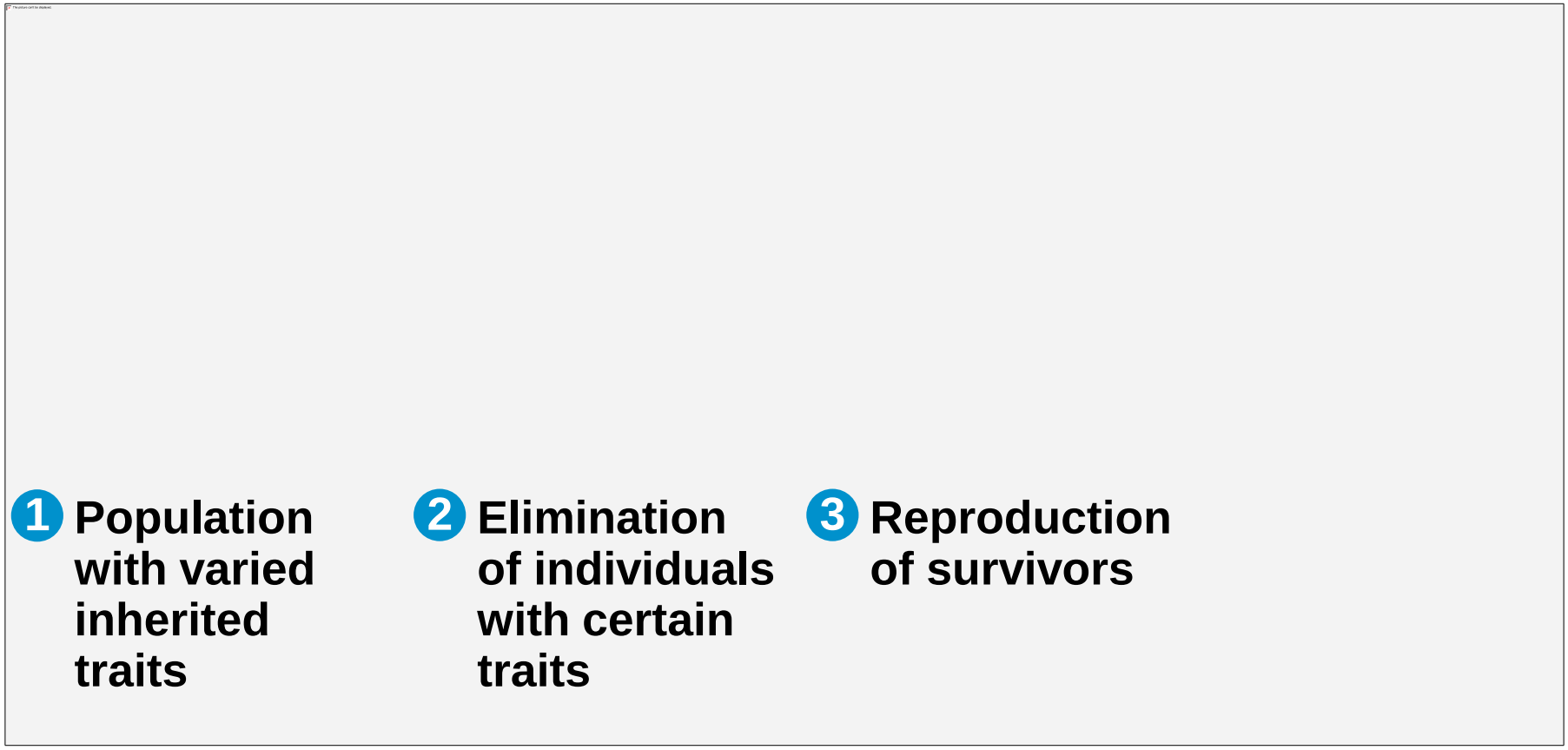


Figure 1.18_2

Figure 1.18_3



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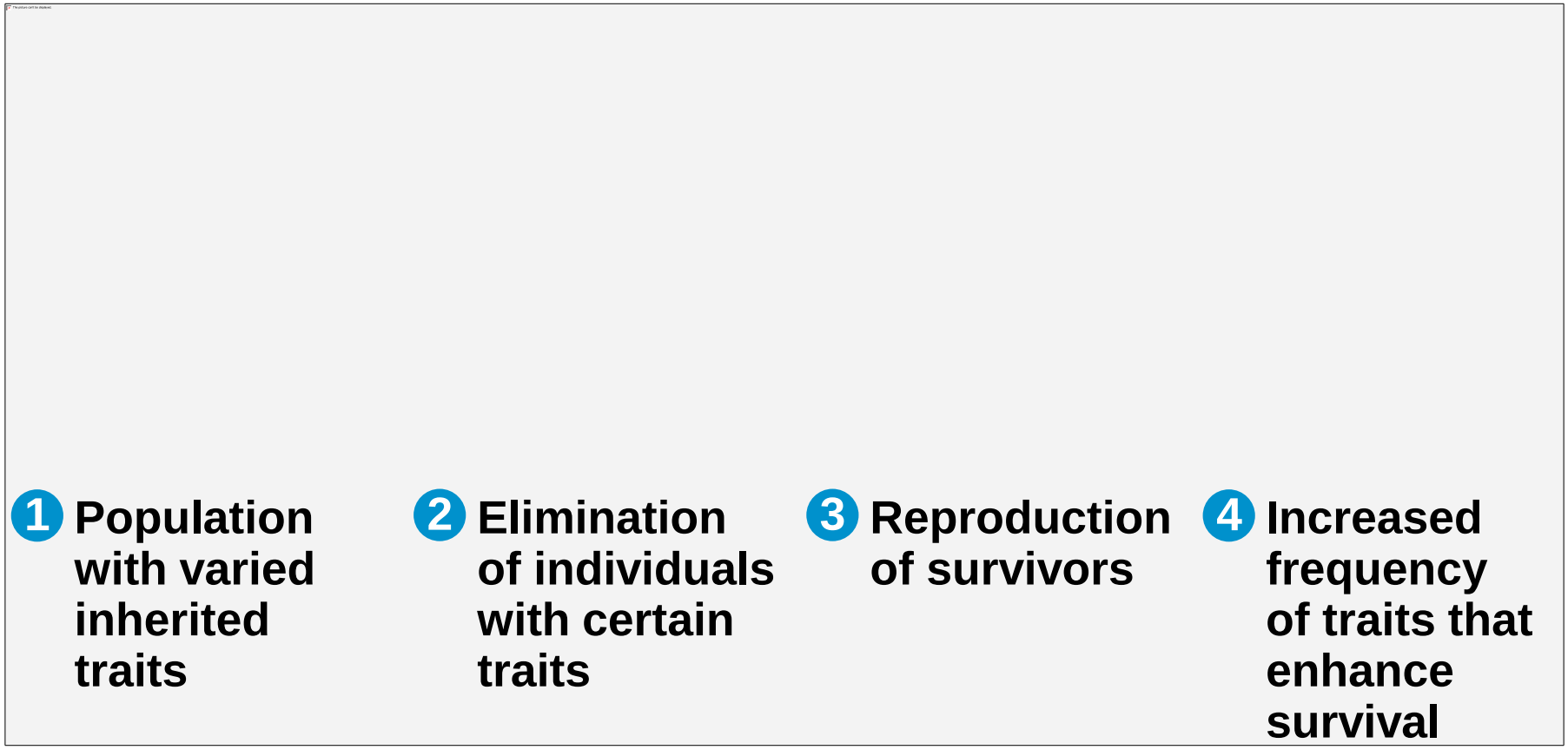


- Natural selection results in the adaptation of organisms to the circumstances of their way of life and their environment
- For example, bat wings are an example of adaptation

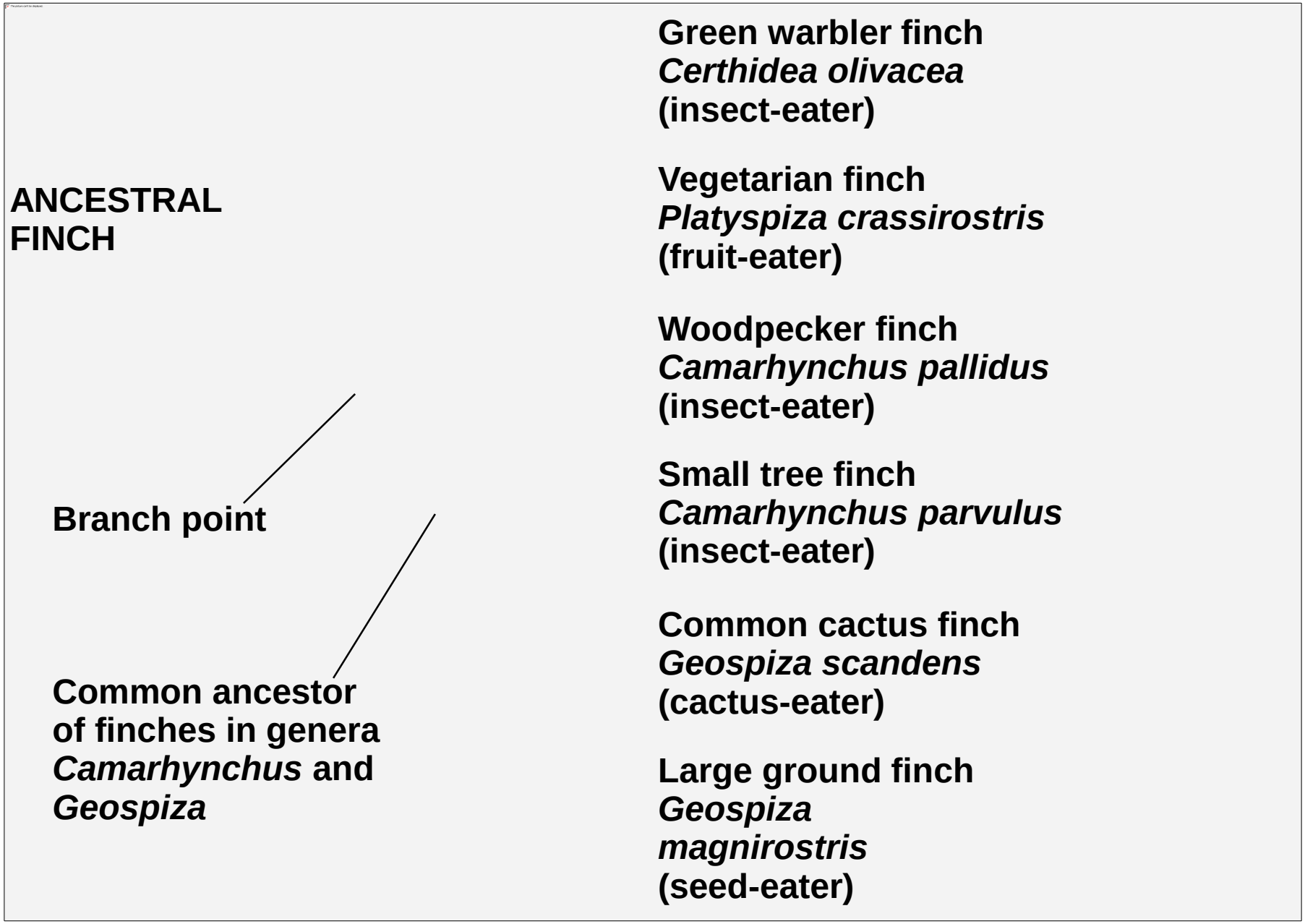
Figure 1.19

The Tree of Life

- The shared anatomy of mammalian limbs reflects the inheritance of the limb structure from a common ancestor
- Fossils provide additional evidence of anatomical unity from 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



Concept 1.3: In studying nature, scientists make observations and 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

- Biologists describe natural structures and processes
- This approach is 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, organized into tables and graphs

Figure 1.21

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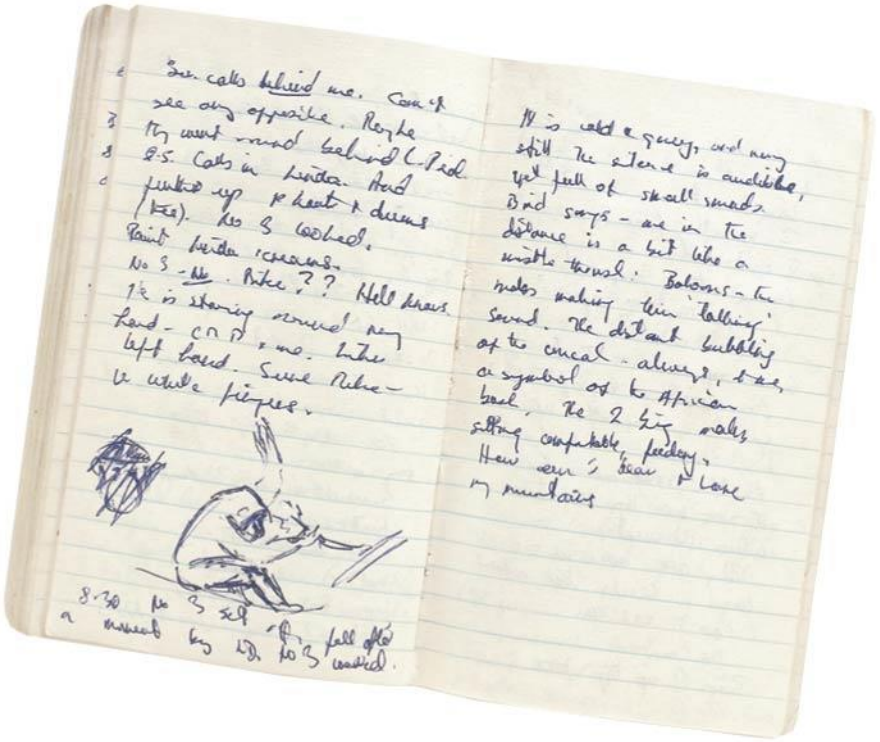
Figure 1.21a

Figure 1.21b



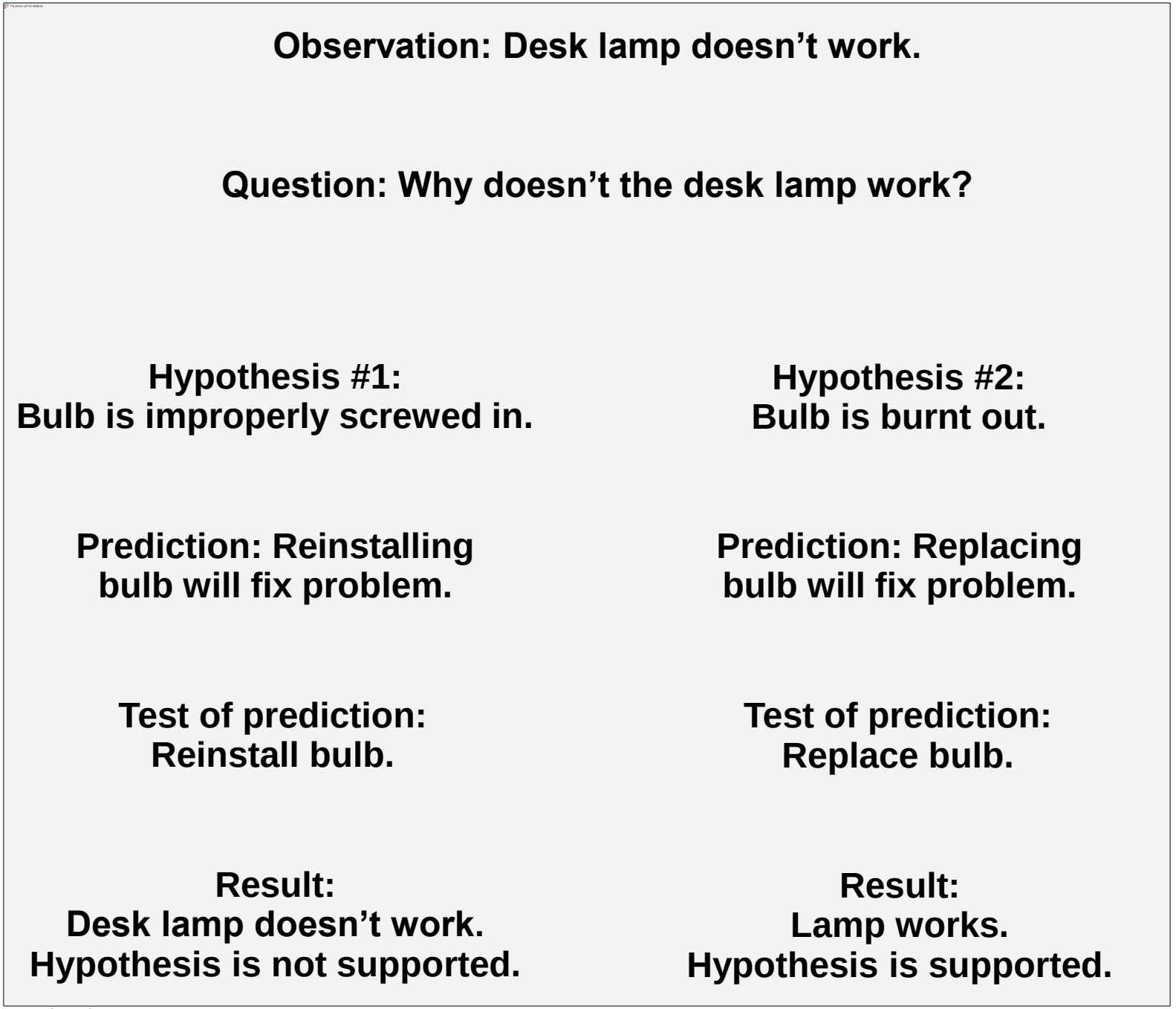
- **Inductive reasoning** draws conclusions through the logical process of induction
- Repeating specific observations can lead to important generalizations
  - For example, “the sun always rises in the east,” or “all organisms are made of cells”

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: Your desk lamp doesn’t work
  - Question: Why doesn’t your desk lamp work?
  - Hypothesis 1: The bulb is not screwed in properly
  - Hypothesis 2: The bulb is burnt out
- Both these hypotheses are testable

Figure 1.22



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

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 and “rethinking” may be necessary partway through the process

Figure 1.23

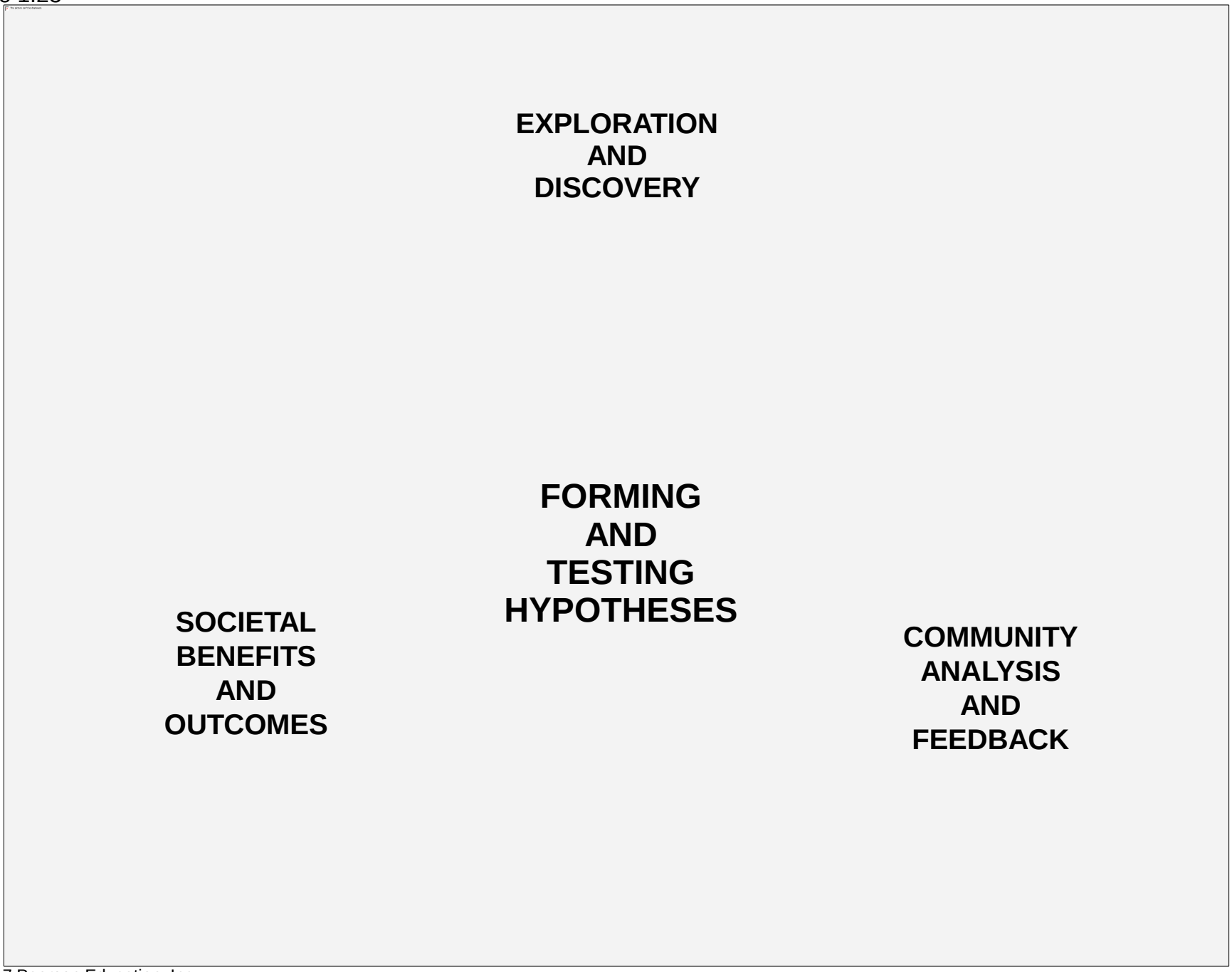
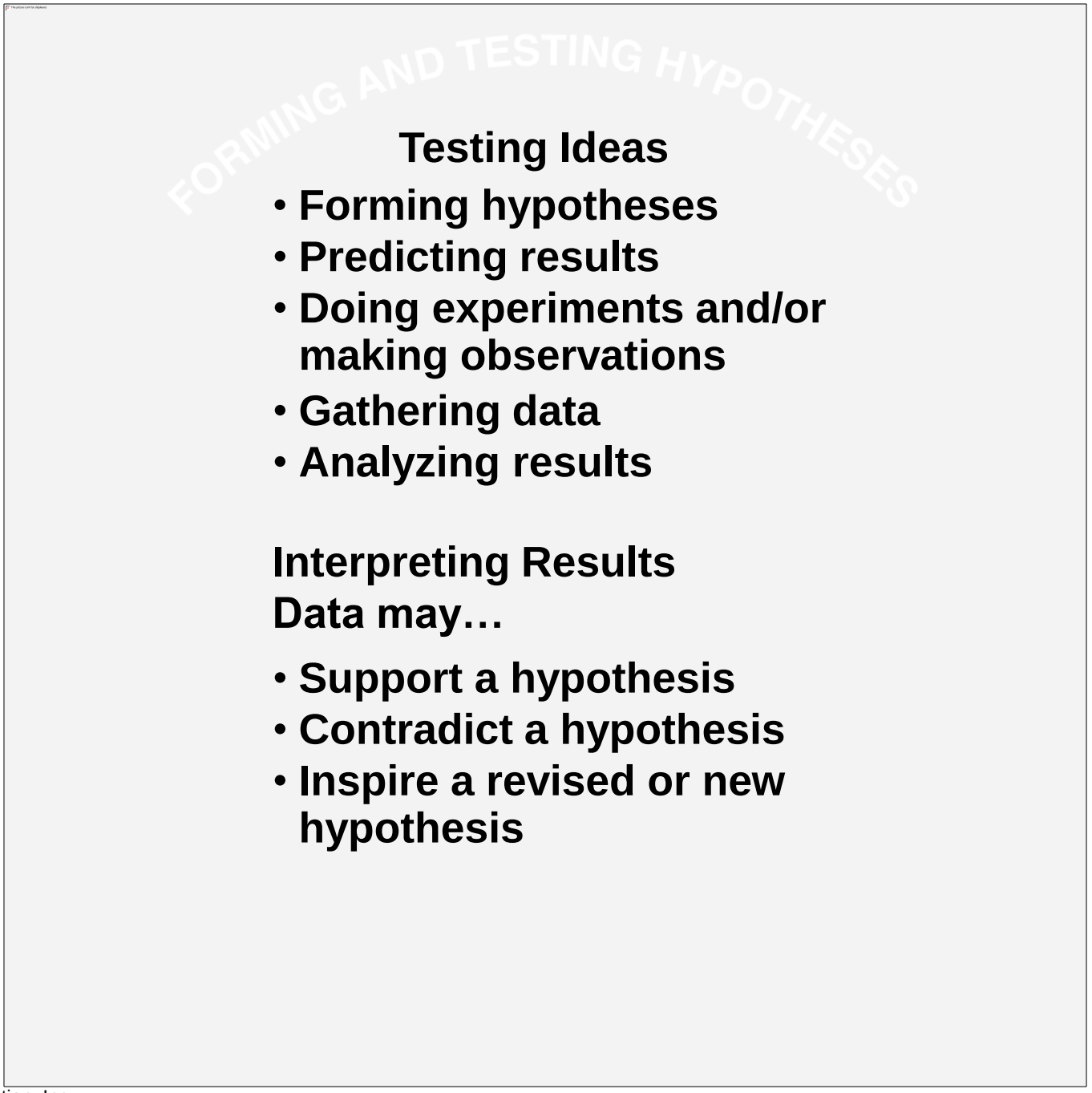


Figure 1.23a



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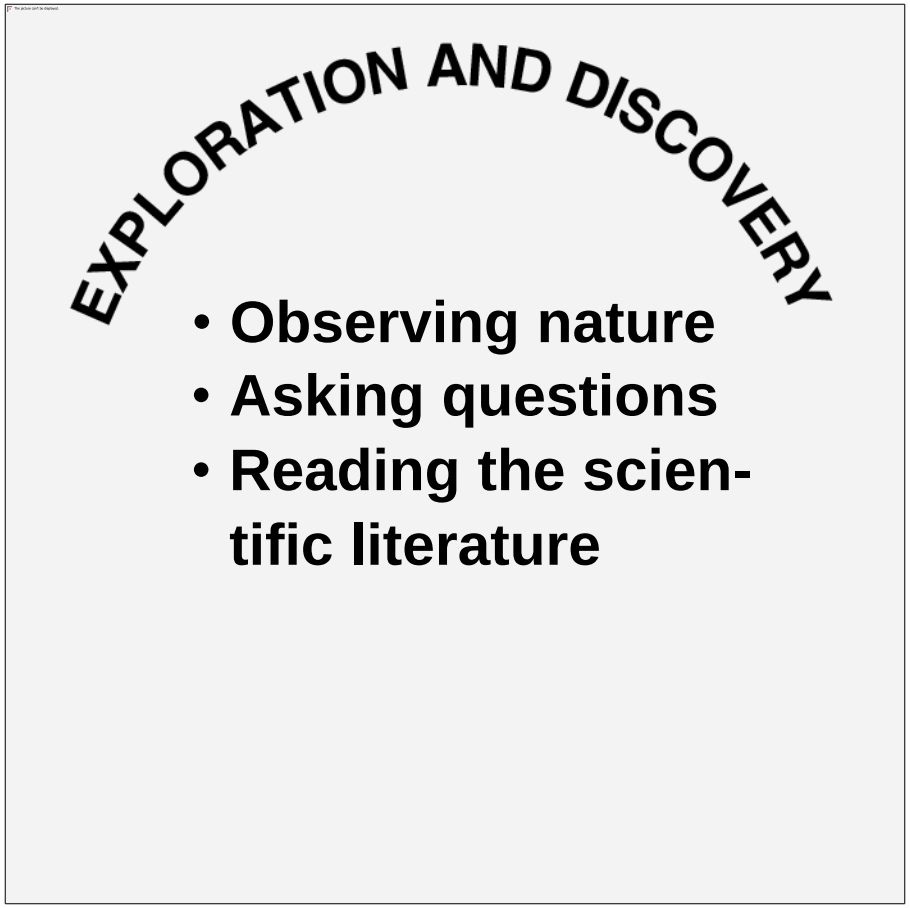


Figure 1.23c

Figure 1.23d

Figure 1.23e

Figure 1.23f

Figure 1.23g

Figure 1.23h

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 belonging to the same species (*Peromyscus polionotus*) but with different color patterns are found in different environments
- The beach mouse lives on white sand dunes with sparse vegetation; the inland mouse lives on darker soil

Figure 1.24

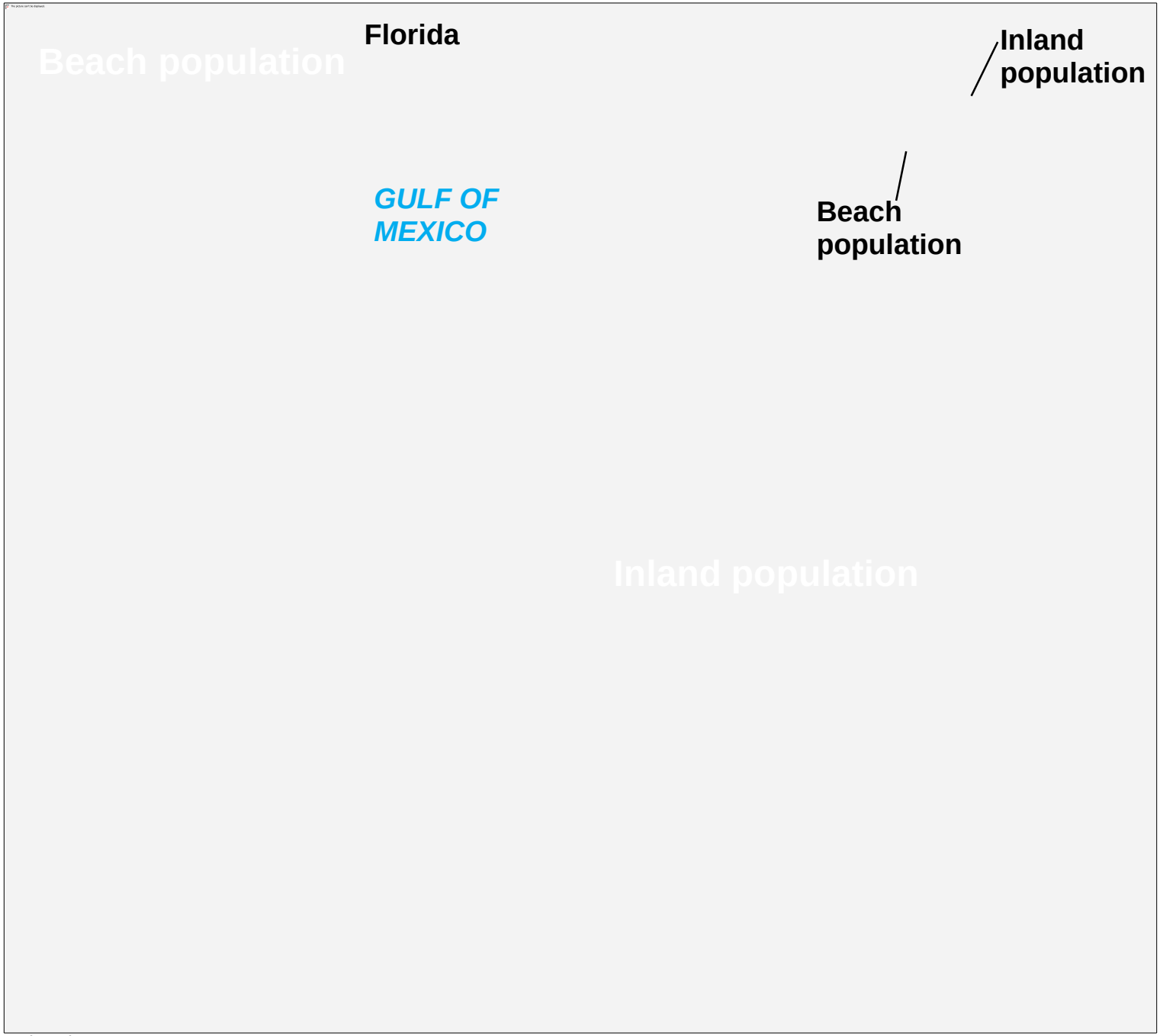


Figure 1.24a

Figure 1.24b

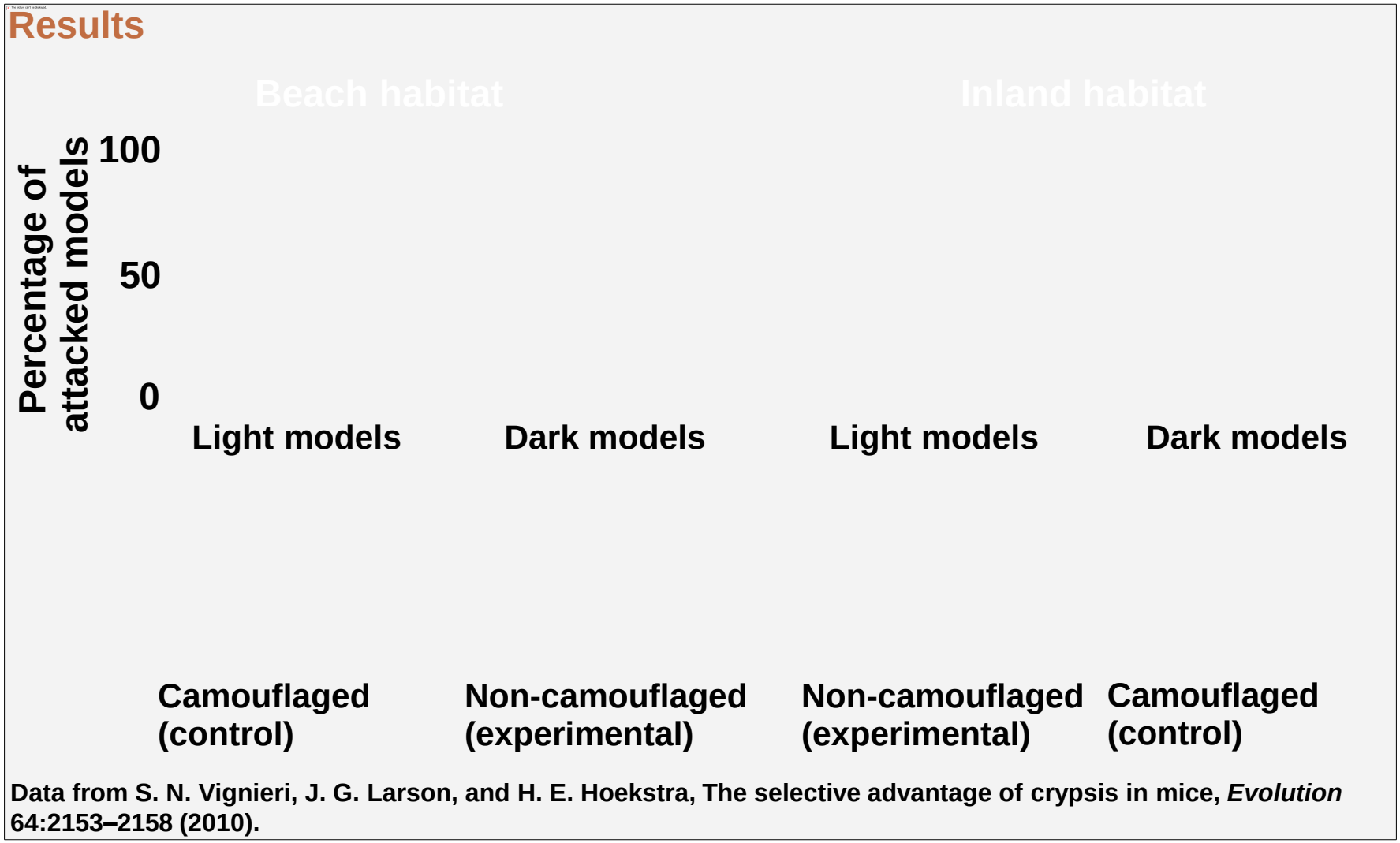
Figure 1.24c

Figure 1.24d

- 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

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).

Figure 1.25a

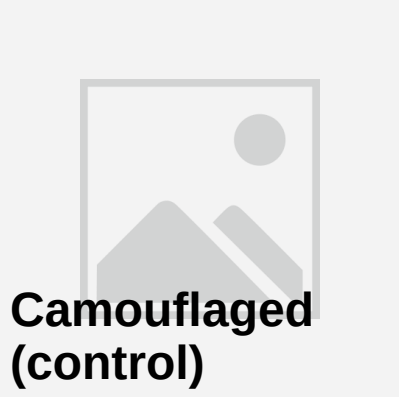
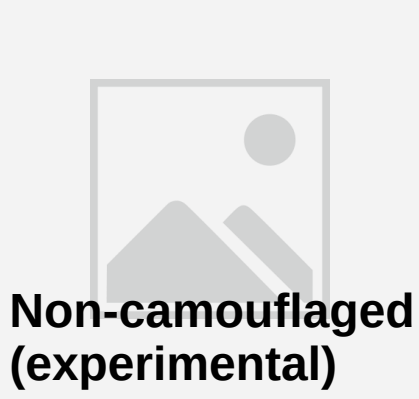


Figure 1.25b



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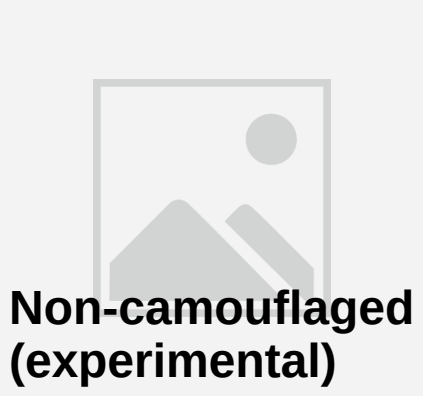

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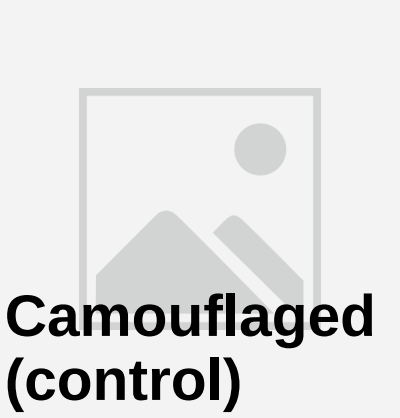


Experimental Variables and Controls

- 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, while 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, and can lead to 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

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*)

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
- 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
- Debates on technology center more on “should we do it” than “can we do it”

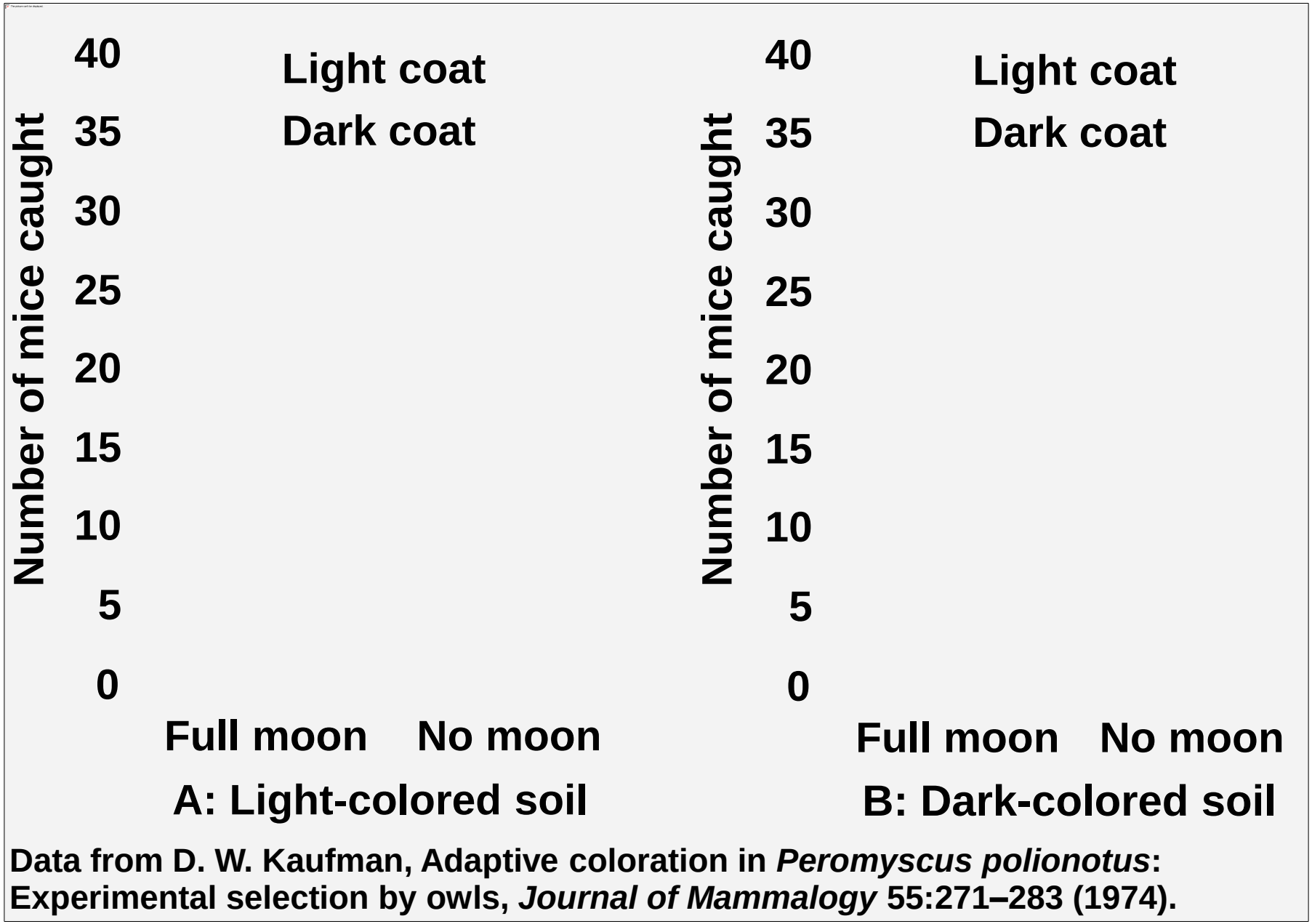
- Ethical issues can arise from new technology, but have as much to do with politics, economics, and cultural values as with science and technology

Figure 1.26

The Value of Diverse Viewpoints in Science

- Many important inventions have occurred where different cultures and ideas mix
  - For example, the printing press relied on innovations from China (paper and ink) and Europe (mass production in mills)
- Science benefits from diverse views from different racial and ethnic groups, and from both women and men
- The more voices heard, the more robust, valuable, and productive the scientific interchange

Figure 1.UN02a



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

Figure 1.UN02b

Figure 1.UN03

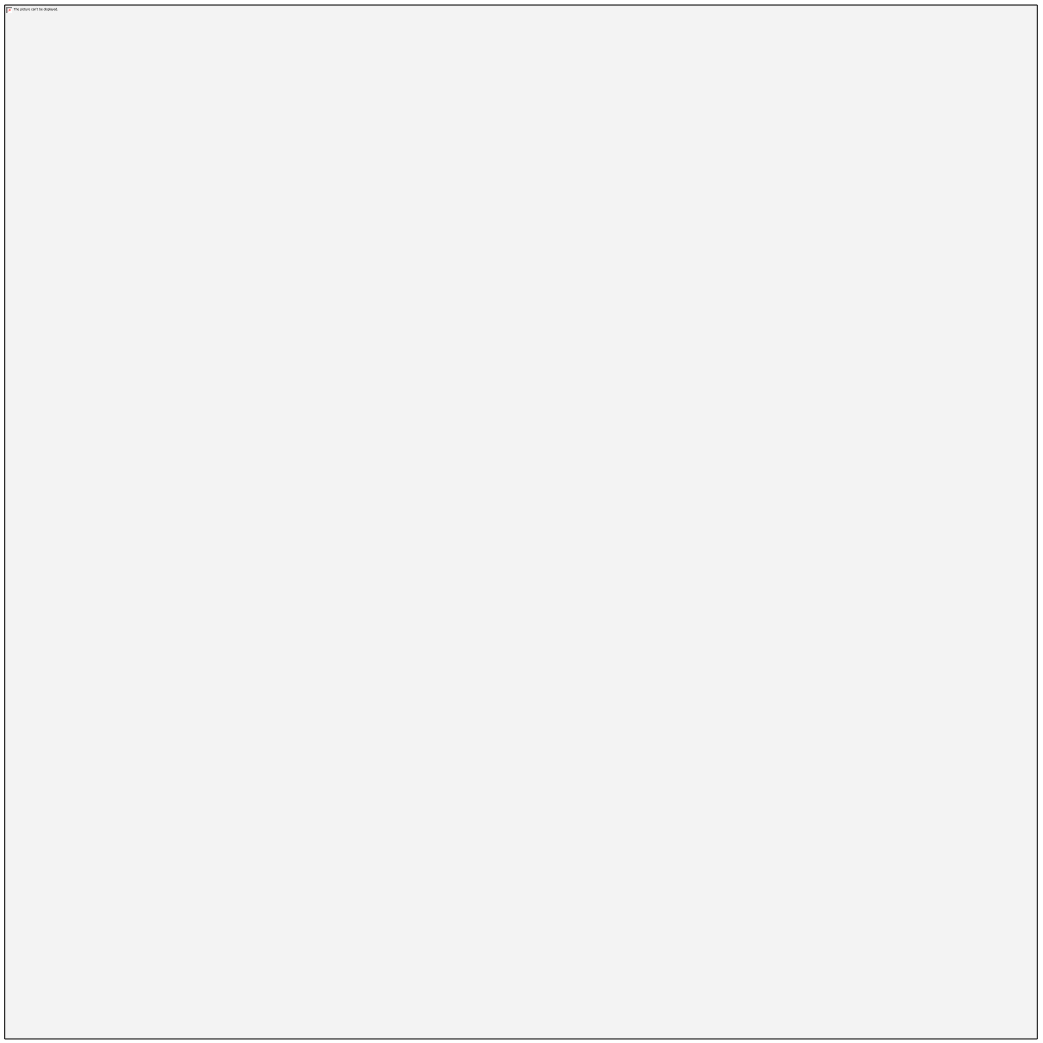


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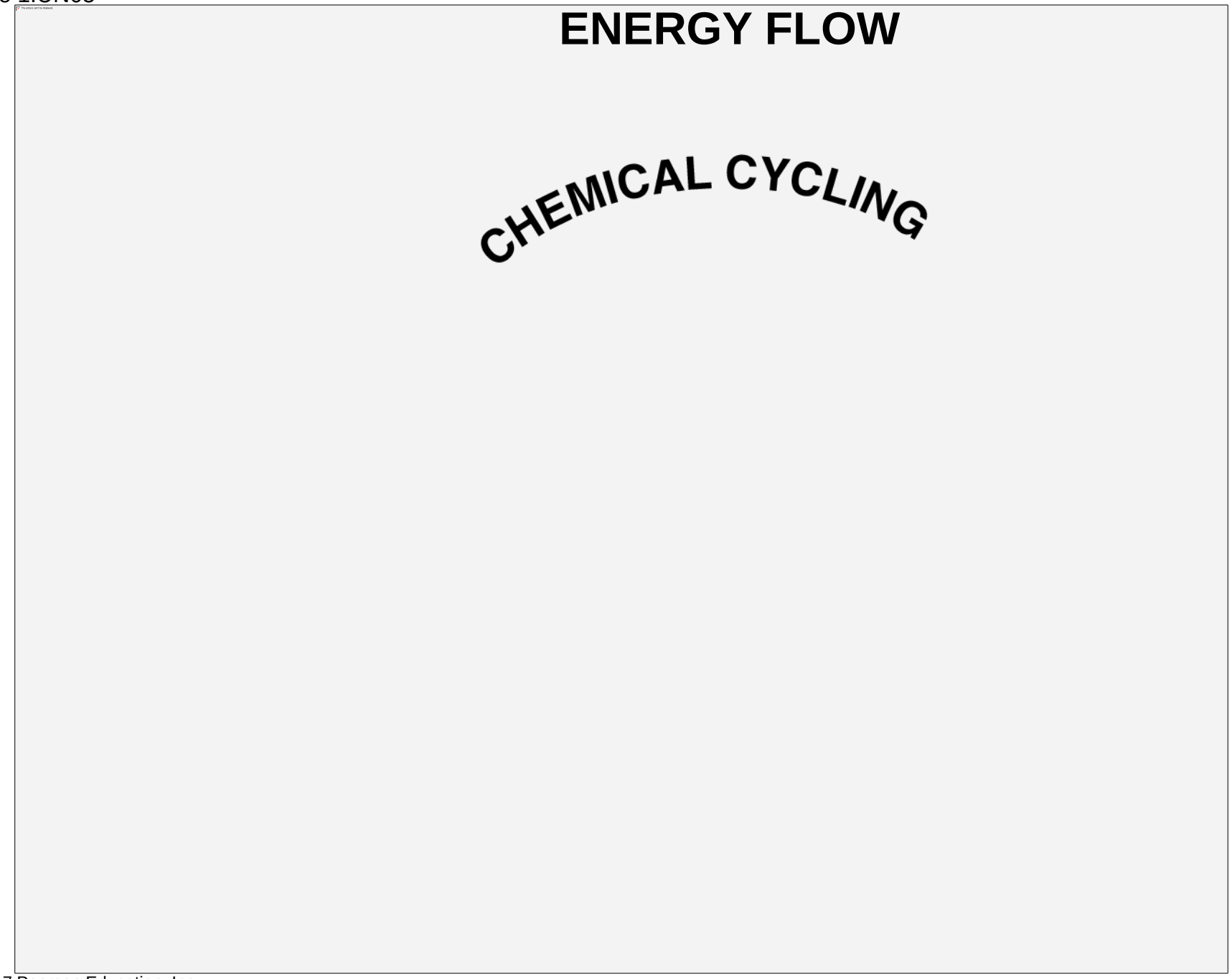
Figure 1.UN05



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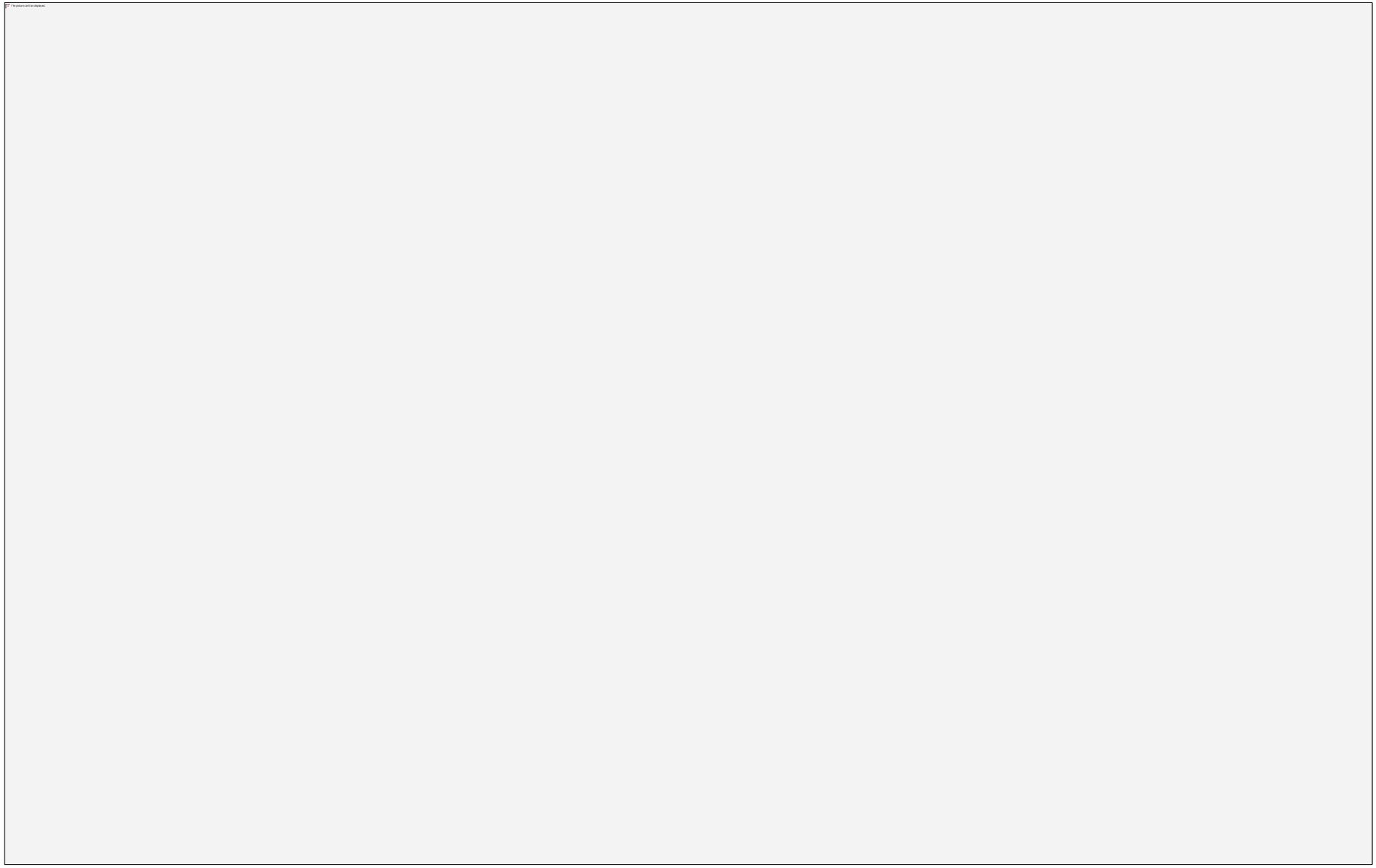

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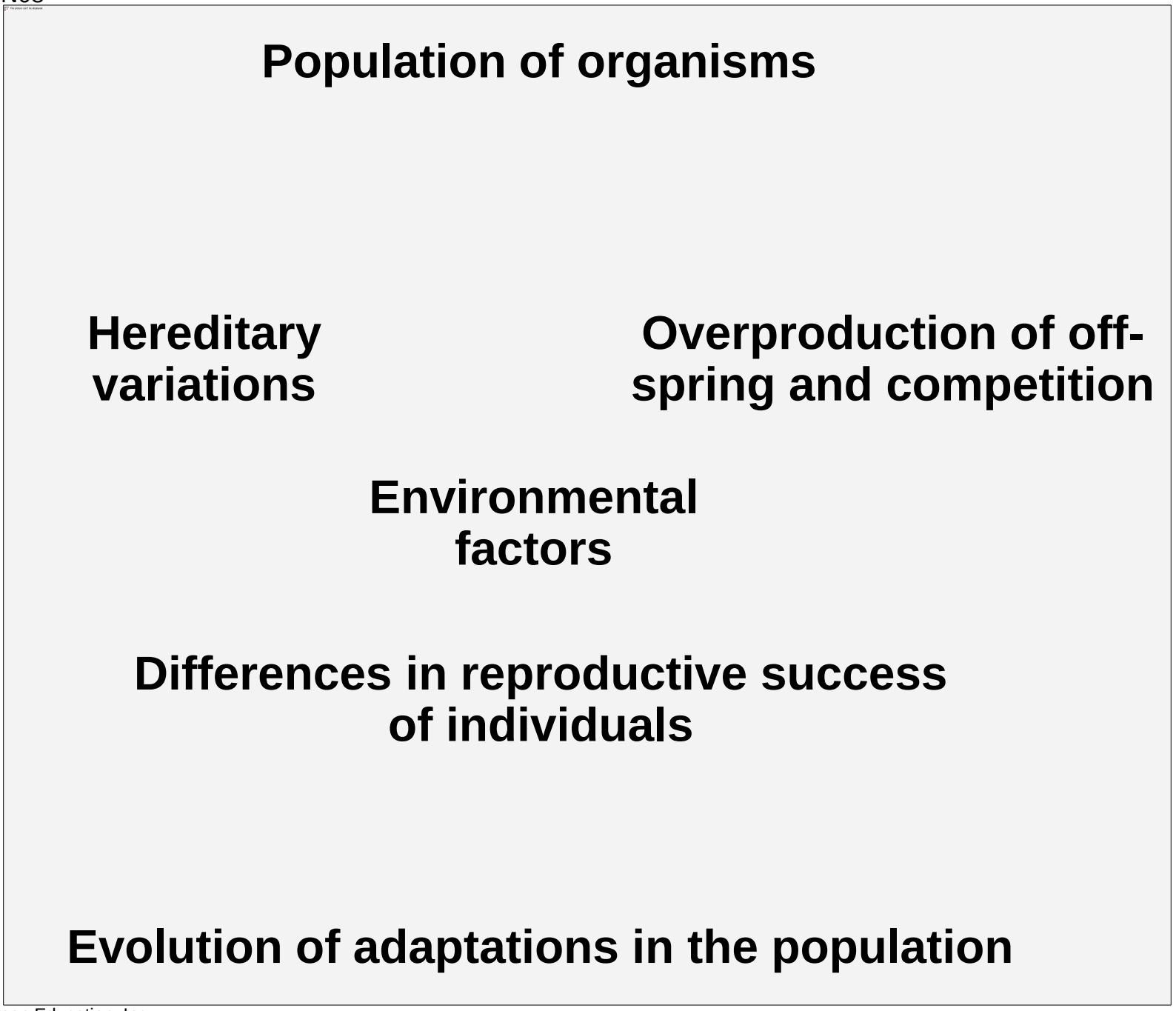

Figure 1.UN09