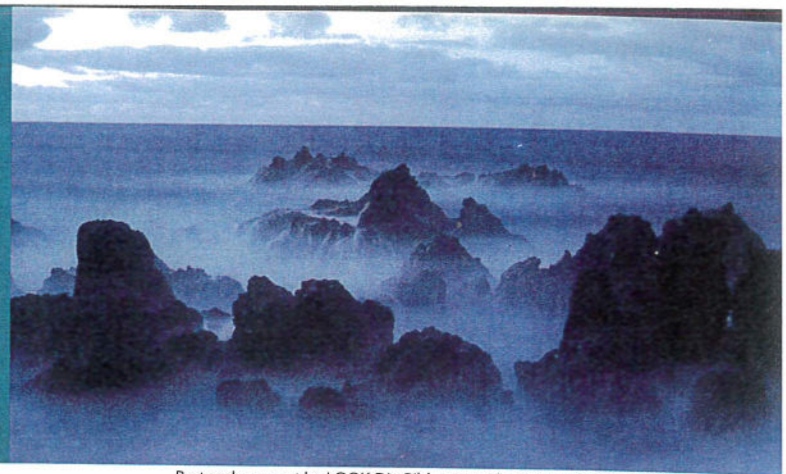
Unit 1
Chemistry of Life



Portugal seacoast by LOOK Die Bildagentur der Fotografen GmbH/Alamy

Module 0
Introduction

LEARNING GOALS ▶**LG 0.1** Four Big Ideas form a fundamental basis for understanding biology.
▶**LG 0.2** Scientific inquiry is a deliberate way of asking and answering questions about nature.

The ears of the snowshoe hare (*Lepus americanus*) stand tall as it listens carefully and its nose twitches as it smells the air for the scent of its predator, the Canada lynx (*Lynx canadensis*). At the same time, the lynx uses its keen eyesight, its sense of smell, and its ears to locate its prey, the hare. Having spotted the hare, the lynx quietly and deliberately moves toward it, slowly closing the distance between itself and the hare. Then, suddenly, the lynx springs upon the hare and the chase for life and food begins.

The activities of predator and prey depend on a number of key processes that they both possess. For instance, both hare and lynx are strong and swift runners. Both are exquisitely adapted to sense their habitats, be aware of danger, and identify potential sources of food. All of the processes employed by the hare and the lynx are part of the study of **biology,** the science of life. **Biologists,** scientists who study life, have come to understand a great deal about these and other processes. They attempt to explain why biology works as it does. That is, they explore the underlying principles and processes that shape and mold biological **organisms,** which are the living beings that display all of the properties of life. We don't know everything about how life works and there is still so much to discover, but the study of biology provides us with an organized way of understanding ourselves, other living things, and the world.

The scope of modern biology is vast and the pace at which we acquire new knowledge continues to accelerate. For example, in recent decades, we have gained unprecedented understanding of the **gene,** which is the unit of heredity, and the **genome,** which is all of the genetic information that an organism contains. This information is helping us come up with new ways of fighting disease in humans, other animals, and plants. It is also helping us understand how different groups of organisms have evolved and how endangered species might be saved. Many new biological frontiers have opened up in recent decades, while others are still waiting to be explored. For example, researchers are only just beginning to understand how bacteria in our digestive system affect our health and well-being. Other researchers are looking at how the temperature and acidity of seawater affect the ecology of coral reefs.

By the time you finish this course, you will have an understanding of how life works. You will explore the structure and function of **cells,** which are the simplest self-reproducing unit that can exist independently. You will look at pathways that cycle carbon through the biosphere. You will understand many of the processes that have shaped the living world. You will see connections among the different ways of investigating life and gain a greater understanding of how to ask and answer scientific questions. This study will help you develop a basis for making informed decisions about issues in your life that have a direct relationship to biology.

In this module, we begin our study of biology with a first look at the four Big Ideas of AP® Biology: Evolution, Energetics, Information Storage and Transmission, and

Systems Interactions. These four Big Ideas provide a framework for understanding and examining biology. After we examine the four Big Ideas, we will consider how biologists use scientific inquiry to understand how scientists ask and answer questions about the natural world.

PREP FOR THE AP® EXAM

FOCUS ON THE BIG IDEAS

Think about ways that each of the big ideas can serve as a different lens to look at life.

0.1 Four Big Ideas form a fundamental basis for understanding biology

Let's return to the snowshoe hare and Canada lynx, which are pictured in **FIGURE 0.1**. We can view this interaction from four different lenses, each providing the perspective of one of the four Big Ideas. From the lens of *evolution*, we can ask how the ancestors of snowshoe hares and lynxes developed their keen senses and ability to run swiftly and skillfully. From the lens of *energetics*, we can explore the food sources of both animals and how they use the fuel they acquire from these sources. From the lens of information storage and transmission, we can learn how the lynx knows to hunt the hare and how the hare knows to run, as well as how this information is passed on to subsequent generations. From the lens of systems interactions, we can investigate the ecosystem dynamics that bring the hare and lynx together or we can examine how the collection of cells that make up each individual animal communicate to enable the lynx to pursue the hare and the hare to evade the lynx.

FIGURE 0.1 Canada lynx and snowshoe hare chase

The photograph shows the snowshoe hare running to escape its predator, the Canada lynx. The lynx gives chase to obtain its food, the hare. The hare runs for its life. The example of the hare and the lynx exemplifies the four Big Ideas of the AP® Biology curriculum.
Photo: Tom & Pat Leeson/Science Source

Every unit in this text examines topics from the perspective of these four Big Ideas. As you read the modules of this book, tie in one or more of the Big Ideas to what you are learning. Doing so will help you to learn about biology and will assist you in understanding how biologists study and learn about life.

In this section, we will take a quick first look at each Big Idea. Although we present them one at a time, they are not really separate or distinct. Instead, they are inseparable in nature. To tackle biological problems—whether building an artificial cell, stopping the spread of infectious diseases like malaria or a coronavirus, feeding a growing population, or preserving endangered species—we need to understand these ideas and how they work together.

Big Idea 1: Evolution

Have you ever noticed how ants have the same body plan, but may be big or small, black or red? In fact, there are more than 10,000 different *species* of ants. A **species** is a group of interbreeding organisms that produce fertile offspring. A species is often distinct from other groups in body form, behavior, or biochemical properties. **FIGURE 0.2** shows two ant species. While there are many different species of ants and each has distinct characteristics, all ants have similar traits that enable us to recognize them as ants. Such similarities and differences are widely observed, and biologists refer to them as the unity and diversity of life. The study of **evolution,** or change over time, explains this unity and diversity of life. Evolution—Big Idea 1—is the central concept that unites all of biology, and biologists recognize it as a key principle of life.

All ants have some shared features, such as their distinctive segmented bodies and bent antennae. Ants are also diverse. For example, they vary in size and color. Some tolerate colder climates while others require warm, tropical places. Ants are not unique in displaying unity and diversity. Unity and diversity occur in all living creatures, from the a.

b.

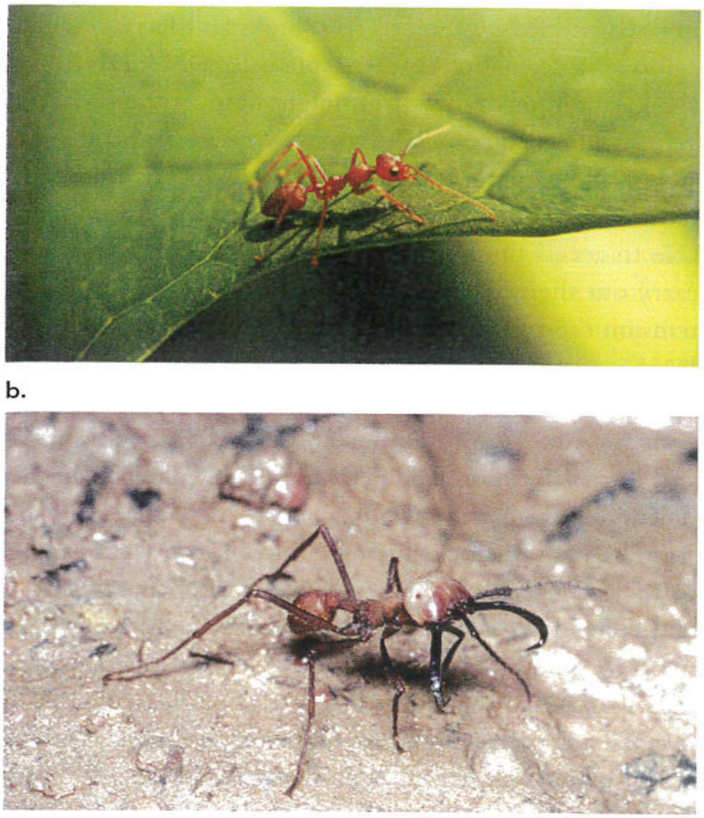


FIGURE 0.2 Unity and diversity in ants

All ants have common features, such as their segmented bodies and six legs. They also display considerable diversity, as evidenced by the shapes and sizes of their heads, mandibles (jaws), and abdomens (hindmost section). (a) This fire ant (*Solenopsis invicta*) is red and known for its painful sting. (b) This Costa Rican army ant (*Eciton burchellii*) has large mandibles and hunts in large groups. Photos: (a) Satrio Adi/EyeEm/Getty Images; (b) John Mason/ARDEA

smallest single-celled organisms to the great Sequoia trees and the largest animal ever, the 150-ton blue whale.

Evolution occurs by several different mechanisms that will be discussed in detail in Unit 7. Of these, perhaps the most significant is a process first described in the nineteenth century by Charles Darwin and Alfred Russel Wallace. Both of these naturalists suggested that species change over time by a process called *natural selection*. **Natural selection** is a mechanism of evolution in which some individuals survive and reproduce more than others in a particular environment as a result of variation among individuals that can be passed on to the next generation.

As Darwin recognized, farmers have used a principle similar to natural selection for thousands of years to develop crops, such as wheat, corn, cabbage, and broccoli. It is how people around the world have developed breeds of horses, pigeons, cats, and dogs, like the two shown in **FIGURE 0.3**. And it is why many bacteria and other disease-causing microorganisms have stopped responding to antibiotics, which is becoming a public health crisis. Life has been shaped by evolution since its origin, and the capacity for Darwinian evolution may be life's most fundamental property.

The concept of natural selection was in part inspired by observing strong competition for survival and reproduction. For example, among animals, individuals often compete for food. In a Canada lynx population, the fastest and most skilled hunters are more likely to succeed in catching hares, and therefore surviving and reproducing. Slower and less skilled Canada lynx are more likely to perish before they can reproduce. If the animals with better hunting skills reproduce more and have more viable offspring, their offspring will predominate in the next generation.

And just as natural selection has shaped predators, it has also shaped prey. Predator–prey interactions are important in every habitat on Earth. After all, every living animal can be classified as either "predator" or "prey"—and often both labels apply. The skills that a predator needs to hunt its prey and that its prey needs to escape depend in large part on

FIGURE 0.3 Dog breeds

Dog breeders use a process similar to natural selection to develop many different breeds of dogs, such as this husky and terrier. Photo: © Rob Brodman 2011 a host of features of their nervous, sensory, musculoskeletal, endocrine, circulatory, and respiratory systems. In short, natural selection has left a physical imprint on both predator and prey, from nose to tail.

As we examine a wide range of biological topics throughout the book, you will notice that evolution permeates these discussions—whether we are explaining the biochemistry of cells, how organisms function and reproduce, how species interact in nature, or the remarkable biological diversity of our planet.

Big Idea 2: Energetics

All life forms require *energy* to survive, grow, move about, and reproduce. **Energy** is the ability to do work and it is absolutely essential for life. The study of **energetics** examines the properties of energy and how energy is distributed in biological, chemical, or physical processes.

Strategies to capture and use energy vary among species and depend on their evolutionary history. Plants use the energy of sunlight to produce their own food to grow, reproduce, and carry out their functions. Humans and other animals obtain energy by eating other organisms. In fact, all organisms obtain energy from just two sources—the sun or chemical compounds. Losing or reducing access to sources of energy can have damaging and sometimes fatal consequences for organisms.

Consider what happens when you eat an apple. The apple contains sugars, which store energy. By breaking down sugar, our cells harness this energy and convert it into a form that can be used to do the work of the cell. Energy from the food we eat allows us to grow, move, communicate, and do all the other things that we do. Using sugar as a source of energy to power the cell is not a strategy that is just used by human cells. It is widespread among organisms and represents another unifying characteristic of most species. This observation suggests that the ability to use sugar as a source of energy evolved early in the history of life and has been retained over time. We will delve more deeply into how organisms access and use energy in Unit 3.

Big Idea 3: Information Storage and Transmission

Big Idea 3 looks at biology from the perspective of information storage and transmission. In this context, information refers to the instructions that all cells have that in part determine what they look like and how they function. For example, how does your skin cell "know" to be a skin cell and not a liver cell? The answer is that it contains information that is used by the cell, so it looks and acts like a skin cell. This information is stored in a cell's *DNA*. **DNA,** the abbreviation for **deoxyribonucleic acid,** is the carrier of genetic information for all organisms.

In addition to storing information, cells must also retrieve this information. In other words, they need to be able to access the information and use to it to grow and carry out their functions. Finally, cells need to be able to transmit their genetic information to the next generation. DNA is remarkable because it can store genetic information, allow this information to be retrieved and used by the cell, and transmit this information to the next generation. We will learn a lot more about DNA and its role later in this unit and throughout the book.

The transmission of genetic information from parents to their offspring enables species of organisms to maintain their identity through time. The genetic information in DNA guides the development of the offspring, ensuring that parental apple trees give rise to apple seedlings and parental geese give rise to goslings. Furthermore, variation in this genetic information allows some organisms to survive and reproduce in particular environments more than others. Through natural selection, these organisms pass on the genetic variants that account for their ability to do well in their environment. For example, if faster speed enhances survival and reproduction among hares and Canada lynx, the underlying genetic variation that accounts for this trait will likely be passed on to the next generation. Therefore, Big Idea 3—Information Storage and Transmission—is essential to the survival, growth, reproduction, and evolution of a species.

Big Idea 4: Systems Interactions

A **system** is a group of things that function together as a whole. We can consider systems at different levels of scale, from a single cell in a hare to an entire forest, which includes many interactions that occur among the organisms and nonliving materials it contains. Biologists refer to living organisms as **biotic,** and nonliving components as **abiotic.** A **biological system** is made up of both biotic and abiotic entities that interact. As a result of these interactions, biological systems show complex properties.

Big Idea 4 recognizes that biological systems exist at different levels, from the simple to the complex, and interactions among the parts of the system lead to new, emergent properties. An emergent property is a property of a system that the individual parts do not have on their own.

For example, the muscles in the leg of the hare in Figure 0.1 interact with the leg bones, tendons, and nerves to provide movement and remarkable agility. The Canada lynx, using its nervous, sensory, musculoskeletal, cardiovascular, and respiratory systems working together, is able to note the presence of the snowshoe hare, plan a strategy, hunt, chase, and possibly catch the hare.

If we examine the various components that interact with one another in an organism, we will observe the resulting emergent property, which is life. The interactions among the parts of a biological system are hallmarks of life and are found at all levels of biological organization. For example, when fresh water from a large river meets the ocean, the ocean's salty water becomes diluted with fresh water. The mixture of these waters results in a number of new environments where animals, plants, and microorganisms may live, including estuaries, like the one shown in **FIGURE 0.4**. The environment of the estuary is different from the river and ocean systems that created it and it provides a unique habitat for many different species.

From the molecular to the cellular to the organismal to the biosphere levels, biological systems are diverse and complex. These features enable biological systems to have a robustness that helps them to withstand, tolerate, and respond to the changes in the environment. Like evolution, energy, and information storage and transmission, biological systems interactions help ensure the survival and reproduction of organisms, populations, species, and—on a larger scale—life. **Visual Synthesis 1.1: The Four Big Ideas of AP® Biology,** on page 18, illustrates the connectedness of these concepts.

FIGURE 0.4 Estuaries as a biological system

Estuaries such as the Sado Estuary Natural Reserve in Portugal are formed in areas where salt water from oceans and fresh water from rivers mix. Photo: Maurício Abreu/AGE Fotostock

✓ Concept Check

1. **Describe** how a comparison of a fire ant and an army ant shows both the unity and diversity of life.
2. **Identify** why a lack of energy would result in the death of an organism.
3. **Describe** what would happen if organisms were unable to retrieve the information contained in their genes.
4. **Describe** an example of how a systems interaction allows an organism to adjust to its environment.

0.2 Scientific inquiry is a deliberate way of asking and answering questions about nature

How do we go about trying to understand the vastness and complexity of nature? **Scientific inquiry** is the process scientists use to ask questions and seek answers about the natural world in a deliberate and ordered way. Scientific inquiry is limited to investigations of the natural world. Examination of questions not in the natural world, such as questions about religion, faith, and morality, are outside the realm of scientific inquiry.

Scientific inquiry provides the opportunity to observe, investigate, and explain how natural phenomena occur. As shown in **FIGURE 0.5**, scientific inquiry consists of three parts: exploration, investigation, and communication. We will now examine how scientists use scientific inquiry to conduct an orderly and logical investigation of the natural world and communicate their findings with others.

Making Observations and Asking Questions

For most scientists, studies of the natural world begin with exploration. In the exploration phase, scientists make observations and ask questions. **Observation** is the act of viewing the world around us. Observations allow us to ask focused questions about nature. For example, Charles Darwin initially made many observations about anatomy, embryology, domesticated plants and animals, fossils, and the distribution of organisms on the Earth. These observations led him to ask questions. Why are organisms adapted, often exquisitely, to their environment? Why do some fossil organisms resemble living ones? Why are there penguins in the Southern Hemisphere but not the Northern Hemisphere? Why are islands home to so many species that are found nowhere else in the world?

Let's say you observe a hummingbird, like the one pictured in **FIGURE 0.6**, hovering near a red flower, occasionally dipping its long beak into the bloom. What motivates this behavior? Is the bird feeding on some substance within the flower? Is it drawn to the flower by its vivid color? What benefit, if any, does the flowering plant derive from the bird?

Having formulated these questions, the next step that scientists often take is to consult the scientific literature, which is the published information about observations and experiments that others have done. In our example, the scientist would likely review those papers that focus on hummingbird feeding habits and possibly on the effects hummingbirds have on plants they visit. Having reviewed the scientific literature, the scientist should have enough knowledge to start refining questions that would be interesting to investigate.

Regardless of where they come from or when they arise in the process, questions are the keys to scientific inquiry. Indeed, learning to ask good questions is a fundamental component of thinking like a scientist.

Formulating Hypotheses

Observations such as those about the hummingbird, the questions observations raise, and consulting the scientific literature allow us to move on to investigation. Scientists use observation and critical thinking to propose a *hypothesis*. A **hypothesis** is a tentative explanation for one or more observations, and it makes predictions that can be tested by experimentation or additional observations. A hypothesis is not just an idea or hunch. It is a working explanation that helps a researcher understand an observation and leads to a better understanding of the observation.

We might, for example, hypothesize that a hummingbird is carrying pollen from one flower to the next, facilitating reproduction in the plant. Or we might hypothesize that nectar produced by the flower provides nutrition for

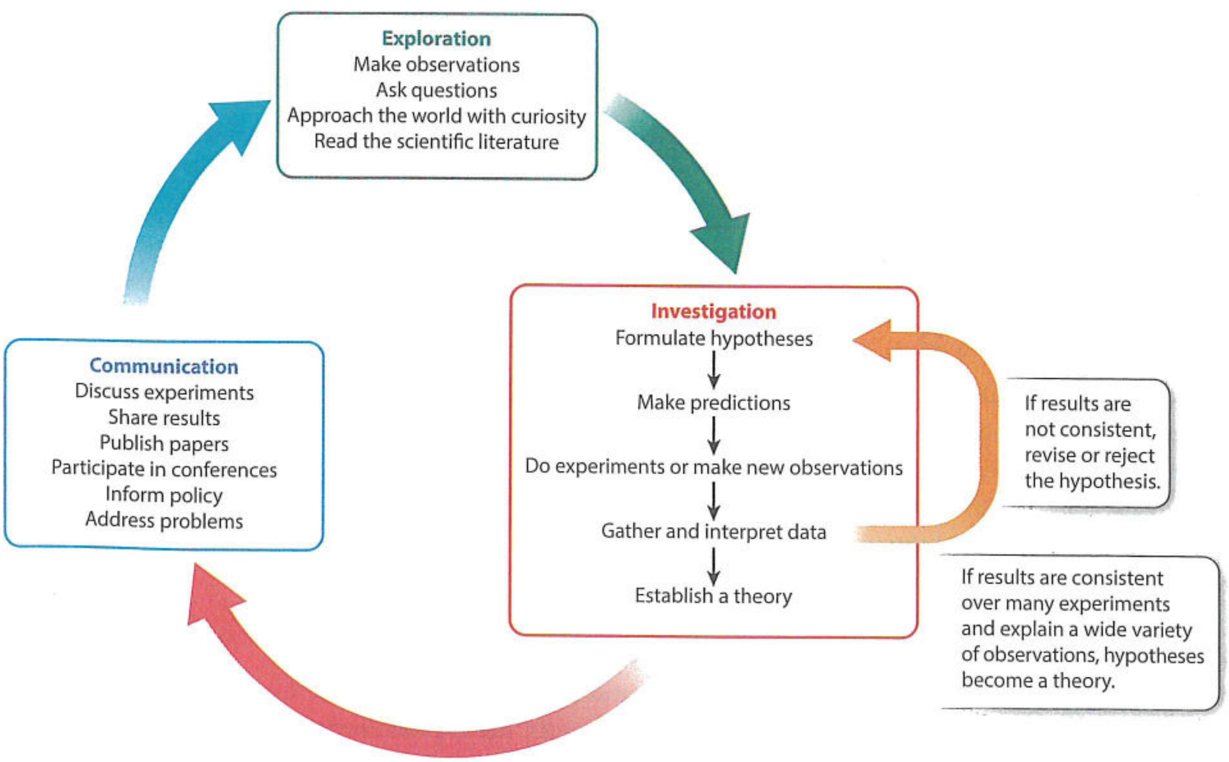


FIGURE 0.5 Scientific Inquiry

Scientific inquiry is the organized, deliberate process that scientists use to examine the natural world. It consists of three parts: exploration, investigation, and communication.

FIGURE 0.6 Observation

Observing a hummingbird visiting a flower may lead to a number of questions that a scientist can explore. Photo: Charles J. Smith

the hummingbird—that the hummingbird's actions reflect its need to take in food. Both hypotheses about the hummingbird's behavior provide a reasonable explanation of our observations, but they may or may not be correct. The predictions of the hypothesis lead to further observation or experimentation.

Because hypotheses make predictions, we can test them. That is, we can devise an experiment to test whether the predictions made by the hypothesis are supported by the evidence, or we can go into the field to make further observations predicted by the hypothesis.

Scientists collect data by observation or experimentation, or both. They will then analyze the data and determine if the data support the hypothesis. If the data do not support the hypothesis, the hypothesis is rejected. In this case, the researcher may generate a new hypothesis. If the data support the hypothesis, it gains support and further questions can be asked. These questions may refine or extend the hypothesis.

Returning to the hummingbird and flower, we can test the hypothesis that the bird is transporting pollen from one flowering plant to the next, enabling the plant to reproduce. Observation provides one type of test: if we catch and examine the bird just after it visits a flower, do we find pollen stuck to its beak or feathers? If so, our hypothesis is supported by the data.

The test, however, cannot prove the hypothesis. Pollen might be stuck on the bird for a different reason—perhaps it provides food for the hummingbird. However, if the birds didn't carry pollen from flower to flower, we would reject the hypothesis that they facilitate pollination. In other words, a single observation or experiment can lead us to reject a hypothesis, or it can support the hypothesis, but it cannot prove that a hypothesis is correct. To move forward, then, we might undertake a second set of observations. Does pollen that adheres to the hummingbird rub off when the bird visits a second flower of the same species? If so, we have stronger evidence and support for our hypothesis.

We might also use observations to test a more general hypothesis about birds and flowers. Does the color red generally attract birds and thereby facilitate pollination in a wide range of flowers? To answer this question, we might catalog the pollination of many red flowers and ask whether they are pollinated mainly by birds. Or we might go the opposite direction and catalog the flowers visited by many different birds—are they more likely to be red than chance alone might predict?

Designing Controlled Experiments

Our hummingbird example used observation to test several different hypotheses, but scientists often test hypotheses through experimentation. One of the most powerful types of experiment is a *controlled experiment*. In a **controlled experiment,** the researcher sets up at least two groups to be tested; the conditions and setup of the groups are identical, except the researcher deliberately introduces a single change, or variable, in one group to see its effect.

Suppose we want to understand the relationship between caffeine consumption and the heart rate when a person is not exercising, which is known as resting heart rate. We might hypothesize that caffeine causes an increase in resting heart rate. This hypothesis could be based on our own experience and observations, or perhaps the scientific literature. To test this hypothesis, we can carry out a controlled experiment. In this case, we might have two groups of people who are similar in terms of age, gender, socioeconomic background, health, and so on. One group is given caffeine, perhaps in the form of a cup of coffee. This group is called the **test group** or **experimental group** because this group experiences the variable—it receives caffeine. In a second group, the people are not given any caffeine. This group is called the **control group** because it is not exposed to the variable.

Why is it necessary to include a control group? Imagine for a moment that there was just a test group and no control group, and the resting heart rate of the people in the test group went up after they drank a cup of coffee. In this case, you might conclude that the hypothesis is supported and caffeine increased heart rate. But how do you know that the heart rate of people in the group didn't increase on its own? How do you know the variable that was changed caused the observed effect? The control group shows what happens without caffeine so researchers can compare what happens with and without the variable, holding every other factor the same. In this way, they can determine if the variable accounts for any changes in heart rate.

In a test of this hypothesis, the action of consuming caffeine is known as the **independent variable,** the variable that is manipulated to test the hypothesis. This variable is considered "independent" because the researchers can manipulate it as they wish. The result of the experiment—resting heart rate—is known as the **dependent variable.** This variable is considered "dependent" because it is expected to vary based on the independent variable.

Scientists use controlled experiments because they are extremely powerful. By changing just one independent variable at a time, the researcher is able to determine whether that variable is important. If many independent variables were changed at once, it would be difficult, if not impossible, to draw conclusions from the experiment because the researcher would not be able to determine which variable caused the outcome.

Our experiment testing the relationship between caffeine consumption and resting heart rate is very simple. In reality, we might include more than two groups of people. For example, we could test how the amount of caffeine affects resting heart rate by giving several groups different numbers of cups of coffee. In this case, there are several test groups, each of which receives the variable of caffeine. We could also include more than one control group. One could receive nothing to drink and the other a cup of water. In both cases, the control groups do not receive caffeine. However, by providing a cup of water, we control for the potential variable of drinking. Both of these control groups are also called **negative control groups** because the expectation is that we will see no effect. We could also include a **positive control group.** This is a group that receives a treatment or variable with a known result. In our example, we could give a medicine that is known to increase heart rate to be sure that heart rate increases as expected.

If observations or experiments do not support a hypothesis, the researcher modifies or rejects the hypothesis. If observations or experiments support a hypothesis, the researcher accepts the hypothesis and then subjects it to more scrutiny by making further observations and doing additional experiments. As we saw in the hummingbird example, a hypothesis may be supported, but it is never proven because we can never know for certain whether it is true in all cases.

FIGURE 0.7 Daffodils

Daffodils, like the ones shown here, were the subject of scientific inquiry by James Kirkham Ramsbottom, who tried to track down what was causing their deaths in the early 1900s. Photo: Victoria Ambrosi/EyeEm/Getty Images

Let's now turn our attention to a real-world experiment that demonstrates some of the features we have been discussing. "Practicing Science 0.1: Using observation and experimentation to examine a horticultural problem" shows how a young scientist used the process of scientific inquiry to determine the cause of death in daffodils, like the ones shown in **FIGURE 0.7**, and to create an effective treatment. This study also gives us a chance to review how to use percentages when evaluating data, described in "Analyzing Statistics and Data: Percent Change" on page 10.

PREP FOR THE AP® EXAM

AP® EXAM TIP

You should know how to design a controlled experiment with a clear and precise hypothesis. The design should include experimental and control groups, and independent and dependent variables.

Practicing Science 0.1

PREP FOR THE AP® EXAM

Using observation and experimentation to investigate a horticultural problem

Background Scientific inquiry is often called upon to address problems that arise in society and industry. In 1916, British horticulturalists were concerned with a disease that killed daffodils. Daffodils grow from bulbs, which are large underground stems that store energy and are seen in many plants, such as daffodils, tulips, and onions. However, the disease caused leaves to wither, bulbs to become discolored, and eventually death of the plant. The demise of the plants represented a substantial loss of commercial production and income to the horticultural industry. While some suspected a fungus caused the plant deaths, no one was able to determine the source of the problem.

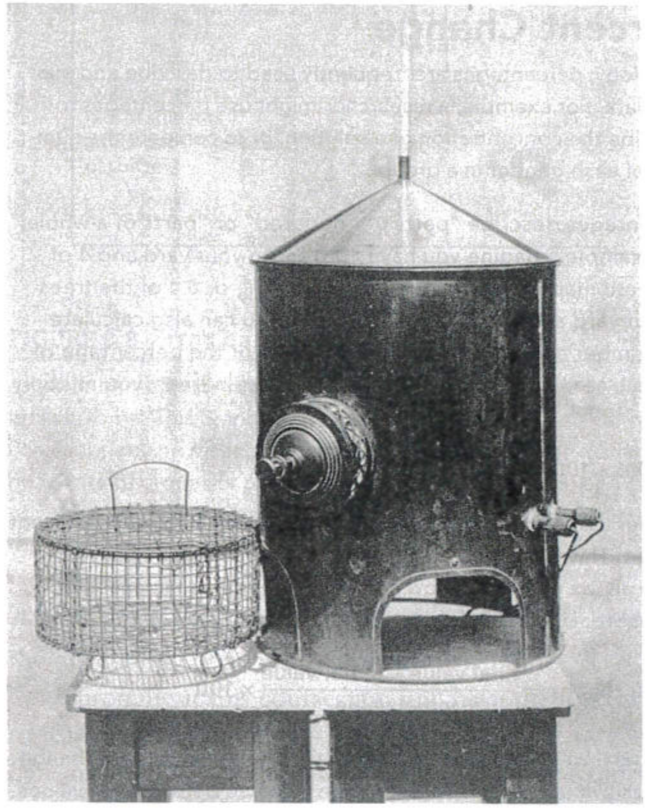
The British Royal Horticultural Society took up the cause and assigned the problem to James Kirkham Ramsbottom. At the time he was a top student at the Royal Horticultural Society's garden in Wisley, a community near London.

Observation and Hypothesis Ramsbottom began by making observations. He examined hundreds of diseased bulbs, preparing microscopic slides and studying them closely. While he did see fungi, Ramsbottom observed that all of the diseased bulbs contained a parasitic worm, *Tylenchus devastratix*. Ramsbottom hypothesized that the worm was the cause of the disease afflicting the plants and predicted that if he could devise a way to kill the worm without killing the bulbs, the disease would be eliminated.

Experimentation Ramsbottom launched a series of experiments where he examined a number of agents that might selectively kill the worm while keeping the plant alive. He tried chemical treatments, spraying the plants and dousing them. He experimented with both gas and formaldehyde. He settled on the use of heat. Ramsbottom immersed the bulbs for different amounts of time in hot water. The photograph shows the removable wire basket and copper boiler that permitted Ramsbottom to heat the daffodil bulbs for different periods of time. He determined that soaking them in 110°F (43°C) water for 2 to 4 hours left the bulbs intact while the parasite was eliminated. Untreated, infected daffodil bulbs failed to grow, died, and did not produce flowers. The heat-treated daffodil bulbs grew normally and produced the sought-after plant and flower. Today, the Ramsbottom heat treatment is still used in virtually the same manner as he developed it.

SOURCE

Flower Preservation, 1916. *The Scientist,* 2:64. Photo: His Majesty's Stationery Office/RHS Lindley Collections



AP® PRACTICE QUESTION

James Kirkham Ramsbottom used the process of scientific inquiry to figure out what was causing the death of daffodils. Organize the description of his experiment by identifying the following:

1. The scientific (testable) question
2. The hypothesis
3. The independent variable
4. The dependent variable
5. The experimental group
6. The control group

Analyzing and Interpreting Data

After conducting an observational or controlled experiment, the scientist has a collection of data. Data are the bedrock of science. Biologists collect, analyze, and interpret data to answer questions about the natural world. Hypotheses are supported or rejected on the basis of data, and our understanding of the world is ultimately built on a foundation of data.

What types of data will you encounter in your AP® Biology course? Data can take many forms, including observations, measurements, and facts. Data can be qualitative

ANALYZING STATISTICS AND DATA

PREP FOR THE AP® EXAM

Percent Change

In biology, percentages are frequently used to describe and analyze data. For example, a researcher might use percentages to describe the concentration of a solution, or to compare the numbers of each gender in a group.

Percentages describe "parts per hundred" or "parts of a whole." For example, imagine you have 10 trees in your yard and 4 of them are maple trees. You could say that $\frac{4}{10}$ or 0.4 of the trees in your yard are maple trees. However, you can also calculate the number of maple trees per 100 trees, or the percentage of maple trees. To find the percentage of maple trees, you multiply 0.4 by 100:

$$0.4 \times 100 = 40\%$$

In other cases, scientists might be interested in calculating percent change. This is useful to compare an initial value to a final value, which allows you to see how much something has increased or decreased. Use the following formula to calculate percent change:

$$\% \text{ change} = \frac{\text{final value} - \text{initial value}}{\text{initial value}} \times 100$$

If the final value is larger than the initial value, the percent change is a positive number, representing an increase between the values you are comparing. If the final value is smaller than the initial value, the percent change is a negative number, signifying a decrease between the values you are comparing.

PRACTICE THE SKILL

Let's look at an example of how percent change might be used. James Kirkham Ramsbottom discovered a way to eliminate parasites from daffodil bulbs by immersing them in hot water. Before he found an effective soaking time of 2 to 4 hours, he immersed 50 bulbs for 30 minutes and 50 bulbs for 1 hour. At the end of 30 minutes, 10 of the daffodil bulbs were free of parasites. After 1 hour, 25 of the bulbs were free of parasites. What was the percent change in the number of healthy, parasite-free bulbs as the immersion time increased?

To start, we must find the two values we need to calculate percent change. After 30 minutes, 10 of the 50 bulbs were free of parasites. The initial value is 10 bulbs. At the end of 1 hour, 25 bulbs were free of parasites. So, the final value is 25 bulbs. Now we can plug these values into our formula:

$$\% \text{ Change} = \frac{25 - 10}{10} \times 100$$

$$\% \text{ Change} = \frac{15}{10} \times 100$$

$$\% \text{ Change} = 1.5 \times 100$$

$$\% \text{ Change} = 150\%$$

There was a 150% increase in parasite-free bulbs as Ramsbottom changed the immersion time from 30 minutes to 1 hour.

Your Turn

The emerald ash borer is an invasive species that has destroyed ash tree populations in North America. Before the insect arrived, one forest contained 300 ash trees. A number of years after the ash borer was introduced to the area, only 60 ash trees remained. By what percent did the ash tree population decrease?

or quantitative. Qualitative data are descriptive. For example, the stem of a corn plant can be described as "short" or "tall." Quantitative data are expressed numerically. For example, a corn stem might measure 2.04 m or 2.76 m in length. Similarly, the heart rate data that we collected in our controlled experiment is an example of quantitative data. Scientists often deal with quantitative data because numbers lend themselves to statistical analysis.

Statistical analysis helps scientists interpret the data they collect. For example, when several measurements are made, they are typically not all the same. In this case, the researcher might report the average of the measurements. The researcher might also indicate the extent to which the observed measurements deviate from the average. The spread of the data can be calculated in various ways, each of which provides an indication of how tightly the data points are clustered around the average.

Statistics can also help researchers understand whether the data collected for the experimental and control groups reflect a real, or what is termed a statistically significant, difference. For example, in the caffeine experiment, let's say we observe that resting heart rate is higher in the test group compared to the control group. Is this difference the result of caffeine, in which case scientists call it a real difference? Or is the difference just due to chance?

To answer this question, researchers begin by stating a **null hypothesis,** which predicts that the intervention or treatment has no effect at all. In other words, any difference between the test and control groups is due to chance alone and nothing else is responsible for the difference between the two groups. In this case, the null hypothesis is that caffeine does not cause an increase in heart rate. They also state an **alternative hypothesis,** which predicts that the intervention or treatment has an effect, so the difference between the test and control groups is real. In this case, the alternative hypothesis is that caffeine causes an increase in resting heart rate.

A statistical test normally yields a number, called the *p*-value, that expresses the likelihood that an observed result could have been observed merely by chance. A *p*-value is a probability. If $p \leq 0.05$ (5%), there is less than or equal to a 5% chance that the observed results are the result of chance. This is a relatively small chance. In this case, it is likely that the observed results in a dataset are real and not due to chance. In other words, the null hypothesis is rejected. By contrast, if $p > 0.05$, there is greater than a 5% chance that the observed results could have been obtained by chance, so you fail to reject the null hypothesis. The phrasing "the null hypothesis has failed to be rejected" reminds us that although the results do not support the alternative hypothesis, it does not mean that the null hypothesis is correct. Rather, it simply means that the null hypothesis has not been disproven.

Finally, scientists are often interested in determining how confident they should be in their data. Uncertainty can be shown graphically as an error bar. An error bar is typically a short vertical line showing a range of values. For example, **FIGURE 0.8** shows results from our controlled experiment investigating the relationship between caffeine and resting heart rate. The data points indicate the average heart rate of the people in the groups. The vertical lines through the data points are error bars. In spite of its name, an error bar doesn't represent an error or a mistake. Instead, it shows a range of values that incorporates small differences among the individuals and perhaps even inaccuracies in the measurements.

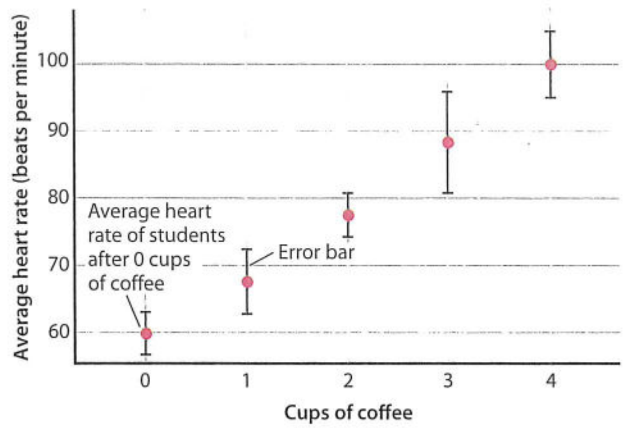


FIGURE 0.8 Error bars

An error bar represents a range of values within which the true value is likely to be. This graph shows the relationship between caffeine consumption and resting heart rate. It plots the average resting heart rate of groups of people who consumed 0, 1, 2, 3, or 4 cups of coffee, with error bars giving an indication of the uncertainty of the data.

As a result, you can think of the error bar as a way to show the uncertainty of a measurement or data point.

Throughout this course, you will have the opportunity to learn some of the techniques researchers use to evaluate data and to work with data yourself. "Tutorial 1: Statistics" on page 20 walks you through some of the statistics tools you will encounter. "Analyzing Statistics and Data: Averages" gives you a chance to practice working with these concepts.

PREP FOR THE AP® EXAM

AP® EXAM TIP

When evaluating the results of an experiment, you should be able to explain whether the alternative hypothesis is supported or not, and whether the null hypothesis should be rejected or fail to be rejected. You should know that data are often analyzed statistically to determine if real differences exist between the data collected from the experimental and control groups.

ANALYZING STATISTICS AND DATA

PREP FOR THE AP® EXAM

Averages

For a detailed explanation of how to calculate mean, median, and mode, see page 20 for "Tutorial 1: Statistics." Here we review how to apply the concepts of mean, median, and mode and offer a problem for you to try.

PRACTICE THE SKILL

Below is a table listing several different ant species and the number of queens commonly found in a colony of each species. Considering the entire dataset, which measurement of the number of queens is largest: the mean, median, or mode?

Ant species	Number of queens in a small colony
Carpenter ant (*Camponotus pennsylvanicus*)	1
Red imported fire ant (*Solenopsis invicta*)	30
Pavement ant (*Tetramorium caespitum*)	5
Crazy ant (*Paratrechina longicornus*)	12
Pharaoh ant (*Monomorium pharaonis*)	2
Ghost ant (*Tapinoma melanocephalum*)	20
Little black ant (*Monomorium minimum*)	5
Argentine ant (*Linepithema humile*)	7

Data from https://www.environmentalscience.bayer.us/-/media/prfunitedstates/documents/resource-library/product-guide/ant-id-guide.ashx

To determine which number is the largest of all of the measurements, we'll have to calculate the mean, median, and mode. Let's begin by calculating the mean of the dataset. In order to do this, we add together all of the values in the dataset and divide the sum by the number of values in the dataset. The sum of the values is:

$$1 + 30 + 5 + 12 + 2 + 20 + 5 + 7 = 82$$

We divide this sum by the number of values in the dataset, which in this case is 8:

$$82 \div 8 = 10.25$$

So, the mean is 10.25.

We can also do this calculation using the following equation, where $\bar{x}$ is the mean, n is the number of values in the dataset, and $\sum_{i=1}^{n} x_i$ is the sum of all of the values in the dataset:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\bar{x} = \frac{1}{8}\sum_{i=1}^{8}(1 + 30 + 5 + 12 + 2 + 20 + 5 + 7)$$

$$\bar{x} = \frac{1}{8}(82) = 10.25$$

We can find the median and mode by placing the values in numerical order:

1, 2, 5, 5, 7, 12, 20, 30

The median is the midpoint of this dataset of eight values. Because we have an even number of values, the median is the mean of the two middle values, 5 and 7.

$$5 + 7 = 12$$
$$12 \div 2 = 6$$

So, the median is 6.

We can now find the mode. The mode is the most frequent value in a dataset. If we look at the number of queens, we can see that the number 5 appears twice, more than any other value. So, the mode is 5.

The mean is 10.3, the median is 6, and the mode is 5. The largest of the three values in this case is the mean. Each of these numbers describes the dataset in a different way, which is described in "Tutorial 1: Statistics."

Your Turn

A researcher has planted bean seedlings under different light, moisture, and nutrient conditions and monitored their growth over several weeks. The data are recorded in the table. What are the mean, median, and mode for seedling height?

Bean seedling plant	Seedling height (cm)
1	20
2	6
3	15
4	23
5	5
6	15
7	21

Communicating Findings

We have seen that scientific inquiry encompasses several careful and deliberate ways of asking and answering questions about the unknown. We ask questions, make observations, collect field or laboratory samples, and design and carry out experiments to make sense of things we initially do not understand.

Another critical step in scientific inquiry, shown in Figure 0.5, is communication with other scientists and the public. Scientists publish their work in journals and present data at meetings and conferences. Sharing this information is crucial because it informs both other scientists and the public. By making the studies and data known, the results from scientific investigation are shared so that others may use the information to inform and guide future research and perhaps public action.

Scientific inquiry is typically not a linear process that proceeds in an orderly way from question to hypothesis to experiment to communication. It more accurately resembles a circle, where questions lead to experiments that lead to more questions. And there are frequent failures, false starts, and rejected hypotheses. These are all part of the process of scientific inquiry. In fact, the ability to make corrections, refine explanations, and reject hypotheses makes scientific inquiry a powerful method to understand the world around us.

Every scientist experiences failure, but good scientists learn from failed experiments, using the results to plan new ways of approaching problems. Once we obtain results that provide new understanding, we communicate what we find with other scientists and the public. Discussing and sharing ideas and results often leads to new questions, which in turn can be tested by more observations and experiments.

Establishing Theories

A hypothesis may initially be tentative. It often provides one of several possible ways to explain an observation. With repeated observation and experimentation, a good hypothesis gathers strength and researchers have more and more confidence in it. When a number of related hypotheses survive repeated testing and come to be accepted as good bases for explaining what we see in nature, scientists articulate a broader explanation that accounts for these hypotheses and the results of their tests. We call this statement a **theory,** a general explanation of the world supported by a large body of experimental evidence and observations. Examples of well-established theories include the theory of gravity, the chromosome theory, the germ theory, the cell theory, and the theory of evolution.

Scientists use the word "theory" in a very particular way. In general conversation, "theory" is often synonymous with "hypothesis," "idea," or "hunch." For example, you might say, "I've got a theory about why the car won't start." But in a scientific context, the word "theory" has a specific meaning. Scientists speak in terms of theories only if hypotheses have withstood testing to the point where they provide a general explanation for many observations and experimental results.

Just as a good hypothesis makes testable predictions, a good theory both generates hypotheses and predicts their outcomes. For example, the theory of gravity arises from a set of hypotheses you test every day by walking down the street or dropping a fork. Similarly, the theory of evolution is not just one explanation among many for the unity and diversity of life. Instead, it is a set of hypotheses that has been tested for more than a century and shown to provide an extraordinarily powerful explanation of biological observations. In fact, as we discuss throughout this book, evolution is one of the most significant theories in all of biology. It provides the most general and powerful explanation of how life works.

✓ Concept Check

5. **Describe** how a scientist turns an observation into a hypothesis and investigates that hypothesis.

6. **Describe** the differences between an experimental (test) group and a control group, and why it is important for an experiment to include both types of groups.

7. **Identify** the differences among a guess, hypothesis, and theory.

Module 0 Summary

PREP FOR THE AP® EXAM

REVISIT THE BIG IDEAS

Using the content of this module, pick your favorite organism and **describe** it in four different ways, using each of the four Big Ideas.

LG 0.1 Four Big Ideas form a fundamental basis for understanding biology.

- Evolution is the unifying principle of biology. Page 2
- Evolution explains how organisms are similar and how they are different from one another. Page 2
- Natural selection is one of the major mechanisms of evolution. Page 3
- Energy is required by all life forms in order to survive, grow, and reproduce. Page 4
- Organisms harness energy from the sun or from chemical compounds. Page 4
- DNA stores and transmits genetic information in all organisms. Page 4
- The ability to store, retrieve, and transmit genetic information is necessary for cellular function and the process of evolution. Page 4
- Cells, organisms, and the biosphere are all systems that work in an integrated and coordinated fashion to sustain life. Page 4
- Interactions of the components of a system often result in emergent or new properties that are more than a simple addition of the individual components. Page 4
- Systems interactions are diverse and occur at every level, from cells to organisms to communities to the biosphere. Page 5

LG 0.2 Scientific inquiry is a deliberate way of asking and answering questions about nature.

- Scientific inquiry involves making observations, asking questions, doing experiments or making further observations, and drawing and sharing conclusions. Page 5
- Observations are used to generate a hypothesis, a tentative explanation that makes predictions that can be tested. Page 6
- On the basis of a hypothesis, scientists design experiments and make additional observations which test the hypothesis. Page 7
- A controlled experiment involves different groups in which all the conditions are the same except for a single variable. In the test group, a variable is deliberately introduced to determine whether that variable has an effect. In the control group, the variable is not introduced. Page 8
- The independent variable in a controlled experiment is the factor that is changed by the researcher; the dependent variable is the effect or result that is being observed or measured. Page 8
- The null hypothesis predicts that an intervention or treatment in an experiment will have no effect; the alternative hypothesis predicts that the intervention or treatment will have an effect. Page 11
- Hypotheses cannot be proven, but they can be modified or rejected based on observation or experiments. Page 13
- If a hypothesis is supported by continued observation and experiments over time, it is elevated to a theory, a sound and broad explanation of some aspect of the world. Page 13

Key Terms

- Biology
- Biologist
- Organism
- Gene
- Genome
- Cell
- Species
- Evolution
- Natural selection
- Energy
- Energetics
- Deoxyribonucleic acid (DNA)
- System
- Biotic
- Abiotic
- Biological system
- Scientific inquiry
- Observation
- Hypothesis
- Controlled experiment
- Test group
- Experimental group
- Control group
- Independent variable
- Dependent variable
- Negative control group
- Positive control group
- Null hypothesis
- Alternative hypothesis
- Theory

Review Questions

1. Biology is the
   (A) study of components that make up organisms.
   (B) study of life.
   (C) categorization of organisms into similar groups.
   (D) study of how organisms give rise to offspring.

2. One mechanism of evolution, or change over time, is
   (A) biotic.
   (B) systems interactions.
   (C) natural selection.
   (D) DNA.

3. Many organisms use sugars as a source of energy to power the cell. This observation suggests that the pathways that break down sugars
   (A) arose relatively recently.
   (B) arose early in life's history.
   (C) are different in different species.
   (D) sugars are not necessary for life.

4. A hypothesis is
   (A) the cause of a scientific phenomenon.
   (B) the solution to a scientific problem.
   (C) a hunch or guess.
   (D) a tentative explanation of how nature functions.

5. An independent variable is
   (A) the factor that differs in the test group compared to the control group.
   (B) the order in which one measures the data collected in an experiment.
   (C) a factor that is larger or smaller than other factors in an experiment.
   (D) the result of the experiment that is being observed or measured.

6. You decide to test whether helium is light enough to cause balloons to rise. In the first group, you fill the balloons with helium. In the second group, you fill the balloons with air. What is the dependent variable in your experiment?
   (A) The presence or absence of helium
   (B) The group of balloons that receives the helium
   (C) The group of balloons that receives the air
   (D) Whether the balloons rise or not

7. A hypotheses is
   (A) supported when data contradict it.
   (B) proven when data can support it.
   (C) modified when data contradict it.
   (D) rejected when data support it.

Module 0 AP® Practice Questions

PREP FOR THE AP® EXAM

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–4.

1. Survival in some mushroom species is enhanced by the presence of gills with large surface areas. Mushrooms with larger gill surface areas produce more spores and reproduce more successfully than those with smaller gill surface areas in a particular environment. Identify which of the four Big Ideas of biology this example best describes.
   (A) Evolution
   (B) Energetics
   (C) Information Storage and Transmission
   (D) Systems Interactions

2. A student accidentally spilled a bag of rock salt on some plants while moving the bag to the garage. After some time, the student noticed that the plants in this area were turning brown and withering. The student formulated a hypothesis that the plants were dying because they do not grow well in salty soil. Among the proposed experiments below, identify the most effective way of testing this hypothesis.
   (A) Keeping a weekly record of any plant regrowth
   (B) Planting some seeds in a container of healthy soil and some in a container of salty soil and observing plant growth in each over a period of weeks
   (C) Removing the rock salt from the area, replanting grass seed, and observing any change in growth
   (D) Spreading rock salt over a larger portion of the lawn to see if the rest of the grass dies

3. A scientist is doing an experiment to see which conditions are best for bacterial growth. The scientist has set up an array of several petri dishes and will subject the bacterial cultures to various cool and warm temperatures, while comparing them to petri dishes at room temperature. Identify how the condition of temperature is used in this experiment.
   (A) As a dependent variable
   (B) As an independent variable
   (C) As a control group
   (D) As an experimental group

4. The table below shows differences in mass among males in four different species of frogs at two different life stages. A metamorph is a young individual that has nearly completed the change from tadpole to frog. Metamorphs have four legs and still have a tail. A fully grown adult frog has no tail.

	Metamorph mass (g)	Adult mass (g)
Green frog	1.1	20.2
Leopard frog	0.98	18.9
Wood frog	0.82	7.9
Gray tree frog	0.57	7.1

Which species has the largest percent change in mass from metamorph to adult?

   (A) Green frog
   (B) Leopard frog
   (C) Wood frog
   (D) Gray tree frog

Section 2: Free-Response Question

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

An experiment was performed on a wild population of Anna hummingbirds (*Calypte anna*) to see if they preferred feeding from a specific color of sugar water. Scientists had previously observed the hummingbirds feeding from a glass feeder with a clear sugar water solution. The scientists placed five identical glass feeders side by side and filled each with a different colored sugar water solution: red, yellow, green, blue, and clear. Every 15 minutes, the scientists changed the positions of the feeders relative to one another to eliminate any position bias. The scientists recorded the color of the first sugar water solution that each hummingbird visited. The experiment was carried out for 2 days. The results of the experiment are shown in the table.

(a) **Identify** the independent and dependent variables.

(b) **Identify** the control group and the experimental group.

(c) **State** an alternative hypothesis and the corresponding null hypothesis.

(d) **Explain** what the data tell us about the hummingbirds' preference.

Average Number of Birds Approaching and Drinking from Each of Five Containers Containing Different Colored Solutions

Color	Mean counts
Red	33.9
Yellow	13.1
Green	8.4
Blue	4.3
Clear	5.3

Data from https://sora.unm.edu/sites/default/files/journals/wilson/v092n01/p0053-p0062.pdf