Introduction to Biology and the Process of Science.

Figure 1.1. This NASA image is a composite of several satellite-based views of Earth. (credit: modification of work by NASA/Concepts of Biology OpenStax).

Viewed from space, Earth offers very few clues about the diversity of life forms that can be found there. The first forms of life on Earth are thought to have been microorganisms that existed for billions of years before plants and animals appeared. Mammals, birds, and flowers are all relatively recent additions to the planet, originating 130 to 200 million years ago. Humans have only inhabited this planet for the last 2.5 million years, and only in the last 200,000 years have humans started looking like we do today.

1.1 Themes and Concepts of Biology.

Biology is the science that studies life. What exactly is life? This may sound like a silly question with an obvious answer; however, it is not always easy to define life. For example, a branch of biology called virology studies viruses. Viruses exhibit some of the characteristics of life but lack others. It turns out that although viruses can attack living organisms, cause diseases, and even reproduce with the help of host cells, they do not meet all the criteria that biologists use to define life.

From its earliest beginnings, biology has wrestled with four questions: What are the shared properties that make something alive? How do those various living things function? Planet earth has a diversity of life forms; how do we organize and classify these different organisms? Finally, how did this diversity arise, and how is it continuing? As new organisms are discovered every day, biologists continue to seek answers to these and other questions.

Properties of Life

All living organisms share the following key characteristics: order, response to stimuli, reproduction, adaptation, growth and development, homeostasis, and energy processing. These seven characteristics serve to define life. It is essential that students know these different properties of life and be able to explain each.

Order

Organisms are highly organized and consist of one or more cells. Even very simple, single-celled organisms are remarkably complex. Inside each cell, atoms come together through chemical bonding and form molecules. Molecules come together to form cell components or structures called organelles. Like the toad shown in Figure 1.2, multicellular organisms can consist of millions of cells. Different groups of cells then specialize in performing specific functions. Without order, specialization would not be possible.

Figure 1.2 A toad represents a highly organized individual. (credit: "Ivengo(RUS)"/Wikimedia Commons)

Response to Stimuli

Organisms respond to diverse stimuli. For example, plants can bend toward a source of light or respond to touch (Figure 1.3). Even tiny bacteria can move toward or away from chemicals, a process called chemotaxis. A movement toward a stimulus is considered a positive response, while movement away from a stimulus is regarded as a negative response.

Humans also respond to stimuli. For example, when we become warm on a hot sunny day, the body has tiny glands called sudoriferous, or sweat, glands that make and release sweat onto the skin's surface. The heat from the body can be transferred to the sweat, which acts as a cooling mechanism and helps to maintain constant body temperature.

Figure 1.3 The leaves of this sensitive plant (Mimosa pudica) will instantly droop and fold when touched. After a few minutes, the plant returns to its normal state. (credit: Alex Lomas/Concepts of Biology OpenStax)

CONCEPTS IN ACTION- Watch this video to see how the sensitive plant responds to a touch stimulus.

Reproduction

Reproduction is necessary on both a cellular and organismal level. For a population to survive, some individuals within that population must reproduce. Organisms that are multicellular, such as plants and animals, also need to reproduce on a cellular level. As old cells become damaged or worn out, they must be replaced by new cells. For example, skin cells are damaged continuously and need to be replaced every two to three weeks; otherwise, the skin would lose its ability to provide protection.

Single-celled organisms must also reproduce. Reproduction begins by first duplicating their genetic material. Once the genetic material is duplicated, it is then divided equally into two new cells (Figure 1.4). The two new daughter cells should be identical to the parent cell.

Figure 1.4 Bacteria cell going through division. (credit: Pradana Aumars/Wikimedia Commons)

Adaptation

All living organisms exhibit a fit to their environment. Biologists refer to this fit as adaptation. Adaptations are a consequence of evolution by natural selection. Evolution has had some impact on every lineage of reproducing organisms. Examples of adaptations are diverse and unique. For example, some microorganisms live in boiling hot springs, whereas some moths have tongues the exact length of the flower from which they feed.

Adaptations are vital because they enhance an individual's ability to survive and reproduce; however, adaptations are not constant. As an environment changes, natural selection causes the individuals in a population to adapt to those changes.

For example, imagine that there is a population of finches living on an island. An environmental event has resulted in two main food sources: soft insects and hard seeds. Not all finches within the population have the same beak length or size. Finches in the population that have long, skinny beaks begin to feed on soft insects because they are easy for those birds to catch and eat. Finches with large, more dense beaks feed on hard seeds because their dense beaks allow them to

crush and open the hard seeds. Unfortunately, finches that have beaks that are neither long nor dense may slowly begin to decline in number because they are limited in their ability to obtain nutrients. Finches that obtain food can put energy into reproduction and survival needs. When those finches reproduce, they pass along those adaptations that allow them to be successful in their respective feeding environments. Over time two distinct groups may arise, those with thick, dense beaks and those with longer skinnier beaks (Figure 1.5). If these individuals genetically change in such a way that they no longer can interbreed with one another, a speciation event will have occurred.

Figure 1.5 Different finch phenotype variations due to environmental changes. (credit: National Human Genome Research Institute's Talking Glossary/Wikimedia Commons)

Growth and Development

Development is often described as the processes that an individual goes through as it grows and matures. For example, in humans, development begins once the sperm fertilizes the egg. Human development can be broken down into different stages including embryonic development, fetal development, infancy, childhood, puberty, and adulthood. Development can also be observed in many other organisms. For example, butterflies go through a developmental process called metamorphosis that begins at the egg stage and then proceeds to the larva, pupa, and adult stages. Both multicellular and single-celled organisms grow and develop according to specific instructions encoded in their DNA. DNA is organized into genes that provide information for cellular growth and development. An individual's DNA ensures that a species young (Figure 1.6) will grow up to exhibit many of the same traits as its parents.

Figure 1.6 Although no two looks alike, these kittens have inherited genes from both parents and share many of the same characteristics. (credit: Pieter & Renée Lanser/ Concepts of Biology OpenStax)

Homeostasis

Even the smallest organisms are complex and require multiple regulatory mechanisms to coordinate internal functions, such as the transport of nutrients (Figure 1.7), response to stimuli, and coping with environmental stresses. Homeostasis or steady state is the ability of an organism to regulate and maintain constant internal conditions.

Figure 1.7 Human circulatory system plays an important role in transporting oxygen, removal of waste, and delivering nutrients to every cell. (credit: Public domain/Wikimedia Commons)

Cells require appropriate conditions such as proper temperature, pH, and concentrations of nutrients to function correctly. Although these conditions may change, organisms can maintain internal conditions within a narrow range. For example, many organisms regulate their body temperature in a process known as thermoregulation. Organisms that live in cold climates, such as the polar bear (Figure 1.8), have body structures such as thick layers of fur or fat, which help them withstand low temperatures and conserve body heat. In hot climates, plants carry out unique versions of photosynthesis to reduce water loss and optimize their potential of making sugar.

Figure 1.8a. Polar bears and other mammals living in ice-covered regions keep their body temperature relatively constant, even though the environment can be very hot during the day and cold at night. (credit: "longhorndave"/Flickr) b. Polar bear maintain their body temperature by generating heat and reducing heat loss through thick fur and a dense layer of fat under their skin. In this infrared image the polar bears body heat hardly registers; only the uninsulated eyes and mouth show temperatures significantly warmer than the environment. (credit: Arno/Coen/Wikimedia Commons)

a b

Organisms like humans (Figure 1.9), use their skeletal muscles to generate heat. The contraction of skeletal muscles helps humans maintain stable internal body temperature as environmental conditions fluctuate. If body temperature drops below a certain point, metabolism begins to slow and may even stop, leading to death. Conversely, if body temperature rises above a certain point, it can lead to the destruction of key molecules called proteins. Students that continue and take Anatomy and Physiology classes will spend time discussing how the body works to maintain homeostasis. Students will also look at what occurs when the body loses its ability to maintain stable internal conditions, otherwise referred to as a homeostatic imbalance.

Figure 1.9 Thermogram of a snake wrapped around a human arm. (credit: Arno/Coen/Wikimedia Commons)

Energy Processing

All organisms, including the California condor shown in Figure 1.10, use a source of energy for their metabolic activities. Some organisms can obtain energy through metabolic pathways such as photosynthesis. Photosynthesis is a process where light energy can be captured and converted into chemical energy. Organisms that are capable of making their own chemical energy are referred to as autotrophs. Others must obtain their chemical energy by consuming other organisms. These individuals are referred to as heterotrophs. Regardless of whether an organism is an autotroph or a heterotroph, all living cells must have energy to drive metabolism.

Figure 1.10 A lot of energy is required for a California condor to fly. (credit: Pacific Southwest Region U.S. Fish and Wildlife/ Concepts of Biology OpenStax)

Levels of Organization of Living Things

Living things are highly organized and structured. 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 a chemical bond. Many biologically important molecules are macromolecules. A macromolecule is a large molecule that is typically formed by combining smaller molecules. For example, nucleotides are small molecules linked together to form the macromolecule, DNA (deoxyribonucleic acid) (Figure 1.11). DNA contains the instructions necessary for cells and organisms to maintain homeostasis.

Figure 1.11 A molecule, like this large DNA molecule, is composed of atoms. (credit: "Brian0918"/Wikimedia Commons)

CONCEPTS IN ACTION- To see an animation of this DNA molecule, click here.

Some cells contain collections of macromolecules surrounded by membranes; these are called organelles. Organelles are small structures that exist within cells and perform specialized functions. For example, in some cells, DNA is enclosed within a membrane-bound organelle called the nucleus (plural: nuclei). All living things are made of cells; the cell is the smallest fundamental unit found in living organisms. Cells exhibit all of the properties of life discussed above. Viruses are often not considered living because they are not made of cells, nor are they capable of reproducing on their own. To make new viruses, they must invade and take over a living cell.

Some organisms consist of a single cell, while others are multicellular. In most multicellular organisms, cells combine to make tissues, which are groups of similar cells carrying out the same function. Organs are collections of tissues grouped based on 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. For example, vertebrate animals have many organ systems, such as the circulatory system that transports blood throughout the body; 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.

Figure 1.12 From an atom to the entire Earth, biology examines all aspects of life. (credit "molecule": modification of work by Jane Whitney; credit "organelles": modification of work by Louisa Howard; credit "cells": modification of work by Bruce Wetzel, Harry Schaefer, National Cancer Institute; credit "tissue": modification of work by "Kilbad"/Wikimedia Commons; credit "organs": modification of work by Mariana Ruiz Villareal, Joaquim Alves Gaspar; credit "organisms": modification of work by Peter Dutton; credit "ecosystem": modification of work by "gigi4791"/Flickr; credit "biosphere": modification of work by NASA/ Concepts of Biology OpenStax)

All the individuals living within a specific area are collectively called a population. For example, a forest may include many white pine trees. All these pine trees represent the population of white pine trees in this forest. Different populations may live in the same area. The forest with the pine trees includes populations of flowering plants, insects, and microbial populations. A community is the set of populations inhabiting a particular area. For instance, all the trees, flowers, insects, and other populations in a forest form the forests community. The forest itself is an ecosystem. An ecosystem consists of all the living things in a particular area together with the abiotic, or non-living, parts of that environment, such as nitrogen in the soil or rainwater. At the highest level of organization (Figure 1.12), the biosphere is the collection of all ecosystems on planet Earth. It includes land, water, and portions of the atmosphere.

Answer: (b)

The Diversity of Life

The science of biology is very broad because there is a tremendous diversity of life on Earth. The source of this diversity is evolution. Evolution is the process of genetic change in a population. Evolution helps explain how new species can arise from older species. Speciation events can occur when individuals within a population are separated and begin to change or evolve independently of one another. If the individuals change to the point where they can no longer interbreed, a speciation event has occurred, and species diversity has increased. Evolution will be discussed in much greater detail in chapter 11.

In the 18th century, a Swedish scientist named Carl Linnaeus first proposed organizing living organisms into a hierarchical taxonomy. In this system, species that are most similar to each other are put together within a grouping known as a genus. Furthermore, similar genera (the plural of genus) are put together within a family. This grouping continues until all organisms are collected together into groups at the highest level. The current taxonomic system now has eight levels in its hierarchy, from lowest to highest, they are species, genus, family, order, class, phylum, kingdom, and domain (Figure 1.13).

Figure 1.13 This diagram shows the levels of taxonomic hierarchy for a dog, from the broadest categorydomainto the most specificspecies. (credit: Fowler et al./Concepts of Biology

OpenStax)

The highest taxonomy level, domain, is a relatively new addition (1990's) to the system. Scientists now recognize three domains of life: the Eukarya, the Archaea, and the Bacteria. The domain Eukarya is very diverse and includes the kingdoms of fungi, plants, animals, and several kingdoms of protists. Humans, plants, yeast, and mushrooms are just a few representatives of the domain Eukarya. These organisms are classified as eukaryotes because they have nuclei and other membrane-bound organelles. Both the Archaea and Bacteria are single-celled organisms classified as prokaryotes (Figure 1.14). Prokaryotes are organisms that lack nuclei and other membrane-bound organelles. Prokaryotes, like eukaryotes, are very diverse and can be subdivided into phyla, class, order, etc.

Figure 1.14 These images represent different domains. The scanning electron micrograph shows (a) bacterial cells belong to the domain Bacteria, while the (b) extremophiles, seen all together as colored mats in this hot spring, belong to domain Archaea. Both the (c) sunflower and (d) lion are part of the domain Eukarya. (credit a: modification of work by Rocky Mountain Laboratories, NIAID, NIH; credit b: modification of work by Steve Jurvetson; credit c: modification of work by Michael Arrighi; credit d: modification of work by Frank Vassen / Concepts of Biology OpenStax)

Evolution in Action - Carl Woese and the Phylogenetic Tree

The evolutionary relationships of various life forms on Earth can be summarized in a phylogenetic tree. 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.

The pioneering research of American microbiologist Carl Woese at the University of Illinois has shown that life on Earth has evolved along three lineages, now called domains. The phylogenic tree in Figure 1.15 can be used to show the separation of living organisms into those three domains: Bacteria, Archaea, and Eukarya.

Figure 1.15 This

phylogenetic tree was
constructed by
microbiologist Carl
Woese using genetic
relationships. (credit:
modification of work
by Eric Gaba/
Concepts of Biology
OpenStax)

Branches of Biological Study

The scope of biology is broad and therefore contains many branches and sub-disciplines. For instance, molecular biology studies biological processes at the molecular level, including interactions among molecules such as DNA, RNA, and proteins. Microbiology is the study of the structure and function of microorganisms. It is quite a broad branch itself, and depending on the subject of study, there are also microbial physiologists, ecologists, and geneticists, among others. Paleontology, another branch of biology, uses fossils to study lifes history (Figure 1.16). 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.

Biotechnologists apply the knowledge of biology to create useful products. Ecologists study the interactions of organisms in their environments. Physiologists study the workings of cells, tissues, and organs. This is just a small sample of the many fields that exist within biology.

Figure 1.16 Researchers work on excavating dinosaur fossils at a site in Castellón, Spain.

(credit: Mario Modesto/ Concepts of Biology

OpenStax)

CAREER CONNECTION - Forensic Scientist

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.

The development of molecular techniques and the establishment of DNA databases have updated the types of work that forensic scientists can do. Their job activities are primarily related to crimes against people, such as murder, rape, and assault. Their work involves analyzing samples such as hair, blood, and other body fluids, and processing DNA (Figure 1.17a) found in many different environments and materials. Forensic scientists also analyze biological evidence left at crime scenes, such as insect parts or pollen grains (Figure 1.17b). 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 1.17a This forensic scientist works in a DNA extraction lab. (credit: U.S. Army CID Command Public Affairs/ Concepts of Biology OpenStax) b. This scientist uses microscopy for sample analysis. (credit: National Cancer Institute /Public Domain)

Section Summary

Biology is the science of life. All living organisms share several key properties such as order, response to stimuli, reproduction, adaptation, growth and development, homeostasis, and energy processing. Living things are highly organized following a hierarchy that includes atoms, molecules, organelles, cells, tissues, organs, and organ systems. Organisms are grouped as populations, communities, ecosystems, and the biosphere. Evolution is the source of the tremendous biological diversity on Earth today. A diagram called a phylogenetic tree can be used to show evolutionary relationships among organisms. Biology is very broad and includes many branches and sub-disciplines. Examples include molecular biology, microbiology, neurobiology, and ecology, among others.

Exercises

1. Which of the following statements is false?

a. Tissues exist within organs which exist within organ systems.

b. Communities exist within populations which exist within ecosystems.

c. Organelles exist within cells which exist within tissues.

d. Communities exist within ecosystems which exist in the biosphere.

2. The smallest unit of biological structure that meets the functional requirements of living is the ________.

a. organ

b. organelle

c. cell

d. macromolecule

3. Which of the following sequences represents the hierarchy of biological organization from the most complex to the least complex level?

a. organelle, tissue, biosphere, ecosystem, population

b. organ, organism, tissue, organelle, molecule

c. organism, community, biosphere, molecule, tissue, organ

d. biosphere, ecosystem, community, population, organism

4. Briefly explain how evolution is a source of species diversity.

Answers

1. (b)

2. (c)

3. (d)

4. Evolution leads to genetic changes in a population. For example, if you had a population of

insects that live on a maple tree, some insects may begin to feed selectively on the bark of the tree, while others may selectively feed on the leaves. Over time, genetic changes can occur that may prevent these two groups from breeding with one another. In this case, a speciation event has occurred, increasing species diversity.

Glossary

atom: a basic unit of matter that cannot be broken down by normal chemical reactions

autotroph: an organism that can make its own food from materials in its environment

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

biosphere: a collection of all ecosystems on Earth

cell: the smallest fundamental unit of structure and function in living things

community: a set of populations inhabiting a particular area

domain: the highest level of the taxonomic hierarchy; includes the Eukarya, Archaea, and Bacteria

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

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

evolution: the process of gradual change in a population that can also lead to new species arising from older species

heterotroph: an organism that cannot make its own food and must consume other organisms to obtain its energy

homeostasis: the ability of an organism to maintain constant internal conditions

macromolecule: a large molecule typically formed by the joining of smaller molecules

molecule: a chemical structure consisting of at least two atoms held together by a chemical bond

organ: a structure formed of tissues operating together to perform a common function

organ system: the higher level of organization that consists of functionally related organs organelle: a membrane-bound compartment or sac within a cell

organism: an individual living entity

phylogenetic tree: a diagram showing the evolutionary relationships among biological species based on similarities and differences in genetic or physical traits or both

population: all individuals within a species living within a specific area

prokaryote: a unicellular organism that lacks a nucleus or any other membrane-bound organelle

tissue: a group of similar cells carrying out the same function

1.2 The Process of Science

Figure 1.18 (a) cyanobacteria seen through a light microscope are some of Earths oldest life forms (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; scale-bar data from Matt Russell; credit b: modification of work by Ruth Ellison / Concepts of Biology OpenStax)

Biology is a science that gathers knowledge about the natural world (Figure 1.18). Specifically, biology is the study of life. Biological discoveries are made by a community of researchers who work both individually and together using agreed-on methods. The methods of science include careful observation, record keeping, logical and mathematical reasoning, experimentation, and submitting conclusions to the scrutiny of others. Science also requires considerable imagination and creativity; a well-designed experiment is commonly described as elegant or beautiful. Science has significant practical implications and applications, for example, in the prevention of disease (Figure 1.19). Other types of science are motivated by curiosity. Whatever its goal, there is no doubt that science, including biology, has transformed human existence and will continue to do so.

Figure 1.19 In this micrograph, the bacterium is visualized using a scanning electron microscope and digital colorization. (credit: Eric Erbe;

digital colorization by Christopher Pooley,

USDA-ARS / Concepts of Biology OpenStax)

The Nature of Science

Science can be defined as knowledge about the natural world. It is a precise way of learning about the world and is largely responsible for the technological revolutions that have taken place. There are, however, areas of knowledge and human experience that the methods of science cannot be applied to. These include such things as answering moral questions, aesthetic questions, or spiritual questions. Science cannot investigate these areas because they are outside the realm of natural phenomena and cannot be observed and measured.

The scientific method is a method of research with defined steps that includes careful observation and experiments. The steps of the scientific method will be examined in greater detail later, but one of the most important aspects of the scientific method is the testing of hypotheses. A hypothesis (plural hypotheses) is a suggested explanation for a scientific question or an observation, which can be tested. A good hypothesis should be clear and concise. It should also lead to predictions, which are statements that describe what should happen if the hypothesis is correct and supported. A hypothesis should also be falsifiable, meaning the hypothesis can be incorrect if data that is collected refutes the hypothesis. An example of a hypothesis that is not falsifiable is, Chicago is the most beautiful city in the world. There is no experiment that might show this statement is false. Once a hypothesis has undergone rigorous testing, and large amounts of data have been collected by multiple research groups who have drawn the same or similar conclusions, the hypothesis is referred to as a theory. In science, a theory is a confirmed explanation for a set of observations or phenomena that has been thoroughly tested and supported with substantial amounts of data. In this way, it is very different than a hypothesis. However, like hypotheses, theories are testable, falsifiable, and lead to predictions. A scientific theory is the foundation of scientific knowledge. Also, in many scientific disciplines (less so in biology), there are scientific laws, often expressed in mathematical formulas. Scientific laws describe how elements of nature will behave under certain specific conditions. There is not a strict process that a hypothesis must go through to become a theory or a law. Hypotheses are the day-to-day material that scientists work with, and they are developed within the context of theories. Laws are concise descriptions of parts of the world that are amenable to formulaic or mathematical description.

Natural Sciences

Those fields of science related to the physical world and its phenomena and processes are considered natural sciences. There is no complete agreement when it comes to defining what the natural sciences include (Figure 1.20). For some experts, the natural sciences are astronomy, biology, chemistry, earth science, and physics. Other scholars choose to divide natural sciences into life sciences and physical sciences. Life sciences study living things and include biology. Physical sciences study nonliving matter and include astronomy, physics, and chemistry. Some disciplines, such as biophysics and biochemistry, build on two sciences, and are interdisciplinary.

Figure 1.20 Some fields of science include astronomy, biology, computer science, geology, logic, physics, chemistry, and mathematics. (credit: "Image Editor" Flickr / Concepts of Biology OpenStax)

Scientific Inquiry

One thing is common to all forms of science: the ultimate goal is to obtain knowledge. Curiosity and inquiry are the driving forces for the development of science. Scientists seek to understand the world and the way it operates. Two methods of logical thinking are used: 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, which is descriptive or categorical, or they can be quantitative, consisting of numbers. 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 often work this way. Many brains are observed while people are doing a task. The part of the brain that lights up, indicating activity, is then demonstrated to be the part controlling the response to that task.

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Deductive reasoning or deduction is the type of logic used in hypothesis-based science. In deductive reasoning, 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 predict specific results. From those general principles, a scientist can extrapolate and predict the specific results that would be valid so long as the general principles are valid. For example, a prediction would be that if the climate is becoming warmer in a region, the distribution of plants and animals should change. Comparisons have been made between distributions in the past and the present, and the many changes that have been found are consistent with a warming climate. Finding the change in distribution is evidence that the climate change conclusion is valid.

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 aims to observe, explore, and discover. Hypothesis-based science 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 because most scientific endeavors combine both approaches. Observations lead to questions, questions lead to forming a hypothesis as a possible answer to those questions, and then the hypothesis is tested. Thus, descriptive science and hypothesis-based science are in continuous dialogue.

Hypothesis Testing

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 typically starts with an observation that leads to a question. Observations can be made using any or all of an individual's general senses such as touch and/or their special senses such as vision. (Students planning to take Anatomy and Physiology will learn more about your different senses.) Lets think about a scenario that starts with an observation and apply the scientific method to address the observation. One Monday morning, a student arrives in 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 arm?

Recall that a hypothesis is a testable explanation to the question. 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 doesnt work.

Once a hypothesis has been formulated, a prediction can be made. 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.

A hypothesis must be testable to ensure that it is valid. For example, a hypothesis that depends on what a bear thinks is not testable, because it can never be known what a bear thinks. To test a hypothesis, a researcher will conduct one or more experiments designed to eliminate one or more of the hypotheses. This is important. A hypothesis can be shown to be false or eliminated, but it can never be proven true. Science does not deal with proof, like mathematics. If an experiment supports the hypothesis, this is not to say that down the road, a better explanation will not be found, which is why the word "prove" is not used when a hypothesis is supported.

Each experiment will have variables, controls, and experimental groups. A variable is any part of the experiment that can vary or change during the experiment. There are typically three kinds of variables: independent, dependent, and standardized. The independent variable is the variable that is being altered or changed by the researcher. It is the variable whose effect is being tested. The dependent variable is the variable that may change when the independent variable is applied. This is what the researcher will observe, measure, and record during the experiment. The standardized variables are variables that must be kept consistent among all test groups; otherwise, they can affect the outcome or results of the experiment. The experimental groups in an experiment receive varying types or amounts of the independent variable. A control group is usually included as a basis of comparison for the experimental groups. For the control group the independent variable is absent or set to some predetermined standard. Look for the variables, controls, and experimental group(s) in the following example.

An experiment is conducted to test the hypothesis that phosphate availability limits the growth of algae in freshwater ponds. A series of artificial ponds are filled with water, and half of them are treated by adding phosphate each week, while the other half is treated by adding salt. Salt is a known substance that is not used by algae. The independent variable here is the phosphate. The experimental groups are the ponds to which phosphate was added, and the control group is the ponds to which the salt was added. Adding the salt is a control against the possibility that adding extra matter to the pond influences algae growth. Some factors must be standardized in both the control and experimental ponds. For example, both the temperature and pH of the water should be standardized. If the water in the control ponds has a significantly higher temperature or pH compared to the water used in the experimental ponds, this could influence the growth of algae. These factors need to be measured and kept relatively constant between the two groups. These are examples of standardized variables. If the ponds treated with phosphate show more algae growth than the control ponds, then we have found support for our hypothesis. If they do not, then we reject our hypothesis. Be aware that rejecting a hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid (Figure 1.21).

Figure 1.21 The scientific method is a

series of defined steps that include

experiments and careful

observation. (credit: Fowler et al. /

Concepts of Biology OpenStax)

In the example below, the scientific method is used to solve an everyday problem.

Answers: (3) hypothesis; (4) prediction; The hypothesis would be rejected.

Hypothesis 2: The toaster has a loose wire and is broken.

The scientific method is not as rigid and structured as it might first appear. Sometimes an experiment leads to conclusions that favor a change in approach. Often, experiments bring about entirely new scientific questions. Many times, science does not operate linearly; 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.

Basic 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 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 knowledges sake, though this does not mean that in the end, it may not result in an application.

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

One example of how basic and applied science can work together occurred with the discovery of the DNA structure. This discovery then led to the understanding of the molecular mechanisms that control DNA replication. Every human has unique chromosomes, strands of DNA wrapped around proteins, found in their cells. DNA provides the instructions necessary for life. During cell division, new copies of DNA must be made before a cell divides to form two new cells (Figure 1.22). Understanding the mechanisms of DNA replication enabled scientists to develop laboratory techniques that are now used to identify genetic diseases, pinpoint individuals who were at a crime scene, and determine paternity. Without basic science, it is unlikely that applied science would exist.

Figure 1.22 Shows DNA replication and cell division by the process of mitosis. Note: diploid means each cell has pairs of chromosomes. (credit: Mysid / Wikimedia Commons)

Reporting Scientific Work

Whether scientific research is basic science or applied science, scientists must share their findings for other researchers to expand and build upon their discoveries. Communication and collaboration within and between sub-disciplines of science are key to the advancement of knowledge in science. For this reason, an essential aspect of a scientists work is disseminating results and communicating with peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only a few individuals who are present. Instead, most scientists present their results in peer-reviewed articles that are published in scientific journals. Peer-reviewed articles are scientific papers that are reviewed, usually anonymously, by a scientists colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether the scientists work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper is original, significant, logical, and thorough.

There are many journals and the popular press that do not use a peer-review system. Results of any studies published in non-peer reviewed forums are not always reliable, and caution should be used when examining the validity of the work. Sometimes information can be portrayed as scientific fact but lack objective, repeatable data. Pseudoscience is claims or beliefs that are represented as scientific fact but cannot be evaluated using the scientific method. For example, astrology is based on a set of beliefs that connect an individual's personality traits with their astrological sign. Scientists using the scientific method have not been able to generate any data that supports these claims and connections. As a result, astrology can be used as an example of pseudoscience.

Today, data and information are readily accessible online through the internet. The internet offers a unique platform to share information across the world, which can help advance both scientific discovery and knowledge. However, it is always important to consider when looking at information online, where the data is coming from, and how valid this information is.

Section Summary

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. Science has many fields; those fields related to the physical world and its phenomena are considered natural sciences.

A hypothesis is a tentative, testable explanation for an observation or question. A scientific theory is a well-tested and consistently verified explanation for a set of observations or phenomena that has been universally accepted by the scientific community. A scientific law is a description, often in the form of a mathematical formula. Two types of logical reasoning are used in science. Inductive reasoning uses 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. Scientists present their results in peer-reviewed scientific papers published in scientific journals.

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.

Exercises

1. In the example below, the scientific method is used to solve an everyday problem. Which part of the example below is the hypothesis? Which is the prediction? Based on the results of the experiment, is the hypothesis supported? If it is not supported, propose some alternative hypotheses. Jose notices that all the trees in his backyard are dying. They are having a usual dry summer with very little rainfall. His mom also applied fertilizer to the lawn in the early spring. Jose is curious, "why are the trees are all dying?" Jose thinks that because there has been very little rainfall that explains why the trees are dying. If he waters the trees, then they should begin to grow and stop dying. After watering the trees every day for two months, Jose notices that the trees still seem to be dying.

2. ________claims or beliefs that are portrayed as scientific fact but cannot be evaluated using the scientific method.

a. Hypothesis

b. Variable

c. Pseudoscience

d. Theory

3. The type of logical thinking that uses related observations to arrive at a general conclusion is called ________.

a. deductive reasoning

b. the scientific method

c. hypothesis-based science

d. inductive reasoning

4. Explain the difference between a hypothesis and a theory.

Answers

1. The hypothesis is the trees are dying because of the lack of water, and the prediction is if he waters the trees, then they should stop dying. The original hypothesis is not supported, because

although he waters the trees, they continue to die. Alternative hypotheses maybe because his mom added fertilizer to the lawn; the trees are dying.

2. (c)

3. (d)

4. A hypothesis is a testable explanation for a scientific question or an observation, which should be both falsifiable and lead to predictions. Once a hypothesis has undergone rigorous testing by many different scientific groups who have drawn the same or similar conclusions, it is referred to as a scientific theory. A scientific theory, therefore, is also testable, leads to predictions, and is falsifiable; however, it has been thoroughly tested and supported with substantial amounts of data. A scientific theory is the foundation of scientific knowledge.

Glossary

biology: the study of life

control: a part of an experiment that does not change during the experiment

deductive reasoning: a form of logical thinking that uses a general statement to forecast results

dependent variable: the variable that will change when the independent variable is altered; this is what the researcher will measure or observe during the experiment

experimental group: the group where the independent variable is applied

falsifiable: it can be shown to be false by experimental results

hypothesis: a suggested explanation for an event, which can be tested

independent variable: is the variable that is being altered or changed by the researcher; it is the variable being tested

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

peer-reviewed article: a scientific report that is reviewed by a scientists colleagues before publication

predictions: statements that describe what should happen if the hypothesis is supported

pseudoscience: claims or beliefs that are portrayed as scientific fact but cannot be evaluated using the scientific method

qualitative data: data that is descriptive

quantitative data: data that is numerical

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

scientific method: a method of research with defined steps that include experiments and careful observation

scientific theory: a thoroughly tested and confirmed explanation for observations or phenomena

standardized variable: variables that must be kept consistent otherwise they can affect the outcome or results of the experiment