

# 1 | THE STUDY OF LIFE



**Figure 1.1** This NASA image is a composite of several satellite-based views of Earth. To make the whole-Earth image, NASA scientists combine observations of different parts of the planet. (credit: NASA/GSFC/NOAA/USGS)

## Chapter Outline

**1.1: The Science of Biology**

**1.2: Themes and Concepts of Biology**

## Introduction

Viewed from space, Earth offers no clues about the diversity of life it harbors. The first forms of life on Earth are thought to be microorganisms that existed for billions of years in the ocean before plants and animals appeared. The mammals, birds, and flowers that we see in modern times are mostly “recent” species, originating 130 to 200 million years ago. In fact, only in the last 200,000 years have humans started looking like we do today.

Organisms evolve in response to each other. One of the best examples is disease-causing organisms, which have to adapt to overcome the defenses of the organisms they infect. One such organism that has evolved to specialize in infection in humans is *Plasmodium*, the organism that causes malaria. Biologists use the process of science to learn about the world and the organisms living in it. For example, people have suspected for quite some time that people with blood type O are less likely to die from severe malaria. Now, a team of scientists have been able to explain why. By examining data from several experiments, and by using both inductive and deductive reasoning, the scientists concluded that A and B type blood reacts with a protein excreted by *Plasmodium*. This reaction causes severe illness. However, type O blood does not react with the protein. You can **read more** (<http://openstaxcollege.org/l/32plasmodium>) about the response of type A and B blood groups to infection by *Plasmodium*.

## 1.1 | The Science of Biology

In this section, you will explore the following questions:

- What are the characteristics shared by the natural sciences?
- What are the steps of the scientific method?

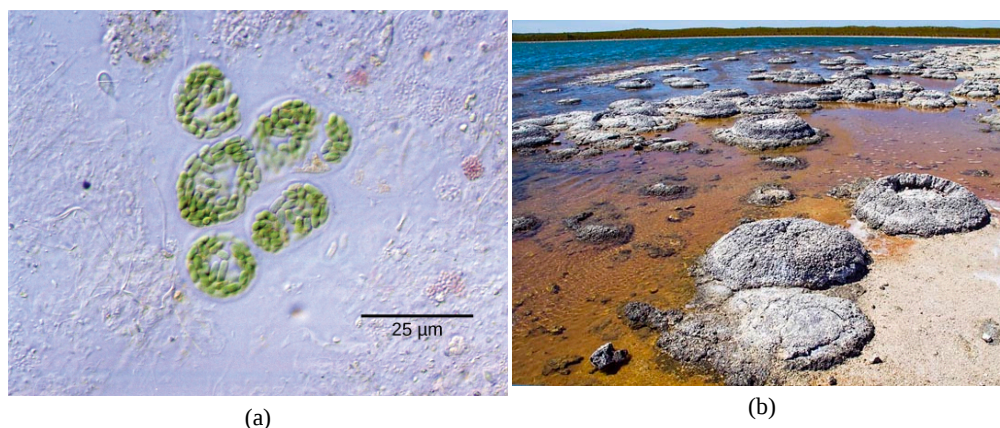
## Connection for AP<sup>®</sup> courses

Biology is the science that studies living organisms and their interactions with one another and with their environment. The process of science attempts to describe and understand the nature of the universe by rational means. Science has many fields; those fields related to the physical world, including biology, are considered natural sciences. All of the natural sciences follow the laws of chemistry and physics. For example, when studying biology, you must remember living organisms obey the laws of thermodynamics while using free energy and matter from the environment to carry out life processes that are explored in later chapters, such as metabolism and reproduction.

Two types of logical reasoning are used in science: inductive reasoning and deductive reasoning. **Inductive reasoning** uses particular results to produce general scientific principles. **Deductive reasoning** uses logical thinking to predict results by applying scientific principles or practices. The scientific method is a step-by-step process that consists of: making observations, defining a problem, posing hypotheses, testing these hypotheses by designing and conducting investigations, and drawing conclusions from data and results. Scientists then communicate their results to the scientific community. Scientific theories are subject to revision as new information is collected.

The content presented in this section supports the Learning Objectives outlined in Big Idea 2 of the AP<sup>®</sup> Biology Curriculum Framework. The Learning Objectives merge Essential Knowledge content with one or more of the seven Science Practices. These objectives provide a transparent foundation for the AP<sup>®</sup> Biology course, along with inquiry-based laboratory experiences, instructional activities, and AP<sup>®</sup> Exam questions.

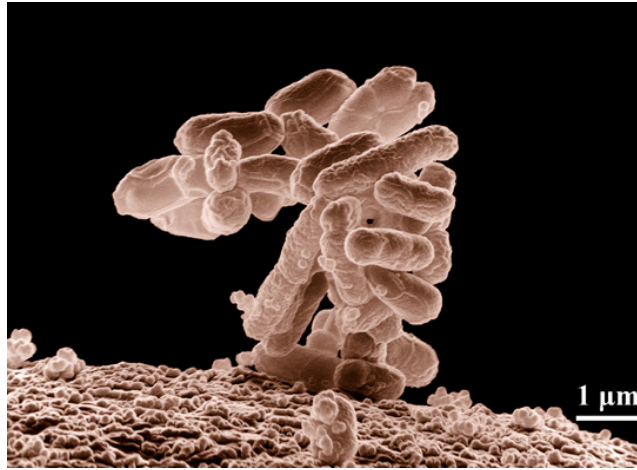
|                                   |  |
|-----------------------------------|--|
| <b>Big Idea 2</b>                 | Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis. |
| <b>Enduring Understanding 2.A</b> | Growth, reproduction and maintenance of living systems require free energy and matter.   |
| <b>Essential Knowledge</b>        | <b>2.A.1</b> All living systems require constant input of free energy.   |
| <b>Science Practice</b>           | <b>6.4</b> The student can make claims and predictions about natural phenomena based on scientific theories and models           |
| <b>Learning Objectives</b>        | <b>2.3</b> The student is able to predict how changes in free energy availability affect organisms, populations and ecosystems.  |



**Figure 1.2** Formerly called blue-green algae, these (a) cyanobacteria, shown here at 300x magnification under a light microscope, are some of Earth's oldest life forms. These (b) stromatolites along the shores of Lake Thetis in Western Australia are ancient structures formed by the layering of cyanobacteria in shallow waters. (credit a: modification of work by NASA; credit b: modification of work by Ruth Ellison; scale-bar data from Matt Russell)

What is biology? In simple terms, **biology** is the study of living organisms and their interactions with one another and their environments. This is a very broad definition because the scope of biology is vast. Biologists may study anything from the microscopic or submicroscopic view of a cell to ecosystems and the whole living planet (Figure 1.2). Listening to the daily news, you will quickly realize how many aspects of biology are discussed every day. For example, recent news topics

include *Escherichia coli* (Figure 1.3) outbreaks in spinach and *Salmonella* contamination in peanut butter. On a global scale, many researchers are committed to finding ways to protect the planet, solve environmental issues, and reduce the effects of climate change. All of these diverse endeavors are related to different facets of the discipline of biology.



**Figure 1.3** *Escherichia coli* (*E. coli*) bacteria, seen in this scanning electron micrograph, are normal residents of our digestive tracts that aid in the absorption of vitamin K and other nutrients. However, virulent strains are sometimes responsible for disease outbreaks. (credit: Eric Erbe, digital colorization by Christopher Pooley, both of USDA, ARS, EMU)

## The Process of Science

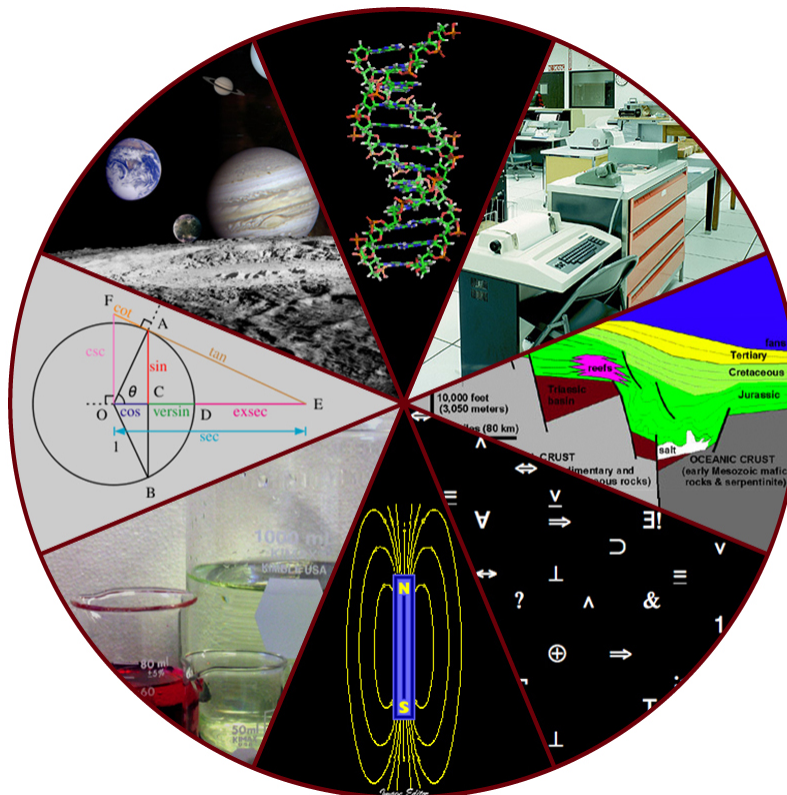
Biology is a science, but what exactly is science? What does the study of biology share with other scientific disciplines? **Science** (from the Latin *scientia*, meaning “knowledge”) can be defined as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that the application of the scientific method plays a major role in science. The **scientific method** is a method of research with defined steps that include experiments and careful observation.

The steps of the scientific method will be examined in detail later, but one of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A **hypothesis** is a suggested explanation for an event, which can be tested. Although using the scientific method is inherent to science, it is inadequate in determining what science is. This is because it is relatively easy to apply the scientific method to disciplines such as physics and chemistry, but when it comes to disciplines like archaeology, psychology, and geology, the scientific method becomes less applicable as it becomes more difficult to repeat experiments.

These areas of study are still sciences, however. Consider archaeology—even though one cannot perform repeatable experiments, hypotheses may still be supported. For instance, an archaeologist can hypothesize that an ancient culture existed based on finding a piece of pottery. Further hypotheses could be made about various characteristics of this culture, and these hypotheses may be found to be correct or false through continued support or contradictions from other findings. A hypothesis may become a verified theory. A **theory** is a tested and confirmed explanation for observations or phenomena. Science may be better defined as fields of study that attempt to comprehend the nature of the universe.

### Natural Sciences

What would you expect to see in a museum of natural sciences? Frogs? Plants? Dinosaur skeletons? Exhibits about how the brain functions? A planetarium? Gems and minerals? Or, maybe all of the above? Science includes such diverse fields as astronomy, biology, computer sciences, geology, logic, physics, chemistry, and mathematics (Figure 1.4). However, those fields of science related to the physical world and its phenomena and processes are considered **natural sciences**. Thus, a museum of natural sciences might contain any of the items listed above.



**Figure 1.4** The diversity of scientific fields includes astronomy, biology, computer science, geology, logic, physics, chemistry, mathematics, and many other fields. (credit: "Image Editor"/Flickr)

There is no complete agreement when it comes to defining what the natural sciences include, however. For some experts, the natural sciences are astronomy, biology, chemistry, earth science, and physics. Other scholars choose to divide natural sciences into **life sciences**, which study living things and include biology, and **physical sciences**, which study nonliving matter and include astronomy, geology, physics, and chemistry. Some disciplines such as biophysics and biochemistry build on both life and physical sciences and are interdisciplinary. Natural sciences are sometimes referred to as “hard science” because they rely on the use of quantitative data; social sciences that study society and human behavior are more likely to use qualitative assessments to drive investigations and findings.

Not surprisingly, the natural science of biology has many branches or subdisciplines. Cell biologists study cell structure and function, while biologists who study anatomy investigate the structure of an entire organism. Those biologists studying physiology, however, focus on the internal functioning of an organism. Some areas of biology focus on only particular types of living things. For example, botanists explore plants, while zoologists specialize in animals.

### Scientific Reasoning

One thing is common to all forms of science: an ultimate goal “to know.” Curiosity and inquiry are the driving forces for the development of science. Scientists seek to understand the world and the way it operates. To do this, they use two methods of logical thinking: inductive reasoning and deductive reasoning.

Inductive reasoning is a form of logical thinking that uses related observations to arrive at a general conclusion. This type of reasoning is common in descriptive science. A life scientist such as a biologist makes observations and records them. These data can be qualitative or quantitative, and the raw data can be supplemented with drawings, pictures, photos, or videos. From many observations, the scientist can infer conclusions (inductions) based on evidence. Inductive reasoning involves formulating generalizations inferred from careful observation and the analysis of a large amount of data. Brain studies provide an example. In this type of research, many live brains are observed while people are doing a specific activity, such as viewing images of food. The part of the brain that “lights up” during this activity is then predicted to be the part controlling the response to the selected stimulus, in this case, images of food. The “lighting up” of the various areas of the brain is caused by excess absorption of radioactive sugar derivatives by active areas of the brain. The resultant increase in radioactivity is observed by a scanner. Then, researchers can stimulate that part of the brain to see if similar responses result.

Deductive reasoning or deduction is the type of logic used in hypothesis-based science. In deductive reason, the pattern of thinking moves in the opposite direction as compared to inductive reasoning. Deductive reasoning is a form of logical

thinking that uses a general principle or law to forecast specific results. From those general principles, a scientist can extrapolate and predict the specific results that would be valid as long as the general principles are valid. Studies in climate change can illustrate this type of reasoning. For example, scientists may predict that if the climate becomes warmer in a particular region, then the distribution of plants and animals should change. These predictions have been made and tested, and many such changes have been found, such as the modification of arable areas for agriculture, with change based on temperature averages.

Both types of logical thinking are related to the two main pathways of scientific study: descriptive science and hypothesis-based science. **Descriptive (or discovery) science**, which is usually inductive, aims to observe, explore, and discover, while **hypothesis-based science**, which is usually deductive, begins with a specific question or problem and a potential answer or solution that can be tested. The boundary between these two forms of study is often blurred, and most scientific endeavors combine both approaches. The fuzzy boundary becomes apparent when thinking about how easily observation can lead to specific questions. For example, a gentleman in the 1940s observed that the burr seeds that stuck to his clothes and his dog's fur had a tiny hook structure. On closer inspection, he discovered that the burrs' gripping device was more reliable than a zipper. He eventually developed a company and produced the hook-and-loop fastener often used on lace-less sneakers and athletic braces. Descriptive science and hypothesis-based science are in continuous dialogue.

## The Scientific Method

Biologists study the living world by posing questions about it and seeking science-based responses. This approach is common to other sciences as well and is often referred to as the scientific method. The scientific method was used even in ancient times, but it was first documented by England's Sir Francis Bacon (1561–1626) (**Figure 1.5**), who set up inductive methods for scientific inquiry. The scientific method is not exclusively used by biologists but can be applied to almost all fields of study as a logical, rational problem-solving method.



**Figure 1.5** Sir Francis Bacon (1561–1626) is credited with being the first to define the scientific method. (credit: Paul van Somer)

The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. One Monday morning, a student arrives at class and quickly discovers that the classroom is too warm. That is an observation that also describes a problem: the classroom is too warm. The student then asks a question: "Why is the classroom so warm?"

### Proposing a Hypothesis

Recall that a hypothesis is a suggested explanation that can be tested. To solve a problem, several hypotheses may be proposed. For example, one hypothesis might be, "The classroom is warm because no one turned on the air conditioning." But there could be other responses to the question, and therefore other hypotheses may be proposed. A second hypothesis might be, "The classroom is warm because there is a power failure, and so the air conditioning doesn't work."

Once a hypothesis has been selected, the student can make a prediction. A prediction is similar to a hypothesis but it typically has the format “If . . . then . . . .” For example, the prediction for the first hypothesis might be, “*If* the student turns on the air conditioning, *then* the classroom will no longer be too warm.”

### Testing a Hypothesis

A valid hypothesis must be testable. It should also be **falsifiable**, meaning that it can be disproven by experimental results. Importantly, science does not claim to “prove” anything because scientific understandings are always subject to modification with further information. This step—openness to disproving ideas—is what distinguishes sciences from non-sciences. The presence of the supernatural, for instance, is neither testable nor falsifiable. To test a hypothesis, a researcher will conduct one or more experiments designed to eliminate one or more of the hypotheses. Each experiment will have one or more variables and one or more controls. A **variable** is any part of the experiment that can vary or change during the experiment. The **control group** contains every feature of the experimental group except it is not given the manipulation that is hypothesized about. Therefore, if the results of the experimental group differ from the control group, the difference must be due to the hypothesized manipulation, rather than some outside factor. Look for the variables and controls in the examples that follow. To test the first hypothesis, the student would find out if the air conditioning is on. If the air conditioning is turned on but does not work, there should be another reason, and this hypothesis should be rejected. To test the second hypothesis, the student could check if the lights in the classroom are functional. If so, there is no power failure and this hypothesis should be rejected. Each hypothesis should be tested by carrying out appropriate experiments. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid (see this figure). Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

While this “warm classroom” example is based on observational results, other hypotheses and experiments might have clearer controls. For instance, a student might attend class on Monday and realize she had difficulty concentrating on the lecture. One observation to explain this occurrence might be, “When I eat breakfast before class, I am better able to pay attention.” The student could then design an experiment with a control to test this hypothesis.

In hypothesis-based science, specific results are predicted from a general premise. This type of reasoning is called deductive reasoning: deduction proceeds from the general to the particular. But the reverse of the process is also possible: sometimes, scientists reach a general conclusion from a number of specific observations. This type of reasoning is called inductive reasoning, and it proceeds from the particular to the general. Inductive and deductive reasoning are often used in tandem to advance scientific knowledge (see this figure)

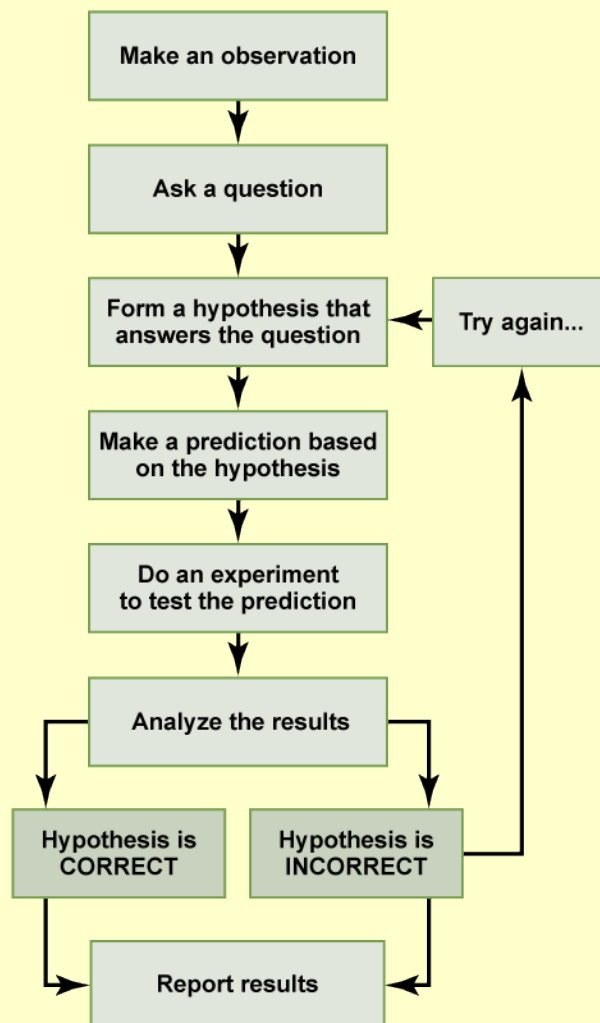
## science practices CONNECTION for AP<sup>®</sup> Courses

### Think About It

Almost all plants use water, carbon dioxide, and energy from the sun to make sugars. Think about what would happen to plants that don’t have sunlight as an energy source or sufficient water. What would happen to organisms that depend on those plants for their own survival?

Make a prediction about what would happen to the organisms living in a rain forest if 50% of its trees were destroyed. How would you test your prediction?

# visual CONNECTION



**Figure 1.6** The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed.

In the example below, the scientific method is used to solve an everyday problem. Order the scientific method steps (numbered items) with the process of solving the everyday problem (lettered items). Based on the results of the experiment, is the hypothesis correct? If it is incorrect, propose some alternative hypotheses.

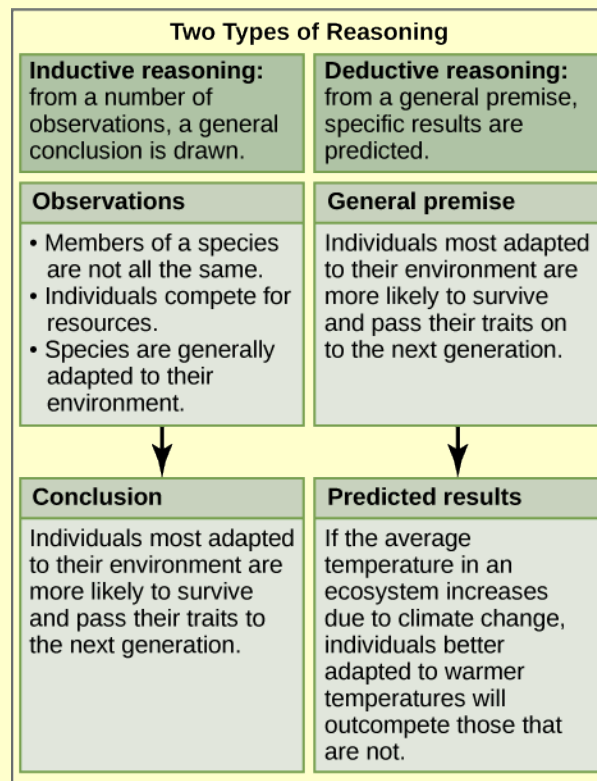
|   | Scientific Method   |   | Everyday process  |
|---|---------------------|---|---|
| 1 | Observation         | A | There is something wrong with the electrical outlet.  |
| 2 | Question            | B | If something is wrong with the outlet, my coffeemaker also won't work when plugged into it. |
| 3 | Hypothesis (answer) | C | My toaster doesn't toast my bread.  |
| 4 | Prediction          | D | I plug my coffee maker into the outlet.   |
| 5 | Experiment          | E | My coffeemaker works.   |

| <b>Scientific Method</b> |        | <b>Everyday process</b> |   |
|--------------------------|--------|-------------------------|---|
| 6                        | Result | F                       | What is preventing my toaster from working? |

- a. The original hypothesis is correct. There is something wrong with the electrical outlet and therefore the toaster doesn't work.
- b. The original hypothesis is incorrect. Alternative hypothesis includes that toaster wasn't turned on.
- c. The original hypothesis is correct. The coffee maker and the toaster do not work when plugged into the outlet.
- d. The original hypothesis is incorrect. Alternative hypotheses includes that both coffee maker and toaster were broken.



# visual CONNECTION



**Figure 1.7** Scientists use two types of reasoning, inductive and deductive reasoning, to advance scientific knowledge. As is the case in this example, the conclusion from inductive reasoning can often become the premise for deductive reasoning.

Decide if each of the following is an example of inductive or deductive reasoning.

- All flying birds and insects have wings. Birds and insects flap their wings as they move through the air. Therefore, wings enable flight.
- Insects generally survive mild winters better than harsh ones. Therefore, insect pests will become more problematic if global temperatures increase.
- Chromosomes, the carriers of DNA, separate into daughter cells during cell division. Therefore, DNA is the genetic material.
- Animals as diverse as insects and wolves all exhibit social behavior. Therefore, social behavior must have an evolutionary advantage for humans.
  - 1- Inductive, 2- Deductive, 3- Deductive, 4- Inductive
  - 1- Deductive, 2- Inductive, 3- Deductive, 4- Inductive
  - 1- Inductive, 2- Deductive, 3- Inductive, 4- Deductive
  - 1- Inductive, 2- Inductive, 3- Inductive, 4- Deductive

The scientific method may seem too rigid and structured. It is important to keep in mind that, although scientists often follow this sequence, there is flexibility. Sometimes an experiment leads to conclusions that favor a change in approach; often, an experiment brings entirely new scientific questions to the puzzle. Many times, science does not operate in a linear fashion; instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests. Notice, too, that the scientific method can be applied to solving problems that aren't necessarily scientific in nature.

## Two Types of Science: Basic Science and Applied Science

The scientific community has been debating for the last few decades about the value of different types of science. Is it valuable to pursue science for the sake of simply gaining knowledge, or does scientific knowledge only have worth if we can apply it to solving a specific problem or to bettering our lives? This question focuses on the differences between two types of science: basic science and applied science.

**Basic science** or “pure” science seeks to expand knowledge regardless of the short-term application of that knowledge. It is not focused on developing a product or a service of immediate public or commercial value. The immediate goal of basic science is knowledge for knowledge’s sake, though this does not mean that, in the end, it may not result in a practical application.

In contrast, **applied science** or “technology,” aims to use science to solve real-world problems, making it possible, for example, to improve a crop yield, find a cure for a particular disease, or save animals threatened by a natural disaster (**Figure 1.8**). In applied science, the problem is usually defined for the researcher.

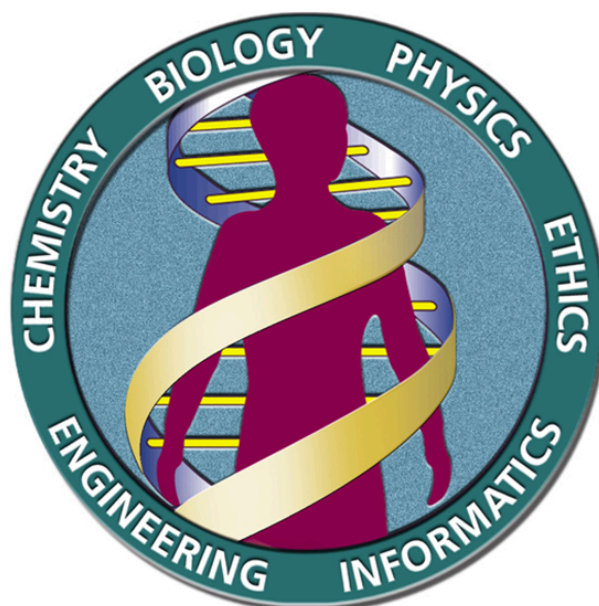


**Figure 1.8** After Hurricane Ike struck the Gulf Coast in 2008, the U.S. Fish and Wildlife Service rescued this brown pelican. Thanks to applied science, scientists knew how to rehabilitate the bird. (credit: FEMA)

Some individuals may perceive applied science as “useful” and basic science as “useless.” A question these people might pose to a scientist advocating knowledge acquisition would be, “What for?” A careful look at the history of science, however, reveals that basic knowledge has resulted in many remarkable applications of great value. Many scientists think that a basic understanding of science is necessary before an application is developed; therefore, applied science relies on the results generated through basic science. Other scientists think that it is time to move on from basic science and instead to find solutions to actual problems. Both approaches are valid. It is true that there are problems that demand immediate attention; however, few solutions would be found without the help of the wide knowledge foundation generated through basic science.

One example of how basic and applied science can work together to solve practical problems occurred after the discovery of DNA structure led to an understanding of the molecular mechanisms governing DNA replication. Strands of DNA, unique in every human, are found in our cells, where they provide the instructions necessary for life. During DNA replication, DNA makes new copies of itself, shortly before a cell divides. Understanding the mechanisms of DNA replication enabled scientists to develop laboratory techniques that are now used to identify genetic diseases. Without basic science, it is unlikely that applied science would exist.

Another example of the link between basic and applied research is the Human Genome Project, a study in which each human chromosome was analyzed and mapped to determine the precise sequence of DNA subunits and the exact location of each gene. (The gene is the basic unit of heredity; an individual’s complete collection of genes is his or her genome.) Other less complex organisms have also been studied as part of this project in order to gain a better understanding of human chromosomes. The Human Genome Project (**Figure 1.9**) relied on basic research carried out with simple organisms and, later, with the human genome. An important end goal eventually became using the data for applied research, seeking cures and early diagnoses for genetically related diseases.



**Figure 1.9** The Human Genome Project was a 13-year collaborative effort among researchers working in several different fields of science. The project, which sequenced the entire human genome, was completed in 2003. (credit: the U.S. Department of Energy Genome Programs (<http://genomics.energy.gov>))

While research efforts in both basic science and applied science are usually carefully planned, it is important to note that some discoveries are made by **serendipity**, that is, by means of a fortunate accident or a lucky surprise. Penicillin was discovered when biologist Alexander Fleming accidentally left a petri dish of *Staphylococcus* bacteria open. An unwanted mold grew on the dish, killing the bacteria. The mold turned out to be *Penicillium*, and a new antibiotic was discovered. Even in the highly organized world of science, luck—when combined with an observant, curious mind—can lead to unexpected breakthroughs.

## Reporting Scientific Work

Whether scientific research is basic science or applied science, scientists must share their findings in order for other researchers to expand and build upon their discoveries. Collaboration with other scientists—when planning, conducting, and analyzing results—are all important for scientific research. For this reason, important aspects of a scientist’s work are communicating with peers and disseminating results to peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the select few who are present. Instead, most scientists present their results in peer-reviewed manuscripts that are published in scientific journals. **Peer-reviewed manuscripts** are scientific papers that are reviewed by a scientist’s colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist’s work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper or grant proposal is original, significant, logical, and thorough. Grant proposals, which are requests for research funding, are also subject to peer review. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings. The experimental results must be consistent with the findings of other scientists.

A scientific paper is very different from creative writing. Although creativity is required to design experiments, there are fixed guidelines when it comes to presenting scientific results. First, scientific writing must be brief, concise, and accurate. A scientific paper needs to be succinct but detailed enough to allow peers to reproduce the experiments.

The scientific paper consists of several specific sections—introduction, materials and methods, results, and discussion. This structure is sometimes called the “IMRaD” format. There are usually acknowledgment and reference sections as well as an **abstract** (a concise summary) at the beginning of the paper. There might be additional sections depending on the type of paper and the journal where it will be published; for example, some review papers require an outline.

The **introduction** starts with brief, but broad, background information about what is known in the field. A good introduction also gives the rationale of the work; it justifies the work carried out and also briefly mentions the end of the paper, where the hypothesis or research question driving the research will be presented. The introduction refers to the published scientific work of others and therefore requires citations following the style of the journal. Using the work or ideas of others without proper citation is considered **plagiarism**.

The **materials and methods** section includes a complete and accurate description of the substances used, and the method

and techniques used by the researchers to gather data. The description should be thorough enough to allow another researcher to repeat the experiment and obtain similar results, but it does not have to be verbose. This section will also include information on how measurements were made and what types of calculations and statistical analyses were used to examine raw data. Although the materials and methods section gives an accurate description of the experiments, it does not discuss them.

Some journals require a results section followed by a discussion section, but it is more common to combine both. If the journal does not allow the combination of both sections, the **results** section simply narrates the findings without any further interpretation. The results are presented by means of tables or graphs, but no duplicate information should be presented. In the **discussion** section, the researcher will interpret the results, describe how variables may be related, and attempt to explain the observations. It is indispensable to conduct an extensive literature search to put the results in the context of previously published scientific research. Therefore, proper citations are included in this section as well.

Finally, the **conclusion** section summarizes the importance of the experimental findings. While the scientific paper almost certainly answered one or more scientific questions that were stated, any good research should lead to more questions. Therefore, a well-done scientific paper leaves doors open for the researcher and others to continue and expand on the findings.

**Review articles** do not follow the IMRAD format because they do not present original scientific findings, or primary literature; instead, they summarize and comment on findings that were published as primary literature and typically include extensive reference sections.

## 1.2 | Themes and Concepts of Biology

By the end of this section, you will be able to:

- Identify and describe the properties of life
- Describe the levels of organization among living things
- Recognize and interpret a phylogenetic tree

### Connection for AP<sup>®</sup> Courses

The AP<sup>®</sup> Biology curriculum is organized around four major themes called the Big Ideas that apply to all levels of biological organization—from molecules and cells to populations and ecosystems. Each Big Idea identifies key concepts called Enduring Understandings, and Essential Knowledges, along with supporting examples. Simple descriptions define the focus of each Big Idea: Big Idea 1, Evolution; Big Idea 2, Energy and Homeostasis; Big Idea 3, Information and Communication; and Big Idea 4, Systems and Interactions. Evolution explains both the unity and diversity of life, Big Idea 1, and all organisms require energy and molecules to carry out life functions, such as growth and reproduction, Big Idea 2. Living systems also store, transmit, and respond to information, from DNA sequences to nerve impulses and behaviors, Big Idea 3. All biological systems interact, and these interactions result in emergent properties and characteristics unique to life, Big Idea 4.

The redesigned AP<sup>®</sup> Biology course also emphasizes the investigative practices that students should master. Scientific inquiry usually uses a series of steps to gain new knowledge. The scientific method begins with an observation and follows with a hypothesis to explain the observation; then experiments are conducted to test the hypothesis, gather results, and draw conclusions from data. The AP<sup>®</sup> program has identified seven major categories of Science Practices, which can be described by short phrases: using representations and models to communicate information and solve problems; using mathematics appropriately; engaging in questioning; planning and implementing data collection strategies; analyzing and evaluating data; justifying scientific explanations; and connecting concepts. A Learning Objective merges content with one or more of the seven Science Practices.

The information presented and the examples highlighted in this section support concepts and Learning Objectives outlined in Big Idea 1 of the AP<sup>®</sup> Biology Curriculum. The Learning Objectives listed in the Curriculum Framework provide a transparent foundation for the AP<sup>®</sup> Biology course, an inquiry-based laboratory experience, instructional activities, and AP<sup>®</sup> Exam questions. A Learning Objective merges required content with one or more of the seven Science Practices.

|                                   |  |
|-----------------------------------|--|
| <b>Big Idea 1</b>                 | The process of evolution drives the diversity and unity of life.   |
| <b>Enduring Understanding 1.B</b> | Organisms are linked by lines of descent from common ancestry.   |
| <b>Essential Knowledge</b>        | <b>1.B.1</b> Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.   |
| <b>Science Practice</b>           | <b>3.1</b> The student can pose scientific questions.  |
| <b>Learning Objective</b>         | <b>1.14</b> The student is able to pose scientific questions that correctly identify essential properties of share, core life processes that provide insights into the history of life on Earth. |
| <b>Essential Knowledge</b>        | <b>1.B.1</b> Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.   |
| <b>Science Practice</b>           | <b>5.3</b> The student can evaluate the evidence provided by data sets in relation to a particular scientific question.  |
| <b>Learning Objective</b>         | <b>1.18</b> The student is able to evaluate evidence provided by a data set in conjunction with a phylogenetic tree or simply cladogram to determine evolutionary history and speciation.        |

Biology is the science that studies life, but what exactly is life? This may sound like a silly question with an obvious response, but it is not always easy to define life. For example, a branch of biology called virology studies viruses, which exhibit some of the characteristics of living entities but lack others. It turns out that although viruses can attack living organisms, cause diseases, and even reproduce, they do not meet the criteria that biologists use to define life. Consequently, virologists are not biologists, strictly speaking. Similarly, some biologists study the early molecular evolution that gave rise to life; since the events that preceded life are not biological events, these scientists are also excluded from biology in the strict sense of the term.

From its earliest beginnings, biology has wrestled with three questions: What are the shared properties that make something “alive”? And once we know something is alive, how do we find meaningful levels of organization in its structure? And, finally, when faced with the remarkable diversity of life, how do we organize the different kinds of organisms so that we can better understand them? As new organisms are discovered every day, biologists continue to seek answers to these and other questions.

## Properties of Life

All living organisms share several key characteristics or functions: order, sensitivity or response to the environment, reproduction, adaptation, growth and development, regulation, homeostasis, energy processing, and evolution. When viewed together, these nine characteristics serve to define life.

### Order



**Figure 1.10** A toad represents a highly organized structure consisting of cells, tissues, organs, and organ systems. (credit: “Ivengo”/Wikimedia Commons)

Organisms are highly organized, coordinated structures that consist of one or more cells. Even very simple, single-celled organisms are remarkably complex: inside each cell, atoms make up molecules; these in turn make up cell organelles and other cellular inclusions. In multicellular organisms (**Figure 1.10**), similar cells form tissues. Tissues, in turn, collaborate to create organs (body structures with a distinct function). Organs work together to form organ systems.

### Sensitivity or Response to Stimuli



**Figure 1.11** The leaves of this sensitive plant (*Mimosa pudica*) will instantly droop and fold when touched. After a few minutes, the plant returns to normal. (credit: Alex Lomas)

Organisms respond to diverse stimuli. For example, plants can bend toward a source of light, climb on fences and walls, or respond to touch (**Figure 1.11**). Even tiny bacteria can move toward or away from chemicals (a process called *chemotaxis*) or light (*phototaxis*). Movement toward a stimulus is considered a positive response, while movement away from a stimulus is considered a negative response.



Watch **this video** ([http://openstaxcollege.org/l/movement\\_plants](http://openstaxcollege.org/l/movement_plants)) to see how plants respond to a stimulus—from opening to light, to wrapping a tendril around a branch, to capturing prey.

Which example most clearly shows a way that humans can respond directly to a change in the environment?

- We shiver when we are cold and sweat when we are hot.
- We walk by putting our front leg forward and pushing off with our back leg.
- We are able to breath in and out unconsciously.
- Our hair and fingernails grow at a constant rate over time.

### Reproduction

Single-celled organisms reproduce by first duplicating their DNA, and then dividing it equally as the cell prepares to divide to form two new cells. Multicellular organisms often produce specialized reproductive germline cells that will form new individuals. When reproduction occurs, genes containing DNA are passed along to an organism's offspring. These genes ensure that the offspring will belong to the same species and will have similar characteristics, such as size and shape.

### Growth and Development

Organisms grow and develop following specific instructions coded for by their genes. These genes provide instructions that

will direct cellular growth and development, ensuring that a species' young (**Figure 1.12**) will grow up to exhibit many of the same characteristics as its parents.



**Figure 1.12** Although no two look alike, these kittens have inherited genes from both parents and share many of the same characteristics. (credit: Rocky Mountain Feline Rescue)

### Regulation

Even the smallest organisms are complex and require multiple regulatory mechanisms to coordinate internal functions, respond to stimuli, and cope with environmental stresses. Two examples of internal functions regulated in an organism are nutrient transport and blood flow. Organs (groups of tissues working together) perform specific functions, such as carrying oxygen throughout the body, removing wastes, delivering nutrients to every cell, and cooling the body.

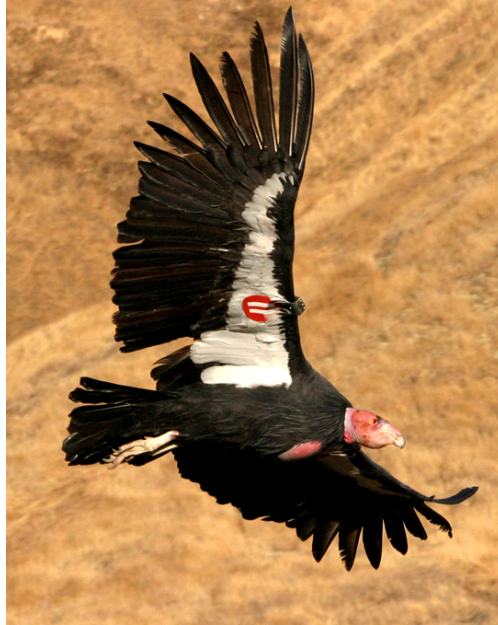
### Homeostasis



**Figure 1.13** Polar bears (*Ursus maritimus*) and other mammals living in ice-covered regions maintain their body temperature by generating heat and reducing heat loss through thick fur and a dense layer of fat under their skin. (credit: "longhornrdave"/Flickr)

In order to function properly, cells need to have appropriate conditions such as proper temperature, pH, and appropriate concentration of diverse chemicals. These conditions may, however, change from one moment to the next. Organisms are able to maintain internal conditions within a narrow range almost constantly, despite environmental changes, through **homeostasis** (literally, "steady state"). For example, an organism needs to regulate body temperature through a process known as thermoregulation. Organisms that live in cold climates, such as the polar bear (**Figure 1.13**), have body structures that help them withstand low temperatures and conserve body heat. Structures that aid in this type of insulation include fur, feathers, blubber, and fat. In hot climates, organisms have methods (such as perspiration in humans or panting in dogs) that help them to shed excess body heat.

## Energy Processing



**Figure 1.14** The California condor (*Gymnogyps californianus*) uses chemical energy derived from food to power flight. California condors are an endangered species; this bird has a wing tag that helps biologists identify the individual. (credit: Pacific Southwest Region U.S. Fish and Wildlife Service)

All organisms use a source of energy for their metabolic activities. Some organisms capture energy from the sun and convert it into chemical energy in food; others use chemical energy in molecules they take in as food (**Figure 1.14**).

## science practices CONNECTION for AP<sup>®</sup> Courses

### Activity

Select an ecosystem of your choice, such as a tropical rainforest, desert, or coral reef, and create a representation to show how several organisms found in the ecosystem interact with each other and the environment. Then, using similarities and differences among the organisms make a hypothesis about their relatedness.

Consider the levels of organization of the biological world and create a diagram to place these items in order from the smallest level of organization to the most encompassing: skin cell, planet Earth, elephant, tropical rainforest, water molecule, liver, wolf pack, and oxygen atom. Justify the reason why you placed the items in the hierarchy that you did.

### Think About It

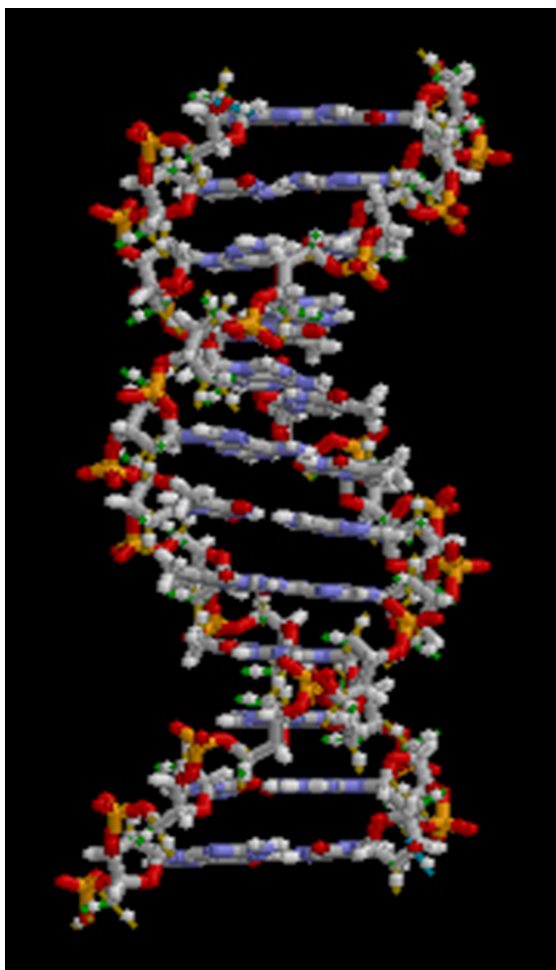
Homeostasis—the ability to “stay the same”—is a feature shared by all living organisms. You go for a long walk on a hot day. Describe how homeostasis keeps your body healthy even though you are sweating profusely. Then describe an example of an adaptation that evolved in a desert plant or animal that allows them to survive in extreme temperatures.

## Levels of Organization of Living Things

Living things are highly organized and structured, following a hierarchy that can be examined on a scale from small to large. The **atom** is the smallest and most fundamental unit of matter. It consists of a nucleus surrounded by electrons. Atoms form molecules. A **molecule** is a chemical structure consisting of at least two atoms held together by one or more chemical bonds. Many molecules that are biologically important are **macromolecules**, large molecules that are typically formed by polymerization (a polymer is a large molecule that is made by combining smaller units called monomers, which are simpler



than macromolecules). An example of a macromolecule is deoxyribonucleic acid (DNA) (**Figure 1.15**), which contains the instructions for the structure and functioning of all living organisms.



**Figure 1.15** All molecules, including this DNA molecule, are composed of atoms. (credit: "brian0918"/Wikimedia Commons)

LINK TO LEARNING



Watch **this video** ([http://openstaxcollege.org/l/rotating\\_DNA](http://openstaxcollege.org/l/rotating_DNA)) that animates the three-dimensional structure of the DNA molecule shown in **this figure**.

The word helix means spiral. What does this tell you about the structure of DNA, which is a double helix macromolecule?

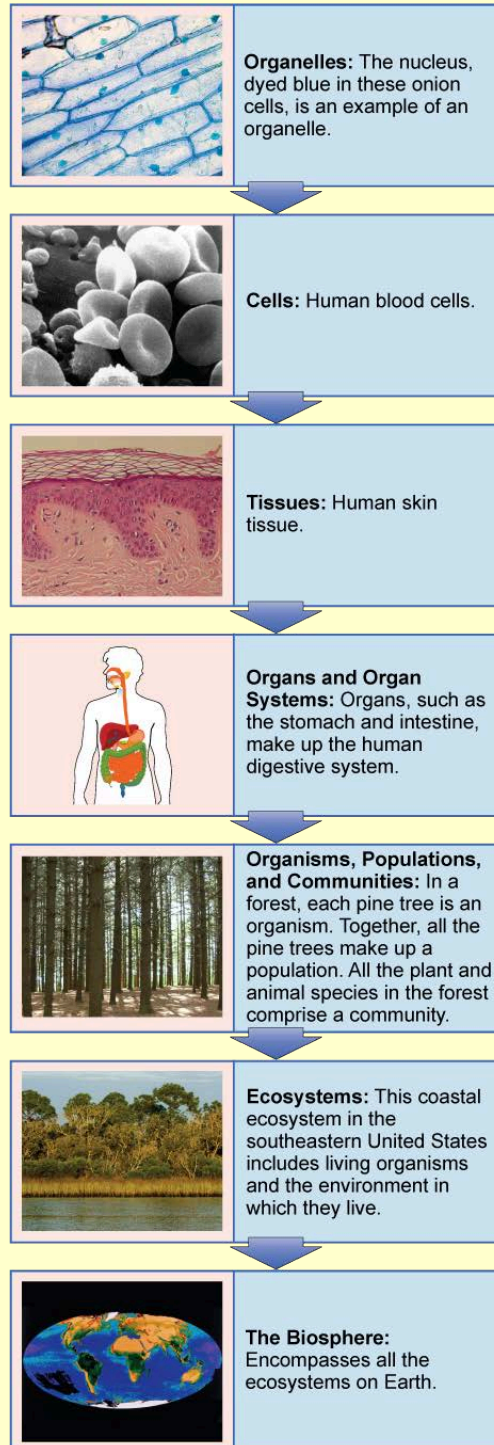
- The nucleotides of the two strands bond together with spiral bonds.
- A double-stranded DNA molecule has two spiral strands bound together.
- DNA is a double helix because it has two spiral strands held together like a spiral staircase.
- Nucleotides are spiral-shaped molecules that bond together to form DNA.

Some cells contain aggregates of macromolecules surrounded by membranes; these are called **organelles**. Organelles are small structures that exist within cells. Examples of organelles include mitochondria and chloroplasts, which carry out indispensable functions: mitochondria produce energy to power the cell, while chloroplasts enable green plants to utilize the energy in sunlight to make sugars. All living things are made of cells; the **cell** itself is the smallest fundamental unit of structure and function in living organisms. (This requirement is why viruses are not considered living: they are not made of cells. To make new viruses, they have to invade and hijack the reproductive mechanism of a living cell; only then can they obtain the materials they need to reproduce.) Some organisms consist of a single cell and others are multicellular. Cells are classified as prokaryotic or eukaryotic. **Prokaryotes** are single-celled or colonial organisms that do not have membrane-bound nuclei; in contrast, the cells of **eukaryotes** do have membrane-bound organelles and a membrane-bound nucleus.

In larger organisms, cells combine to make **tissues**, which are groups of similar cells carrying out similar or related functions. **Organs** are collections of tissues grouped together performing a common function. Organs are present not only in animals but also in plants. An **organ system** is a higher level of organization that consists of functionally related organs. Mammals have many organ systems. For instance, the circulatory system transports blood through the body and to and from the lungs; it includes organs such as the heart and blood vessels. **Organisms** are individual living entities. For example, each tree in a forest is an organism. Single-celled prokaryotes and single-celled eukaryotes are also considered organisms and are typically referred to as microorganisms.

All the individuals of a species living within a specific area are collectively called a **population**. For example, a forest may include many pine trees. All of these pine trees represent the population of pine trees in this forest. Different populations may live in the same specific area. For example, the forest with the pine trees includes populations of flowering plants and also insects and microbial populations. A **community** is the sum of populations inhabiting a particular area. For instance, all of the trees, flowers, insects, and other populations in a forest form the forest's community. The forest itself is an ecosystem. An **ecosystem** consists of all the living things in a particular area together with the abiotic, non-living parts of that environment such as nitrogen in the soil or rain water. At the highest level of organization ([see this figure](#)), the **biosphere** is the collection of all ecosystems, and it represents the zones of life on earth. It includes land, water, and even the atmosphere to a certain extent.

# visual CONNECTION



**Figure 1.16** The biological levels of organization of living things are shown. From a single organelle to the entire biosphere, living organisms are parts of a highly structured hierarchy. (credit “organelles”: modification of work by Umberto Salvagnin; credit “cells”: modification of work by Bruce Wetzels, Harry Schaefer/ National Cancer Institute; credit “tissues”: modification of work by Kilbad; Fama Clamosa; Mikael Häggström; credit “organs”: modification of work by Mariana Ruiz Villareal; credit “organisms”: modification of work by “Crystal”/Flickr; credit “ecosystems”:

modification of work by US Fish and Wildlife Service Headquarters; credit “biosphere”: modification of work by NASA)

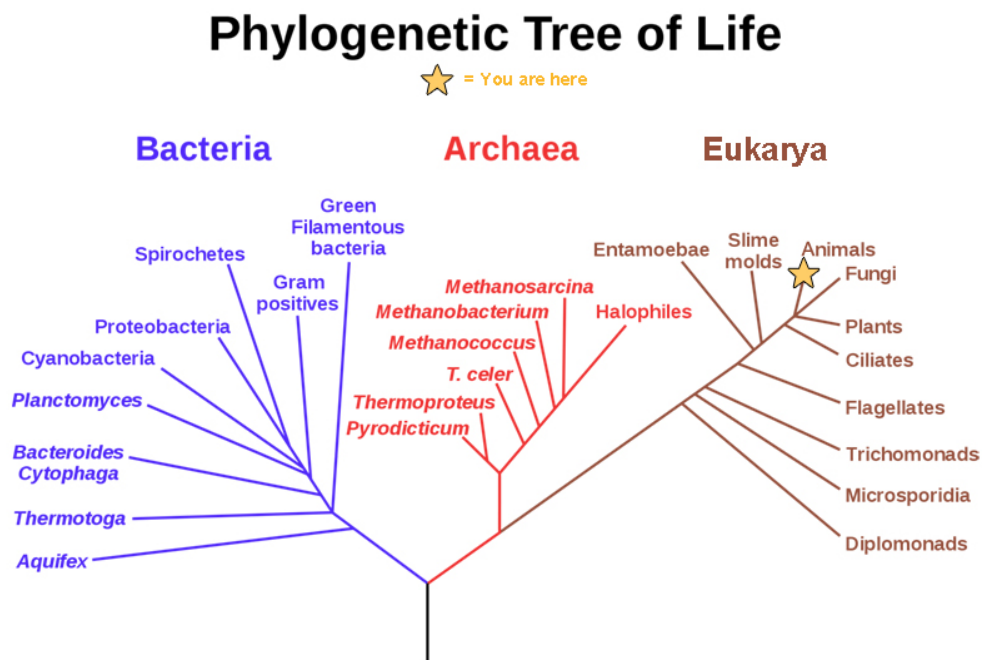
Which of the following statements is false?

- Tissues exist within organs which exist within organ systems.
- Communities exist within populations which exist within ecosystems.
- Organelles exist within cells which exist within tissues.
- Communities exist within ecosystems which exist in the biosphere.

## The Diversity of Life

The fact that biology, as a science, has such a broad scope has to do with the tremendous diversity of life on earth. The source of this diversity is **evolution**, the process of gradual change during which new species arise from older species. Evolutionary biologists study the evolution of living things in everything from the microscopic world to ecosystems.

The evolution of various life forms on Earth can be summarized in a phylogenetic tree (Figure 1.17). A **phylogenetic tree** is a diagram showing the evolutionary relationships among biological species based on similarities and differences in genetic or physical traits or both. A phylogenetic tree is composed of nodes and branches. The internal nodes represent ancestors and are points in evolution when, based on scientific evidence, an ancestor is thought to have diverged to form two new species. The length of each branch is proportional to the time elapsed since the split.



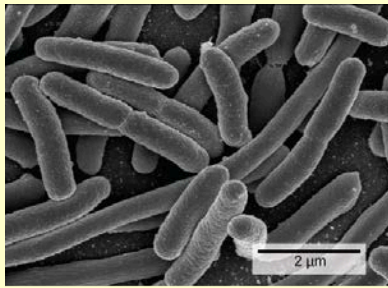
**Figure 1.17** This phylogenetic tree was constructed by microbiologist Carl Woese using data obtained from sequencing ribosomal RNA genes. The tree shows the separation of living organisms into three domains: Bacteria, Archaea, and Eukarya. Bacteria and Archaea are prokaryotes, single-celled organisms lacking intracellular organelles. (credit: Eric Gaba; NASA Astrobiology Institute)

# evolution CONNECTION

## Carl Woese and the Phylogenetic Tree

In the past, biologists grouped living organisms into five kingdoms: animals, plants, fungi, protists, and bacteria. The organizational scheme was based mainly on physical features, as opposed to physiology, biochemistry, or molecular biology, all of which are used by modern systematics. The pioneering work of American microbiologist Carl Woese in the early 1970s has shown, however, that life on Earth has evolved along three lineages, now called domains—Bacteria, Archaea, and Eukarya. The first two are prokaryotic cells with microbes that lack membrane-enclosed nuclei and organelles. The third domain contains the eukaryotes and includes unicellular microorganisms together with the four original kingdoms (excluding bacteria). Woese defined Archaea as a new domain, and this resulted in a new taxonomic tree (see this figure). Many organisms belonging to the Archaea domain live under extreme conditions and are called extremophiles. To construct his tree, Woese used genetic relationships rather than similarities based on morphology (shape).

Woese's tree was constructed from comparative sequencing of the genes that are universally distributed, present in every organism, and conserved (meaning that these genes have remained essentially unchanged throughout evolution). Woese's approach was revolutionary because comparisons of physical features are insufficient to differentiate between the prokaryotes that appear fairly similar in spite of their tremendous biochemical diversity and genetic variability (Figure 1.18). The comparison of homologous DNA and RNA sequences provided Woese with a sensitive device that revealed the extensive variability of prokaryotes, and which justified the separation of the prokaryotes into two domains: bacteria and archaea.



(a)



(b)



(c)



(d)

**Figure 1.18** These images represent different domains. The (a) bacteria in this micrograph belong to Domain Bacteria, while the (b) extremophiles (not visible) living in this hot vent belong to Domain Archaea. Both the (c) sunflower and (d) lion are part of Domain Eukarya. (credit a: modification of work by Drew March; credit b: modification of work by Steve Jurvetson; credit c: modification of work by Michael Arrighi; credit d: modification of work by Leszek Leszcynski)

In which domain would a fish be classified? Why?

- a. Archaea, because fish are multicellular.
- b. Eukarya, because fish are multicellular.
- c. Archaea, because fish are single-celled.
- d. Eukarya because fish are single-celled.

## everyday CONNECTION for AP® Courses

Phylogenetic trees can represent traits that are derived or lost due to evolution. One example is the absence of legs in some sea mammals. For example, Cetaceans are marine mammals that include toothed whales, such as dolphins and killer whales, and baleen whales, such as humpback whales. Cetaceans are descended from even-toed ungulates and share a common ancestry with the hippopotamus, cow, sheep, camel, and pig.

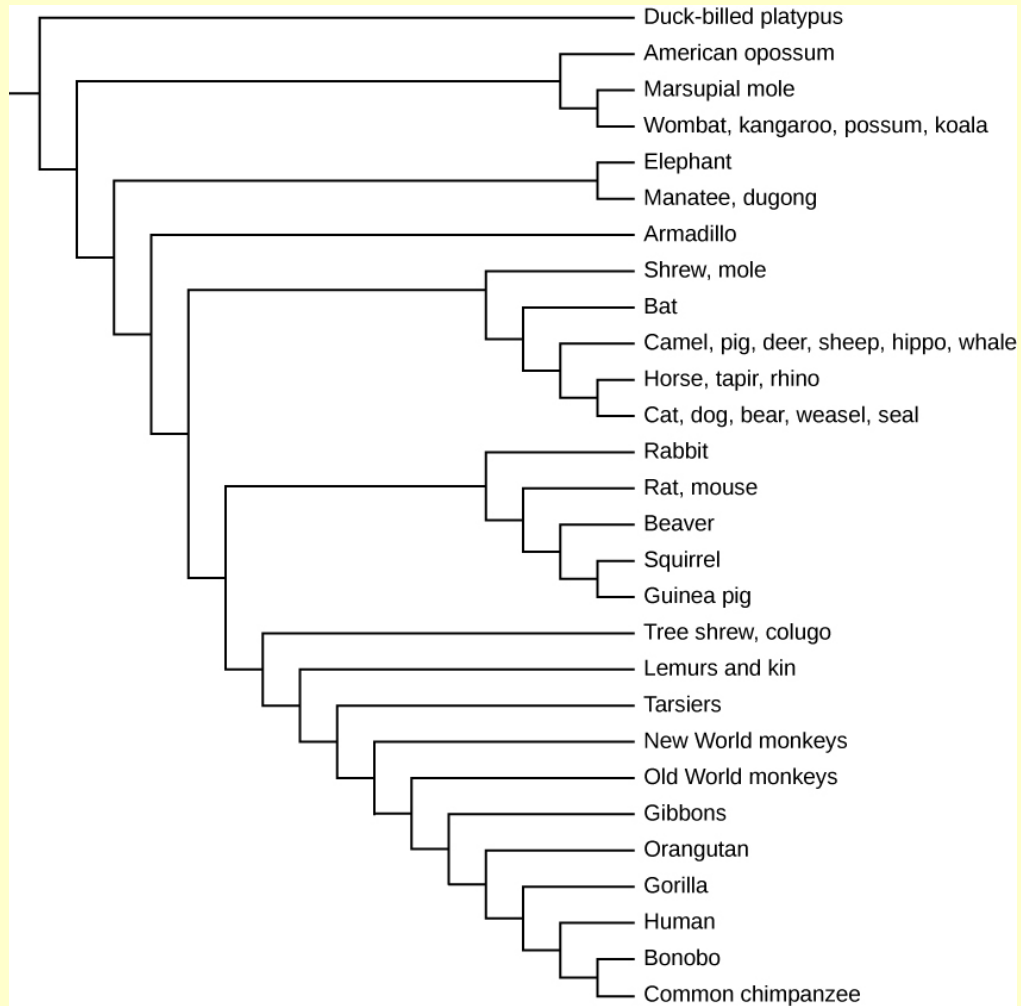
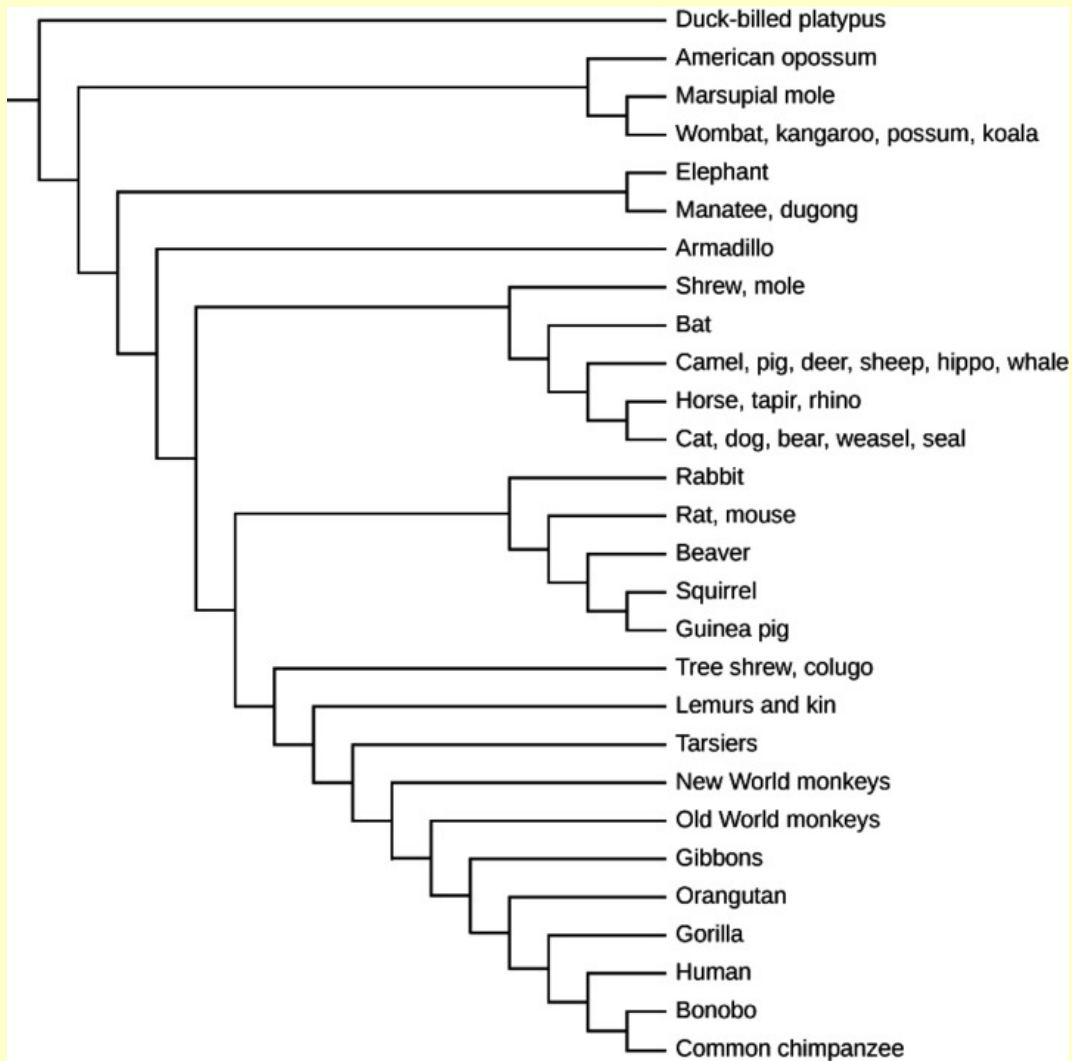


Figure 1.19



Phylogenetic trees can represent traits that are derived or lost due to evolution. One example is the absence of legs in some marine mammals. One such group is the Cetaceans, which includes toothed whales, such as dolphins and killer whales, and baleen whales, such as humpback whales. Cetaceans are descended from even-toed ungulates and share a common ancestry with the hippopotamus, cows, sheep, camel, and pig. Based on this phylogenetic tree, which of the following animal is the most closely related to a horse?

- an armadillo
- a camel
- a bat
- a cat

## Branches of Biological Study

The scope of biology is broad and therefore contains many branches and subdisciplines. Biologists may pursue one of those subdisciplines and work in a more focused field. For instance, **molecular biology** and **biochemistry** study biological processes at the molecular and chemical level, including interactions among molecules such as DNA, RNA, and proteins, as well as the way they are regulated. **Microbiology**, the study of microorganisms, is the study of the structure and function of organisms that cannot be seen with the naked eye. It is quite a broad branch itself, and depending on the subject of study, there are also microbial physiologists, ecologists, and geneticists, among others.



## career CONNECTION

Forensic science is the application of science to answer questions related to the law. Biologists as well as chemists and biochemists can be forensic scientists. Forensic scientists provide scientific evidence for use in courts, and their job involves examining trace materials associated with crimes. Interest in forensic science has increased in the last few years, possibly because of popular television shows that feature forensic scientists on the job. Also, the development of molecular techniques and the establishment of DNA databases have expanded the types of work that forensic scientists can do. Their work involves analyzing samples such as hair, blood, and other body fluids and also processing DNA (Figure 1.20) found in many different environments and materials. Forensic scientists also analyze other biological evidence left at crime scenes, such as insect larvae or pollen grains. Students who want to pursue careers in forensic science will most likely be required to take chemistry and biology courses as well as some intensive math courses.



**Figure 1.20** This forensic scientist works in a DNA extraction room at the U.S. Army Criminal Investigation Laboratory at Fort Gillem, GA. (credit: United States Army CID Command Public Affairs)

Another field of biological study, **neurobiology**, studies the biology of the nervous system, and although it is considered a branch of biology, it is also recognized as an interdisciplinary field of study known as neuroscience. Because of its interdisciplinary nature, this subdiscipline studies different functions of the nervous system using molecular, cellular, developmental, medical, and computational approaches.



**Figure 1.21** Researchers work on excavating dinosaur fossils at a site in Castellón, Spain. (credit: Mario Modesto)

**Paleontology**, another branch of biology, uses fossils to study life's history (Figure 1.21). **Zoology** and **botany** are the study of animals and plants, respectively. Biologists can also specialize as biotechnologists, ecologists, or physiologists, to name just a few areas. This is just a small sample of the many fields that biologists can pursue.

Biology is the culmination of the achievements of the natural sciences from their inception to today. Excitingly, it is the cradle of emerging sciences, such as the biology of brain activity, genetic engineering of custom organisms, and the biology of evolution that uses the laboratory tools of molecular biology to retrace the earliest stages of life on earth. A scan of news headlines—whether reporting on immunizations, a newly discovered species, sports doping, or a genetically-modified food—demonstrates the way biology is active in and important to our everyday world.

## KEY TERMS

**abstract** opening section of a scientific paper that summarizes the research and conclusions

**applied science** form of science that aims to solve real-world problems

**atom** smallest and most fundamental unit of matter

**basic science** science that seeks to expand knowledge and understanding regardless of the short-term application of that knowledge

**biochemistry** study of the chemistry of biological organisms

**biology** the study of living organisms and their interactions with one another and their environments

**biosphere** collection of all the ecosystems on Earth

**botany** study of plants

**cell** smallest fundamental unit of structure and function in living things

**community** set of populations inhabiting a particular area

**conclusion** section of a scientific paper that summarizes the importance of the experimental findings

**control** part of an experiment that does not change during the experiment

**deductive reasoning** form of logical thinking that uses a general inclusive statement to forecast specific results

**descriptive science** (also, discovery science) form of science that aims to observe, explore, and investigate

**discussion** section of a scientific paper in which the author interprets experimental results, describes how variables may be related, and attempts to explain the phenomenon in question

**ecosystem** all the living things in a particular area together with the abiotic, nonliving parts of that environment

**eukaryote** organism with cells that have nuclei and membrane-bound organelles

**evolution** process of gradual change during which new species arise from older species and some species become extinct

**falsifiable** able to be disproven by experimental results

**homeostasis** ability of an organism to maintain constant internal conditions

**hypothesis** suggested explanation for an observation, which can be tested

**hypothesis-based science** form of science that begins with a specific question and potential testable answers

**inductive reasoning** form of logical thinking that uses related observations to arrive at a general conclusion

**introduction** opening section of a scientific paper, which provides background information about what was known in the field prior to the research reported in the paper

**life science** field of science, such as biology, that studies living things

**macromolecule** large molecule, typically formed by the joining of smaller molecules

**materials and methods** section of a scientific paper that includes a complete description of the substances, methods, and techniques used by the researchers to gather data

**microbiology** study of the structure and function of microorganisms

**molecular biology** study of biological processes and their regulation at the molecular level, including interactions among

molecules such as DNA, RNA, and proteins

**molecule** chemical structure consisting of at least two atoms held together by one or more chemical bonds

**natural science** field of science that is related to the physical world and its phenomena and processes

**neurobiology** study of the biology of the nervous system

**organ** collection of related tissues grouped together performing a common function

**organ system** level of organization that consists of functionally related interacting organs

**organelle** small structures that exist within cells and carry out cellular functions

**organism** individual living entity

**paleontology** study of life's history by means of fossils

**peer-reviewed manuscript** scientific paper that is reviewed by a scientist's colleagues who are experts in the field of study

**phylogenetic tree** diagram showing the evolutionary relationships among various biological species based on similarities and differences in genetic or physical traits or both; in essence, a hypothesis concerning evolutionary connections

**physical science** field of science, such as geology, astronomy, physics, and chemistry, that studies nonliving matter

**plagiarism** using other people's work or ideas without proper citation, creating the false impression that those are the author's original ideas

**population** all of the individuals of a species living within a specific area

**prokaryote** single-celled organism that lacks organelles and does not have nuclei surrounded by a nuclear membrane

**results** section of a scientific paper in which the author narrates the experimental findings and presents relevant figures, pictures, diagrams, graphs, and tables, without any further interpretation

**review article** paper that summarizes and comments on findings that were published as primary literature

**science** knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method

**scientific method** method of research with defined steps that include observation, formulation of a hypothesis, testing, and confirming or falsifying the hypothesis

**serendipity** fortunate accident or a lucky surprise

**theory** tested and confirmed explanation for observations or phenomena

**tissue** group of similar cells carrying out related functions

**variable** part of an experiment that the experimenter can vary or change

**zoology** study of animals

## CHAPTER SUMMARY

### 1.1 The Science of Biology

Biology is the science that studies living organisms and their interactions with one another and their environments. Science attempts to describe and understand the nature of the universe in whole or in part by rational means. Science has many fields; those fields related to the physical world and its phenomena are considered natural sciences.

Science can be basic or applied. The main goal of basic science is to expand knowledge without any expectation of short-term practical application of that knowledge. The primary goal of applied research, however, is to solve practical problems.

Two types of logical reasoning are used in science. Inductive reasoning uses particular results to produce general scientific principles. Deductive reasoning is a form of logical thinking that predicts results by applying general principles. The common thread throughout scientific research is the use of the scientific method, a step-based process that consists of making observations, defining a problem, posing hypotheses, testing these hypotheses, and drawing one or more conclusions. The testing uses proper controls. Scientists present their results in peer-reviewed scientific papers published in scientific journals. A scientific research paper consists of several well-defined sections: introduction, materials and methods, results, and, finally, a concluding discussion. Review papers summarize the research done in a particular field over a period of time.

## 1.2 Themes and Concepts of Biology

Biology is the science of life. All living organisms share several key properties such as order, sensitivity or response to stimuli, reproduction, growth and development, regulation, homeostasis, and energy processing. Living things are highly organized parts of a hierarchy that includes atoms, molecules, organelles, cells, tissues, organs, and organ systems. Organisms, in turn, are grouped as populations, communities, ecosystems, and the biosphere. The great diversity of life today evolved from less-diverse ancestral organisms over billions of years. A diagram called a phylogenetic tree can be used to show evolutionary relationships among organisms.

Biology is very broad and includes many branches and subdisciplines. Examples include molecular biology, microbiology, neurobiology, zoology, and botany, among others.

## REVIEW QUESTIONS

- What is a suggested and testable explanation for an event called?
  - discovery
  - hypothesis
  - scientific method
  - theory
- Which of the following sciences is not considered a natural science?
  - Astronomy
  - Biology
  - Computer science
  - Physics
- What is the name for the formal process through which scientific research is checked for originality, significance, and quality before being accepted into scientific literature?
  - publication
  - public speaking
  - peer review
  - the scientific method
- What are two topics that are likely to be studied by biologists and two areas of scientific study that would fall outside the realm of biology?
  - diseases affecting humans, pollution affecting species habitat, calculating surface area of rectangular ground, functioning of planetary orbitals
  - calculating surface area of rectangular ground, functioning of planetary orbitals, formation of metamorphic rocks, galaxy formation and evolution
  - plant responses to external stimuli, functioning of planetary orbitals, formation of metamorphic rocks, galaxy formation and evolution
  - plant responses to external stimuli, study of the shape and motion of physical objects, formation of metamorphic rocks, galaxy formation and evolution
- Which of the following is an example of deductive reasoning?
  - Most swimming animals use fins; therefore, fins are an adaptation to swimming.
  - Mitochondria are inherited from the mother; therefore, maternally inherited traits are encoded by mitochondrial DNA
  - Small animals lose more heat than larger animals. One would not expect to find wild mice in the poles.
  - Water conservation is a major requirement to survive in the desert. Long leaves increase loss of water by evaporation. Therefore, desert plants should have smaller leaves.

6. Why are viruses not considered living?
- They are not made of cells.
  - Viruses do not have genetic material.
  - Viruses have DNA and RNA.
  - Viruses are obligate parasites and require a host.
7. The presence of a membrane-enclosed nucleus is a characteristic of what?
- bacteria
  - eukaryotic cells
  - all living organisms
  - prokaryotic cells
8. What is a group of individuals of the same species living in the same area called?
- a community
  - an ecosystem
  - a family
  - a population
9. Which of the following sequences represents the hierarchy of biological organization from the most inclusive to the least complex level?
- biosphere, ecosystem, community, population, organism
  - organelle, tissue, biosphere, ecosystem, population
  - organism, organ, tissue, organelle, molecule
  - organism, community, biosphere, molecule, tissue, organ
10. Where in a phylogenetic tree would you expect to find the organism that had evolved most recently?
- at the base
  - at the nodes
  - at the branch tips
  - within the branches
11. What is a characteristic that is not present in all living things?
- homeostasis and regulation
  - metabolism
  - nucleus containing DNA
  - reproduction

## CRITICAL THINKING QUESTIONS

12. Is mathematics a natural science? Explain your reasoning.
- No, it is not a natural science because it is not used in the study of the natural world.
  - No, it is not a natural science. Mathematics focuses on understanding mathematical relations and calculations, which is useful in natural sciences but which is distinct.
  - Yes, it is a natural science. Mathematics deals with verifying the experimental data.
  - Yes, it is a natural science. It uses chemical and physical measurements.
13. Although the scientific method is used by most of the sciences, it can also be applied to everyday situations. A situation is given below. Using the scientific method try to arrange the given steps in the correct order. Situation:
- If the car doesn't start the problem might be in the battery.
  - Car doesn't start.
  - After changing the battery. Car starts working.
  - The car should start after charging the battery or changing the battery.
  - The car doesn't start because the battery is dead.
  - The car doesn't start even after charging the battery, the battery must have stopped working.
- 1, 2, 3, 4, 5, 6
  - 2, 1, 3, 4, 5, 6
  - 2, 1, 5, 4, 6, 3
  - 2, 1, 5, 6, 3, 4
14. Read the following questions. Does the statement lend itself to investigation using the scientific method? In other words, is the hypothesis falsifiable (can be proven false)?
- Is macaroni and cheese tastier than broccoli soup?
  - Are hummingbirds attracted to the color red?
  - Is the moon made out of green cheese?
  - Is plagiarism dishonest?
- Questions 1 and 2 are subjective and cannot be disproven using scientific method. Questions 3 and 4 can be tested using scientific method.
  - Questions 3 and 4 are subjective and cannot be disproven using scientific method. Questions 1 and 2 can be tested using scientific method.
  - Questions 1 and 3 are subjective and cannot be disproven using scientific method. Questions 2 and 4 can be tested using scientific method.
  - Questions 1 and 4 are subjective and cannot be disproven using scientific method. Questions 2 and 3 can be tested using scientific method.
15. Consider the levels of organization of the biological

world and place each of these items in order from smallest level of organization to most encompassing: skin cell, elephant, water molecule, planet Earth, tropical rainforest, hydrogen atom, wolf pack, liver.

- hydrogen atom, water molecule, skin cell, liver, elephant, wolf pack, tropical rainforest, planet Earth
- hydrogen atom, skin cell, water molecule, liver, elephant, wolf pack, tropical rainforest, planet Earth
- hydrogen atom, skin cell, water molecule, liver, wolf pack, elephant, tropical rainforest, planet Earth
- water molecule, hydrogen atom, skin cell, liver, elephant, wolf pack, tropical rainforest, planet Earth

16. What scientific evidence was used by Carl Woese to determine there should be a separate domain for Archaea?

- a sequence of DNA
- a sequence of rRNA
- a sequence of mRNA.
- a sequence of tRNA.

17. Both astronomy and astrology study the stars. Which one is considered a natural science? Explain your reasoning.

- Astrology is a natural science as it indirectly influences human affairs and the natural world.
- Astronomy is a natural science as it deals with observations and prediction of events in the sky, which is based on the laws of physics.
- Astrology is a natural science as it deals with observations and prediction of events in the sky, influences human affairs and the natural world.
- Astrology is a natural science as it deals with the study of asteroids and comets, which is based on the laws of natural sciences.

## TEST PREP FOR AP® COURSES

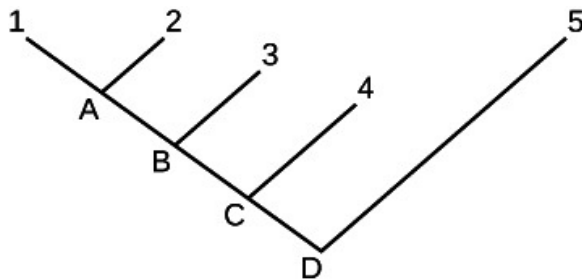
18. Which of the following structures is conserved in all living organisms and points to a common origin?

- All living organisms have mitochondria that produce energy.
- All living organisms store genetic material in DNA/RNA.
- All living organisms use the energy from sunlight
- All living organisms have a nucleus.

19. Which of the following statements is the strongest argument in favor of two organisms, A and B, being closely related evolutionarily?

- A and B look alike.
- A and B live in the same ecosystem.
- A and B use the same metabolic pathways.
- The DNA sequences of A and B are highly homologous.

20.

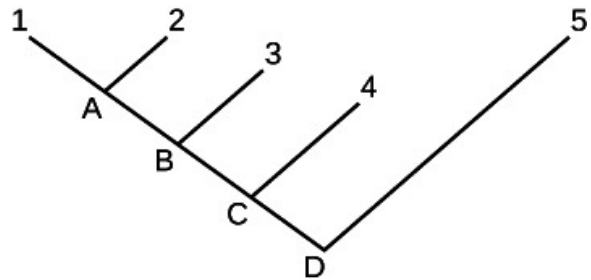


In the phylogenetic tree shown, which organism is most

distantly related to 2?

- 1
- 3
- 4
- 5

21.



In the diagram shown which is the most recent common ancestor of 1 and 3?

- A
- B
- C
- D

22. The French scientist Jacques Monod famously said, "Anything found to be true of *E. coli* must also be true of elephants." How is this statement based on the notion that living organisms share a common ancestor?

- a. *E. coli* is a eukaryote and share similarities with most of the living organisms.
- b. *E. coli* is a prokaryote. The various metabolic processes and core functions in *E. coli* share homology with higher organisms.
- c. *E. coli* contains a nucleus and membrane bound cell organelles that are shared by all the living organisms.
- d. *E. coli* is a prokaryote and reproduces through binary fission which is common to most of the living organisms.

23. Birds have been reclassified as reptiles. What is one

line of evidence that has led to this reclassification?

- a. *Archeopteryx* is the connecting link between birds and reptiles which shows that birds and reptiles are related.
- b. Birds have scales, having the same origin as that of reptiles.
- c. Birds and reptiles have the same circulatory and excretory systems and both are egg laying animals.
- d. Birds and reptiles have similar anatomical and morphological features.