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Please feel free to contact any of the collaborators to discuss how they are using the text with their students.

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# Biology

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CHAPTER 1: THE STUDY OF LIFE

1.1 Nature of Science

Objectives:

- Understand that science is a system based on evidence, testing, and reasoning.
- Describe what the life sciences are and some of the many life science specialties.
- Describe scientific methods and why they are important.
- Define the words "fact," "theory," and "hypothesis."
- Describe some of the tools of life science.
- Know that scientists are required to follow strict guidelines.

Questions to think about:

1) Why is modern science producing many more improvements in our lives than it did a hundred years ago?
   - Modern science is based on evidence, inquiry and testing which have replaced personal beliefs, mythology and other biased sources of information.

2) Is there anything that science cannot explain?
   - Yes there is. Questions about ethics (right and wrong) and belief in supernatural forces cannot be explained through science.

3) How can we "think like scientists?"
   - To think like a scientist, you would need to:
     1. Ask questions about the world around you and seek new evidence that will help answer questions
     2. Base your understanding of the world on evidence, testing and reasoning instead of biased belief systems
3. Continuously question and test the accuracy of your knowledge and assumptions (including so-called "common sense")

---

**Goals of Science**

Science, religion, mythology, and magic share the goal of knowing about and explaining the world, such as the physical world, but their approaches are vastly different. The difference between them is their approach to “knowing.” The vastness of the living, physical world includes all organisms, on land and in the sea (Figure 1.1). As humans, some of the things we want to know and understand are what makes us healthy, what makes us sick, and how we can protect ourselves from floods, famine and drought.

![Image](image1.png)

**Figure 1.1: Bacteria, a male lion, and a humpback whale live in different habitats but share similar characteristics of life.**

Throughout history, humans have looked for ways to understand and explain the physical world. Try to imagine what humans thought about themselves and the world around them 1,000 years ago, or 5,000 years ago, or more. If you were born then, how would you have explained why the sun moved across the sky, then disappeared? How would you explain why your body changes as you grow, or birth and death? What explanation would you have for lightning, thunder, and storms?

**Science as a Way of Knowing**

During your own and your parents’ lifetimes, advances in medicine (Figure 1.2), technology, and other fields have progressed faster than any other time in history. This explosion of advances in our lives is largely due to human use of modern science as a way of understanding. Today’s scientists are trained to base their comprehension of the world on evidence and reasoning rather than belief and assumptions.
Modern science is:
- A way of understanding about the physical world, based on observable evidence, reasoning, and repeated testing.
- A body of knowledge that is based on observable evidence, experimentation, reasoning, and repeated testing.

As we learn more, new information occasionally conflicts with our current understanding. When this happens scientific explanations are revised, as Figure 1. 3 demonstrates. However, science cannot scrutinize what is good versus what is bad (morality), because these are values which lack measurable evidence. Science is not used to examine philosophy or supernatural entities, such as the existence of God. However, science can be used to examine the effects of these experiences.

Figure 1. 3: In 1847, a doctor, Ignaz Semmelweis, demonstrated that when he washed his hands before delivering babies fewer women died from infection. Before this, doctors held untested beliefs about the causes of disease, such as a person’s behavior, or the air they breathed.

The most important message from this chapter is that science is not only a way of knowing, but also a way of thinking and reasoning. Scientists try to look at the world objectively—without bias or making assumptions. How? Scientists learn to be skeptical, or to question the accuracy of our ideas. They learn to base their understanding of the physical world on evidence, reasoning and repeated testing of ideas.

To Think Like a Scientist

To think like a scientist, you need to be skeptical about and question your assumptions, including what often seems like common sense. Questioning ideas can often lead to surprising results. For example, if you ask people whether it's easier to keep a plastic cutting board clean or
a wooden one clean, most people will think that the plastic board is easier to keep clean and has fewer germs (Figure 1. 4).

Why do most people believe that plastic is safer? Probably because we assume that it is easier to wash germs off of plastic than off of wood. The makers of plastic cutting boards promote this assumption and it sounds reasonable. After all, wood looks unhygienic and stains; plastic cutting boards come out of the dishwasher shiny and clean looking. But is plastic actually better?

When scientists tested this idea, the answer turned out to be no. The researchers treated used cutting boards with different kinds of germs and then washed the boards. Much to their surprise, they found that gouged and sliced wooden cutting boards had far fewer germs than gouged and sliced plastic boards. The researchers discovered that germs that cause food poisoning, such as *E. coli* and *Salmonella*, are absorbed into the wood and seem to vanish. On plastic, the germs sit in cuts in the surface where they are difficult to clean out, but can still contaminate food. Furthermore, in a different study of food poisoning, people who used wooden cutting boards were less than half as likely to get sick as people using plastic ones.

"Common sense" may seem to have all the answers, but science is all about following the evidence. So what is good evidence? Evidence is information that can be used to confirm or refute an idea or to explain something. Both scientists and lawyers use evidence to support an idea or to show that an idea is probably wrong. Scientific evidence has certain features, which may be different from legal evidence.

**Evidence** is:

1. A direct, physical observation of a thing, a group of things, or of a process over time.
2. Usually, something measurable or "quantifiable"
3. The result of something

For example, a book falling to the ground is evidence in support of the theory of gravity. A bear skeleton in the woods would be supporting evidence for the presence of bears.

**Scientific Theories**

Scientific theories are produced through repeated studies, usually performed and confirmed by many individuals. Scientific theories are well established and tested explanations of observations. These theories produce a body of knowledge about the physical world that is collected and tested through the scientific method.
The word “theory” has a very different meaning in daily life than it does in science. When someone at school says, “I have a theory,” they sometimes just mean a hunch or a guess. This everyday meaning for “theory” can confuse people when well-tested and widely accepted scientific theories are discussed by nonscientists. For example, the theory of evolution is a well-established scientific theory that some people incorrectly say is just a hunch.

A scientific theory is based on evidence and testing that supports the explanation. Scientific theories are so well studied and tested that it is extremely unlikely that new data will discredit them. Evolution, gravity, and the idea that matter is made up of atoms are all scientific theories about how the world works that scientists accept as fundamental principles of pure science. However, any theory may be altered or revised to make it consistent with new evidence.

**Two Important Scientific Theories**

In the many life sciences, there are hundreds or thousands of theories. Yet there are at least two fundamental theories which provide a foundation for modern biology. They are:

1. **The Cell Theory**
2. **The Theory of Evolution**

**The Cell Theory**

The Cell Theory states that:
- All organisms are composed of cells (Figure 1.5). Cells are the basic units of structure and function in an organism.
- Cells only come from preexisting cells; life comes from life.

The development of the microscope in the mid-1600s made it possible to come up with this theory (Figure 1.6).
The Theory of Evolution

In biology, evolution is the process of change in the inherited traits of a population of organisms over time. Natural selection is the process where organisms that are better suited to the environment are more likely to survive and reproduce than others that are less suited to the environment. This theory basically states that better suited organisms live longer and have an easier time reproducing, passing on their traits that made them better suited to their environment. The theory of evolution by natural selection is often called the “great unifier” of biology, because it applies to every field of biology. It also explains the tremendous diversity and distribution of organisms across Earth. All living organisms on Earth are descended from common ancestors.

Review Questions

1. How is modern science different from other ways of knowing?
2. Explain why science cannot be used to examine whether someone is good or bad?
3. How is the scientific meaning of the word “theory” different from its use in day-to-day conversation?
4. What is the goal of science?
5. What qualities do you need to THINK like a scientist?
1.2 Scientific Method

Objectives:

- Describe the scientific method as a process
- Explain why the scientific method allows scientists and others to examine the physical world more objectively than other ways of knowing.
- Describe the important components of the scientific process and why they are needed in order to create logical explanations of the world.

Scientific Method

The scientific method is a process used to investigate the unknown. It is a general process of scientific investigation. This process uses evidence and testing. Scientists use the scientific method so they can find information. A common method allows all scientists to answer questions in a similar way. Scientists who use this method can reproduce another scientist's experiments.

Almost all versions of the scientific method include the following, although scientists do not always use the same set of procedures. There is more than one way to conduct science experiments.

- Make observations.
- Identify a question you would like to answer based on the observation.
- Find out what is already known about your observation (research).
- Form a hypothesis.
- Test the hypothesis.
- Analyze your results and draw conclusions.
- Communicate your results.

Make Observations

Observe something in which you are interested. Here is an example of a real observation made by students in Minnesota (Figure 1. 7). Imagine that you are one of the students who discovered this strange frog.

Figure 1. 7: A frog with an extra leg.
Imagine that you are on a field trip to look at pond life. While collecting water samples, you notice a frog with five legs instead of four. As you start to look around, you discover that many of the frogs have extra limbs, extra eyes or no eyes. One frog even has limbs coming out of its mouth. You look at the water and the plants around the pond to see if there is anything else that is obviously unusual, like a source of pollution. Observations are what you can detect with your five (5) senses: sight, sound, touch, smell, and taste. An inference is an assumption based on past knowledge. Observations should not contain inferences.

**Identify a Question that is Based on Your Observations**

The next step is to ask a question about these frogs. For example, you may ask why so many frogs are deformed. You may wonder if there is something in their environment causing these defects. You could ask if deformities are caused by such materials as water pollution, pesticides, or something in the soil nearby (Figure 1.8). Yet, you do not even know if this large number of deformities is “normal” for frogs. What if many of the frogs found in ponds and lakes all over the world have similar deformities? Before you look for causes, you need to find out if the number and kind of deformities is unusual. So besides finding out why the frogs are deformed, you should also ask:

“Is the percentage of deformed frogs in pond A (your pond) greater than the percentage of deformed frogs in other places?”

**Research Existing Knowledge About the Topic**

No matter what you observe, you need to find out what is already known about your topic. For example, is anyone else doing research on deformed frogs? If yes, what did they find out? Do you think that you should repeat their research to see if it can be duplicated? During your research, you might learn something that convinces you to alter your question.

**Construct a Hypothesis**

A hypothesis is a proposed explanation of an observation. For example, you might hypothesize that a certain pesticide is causing extra legs. If that's true, then you can predict that the water in a pond of healthy non-deformed frogs will have lower levels of that pesticide. That's a prediction you can test by measuring pesticide levels in two sets of ponds, those with deformed frogs and those with nothing but healthy frogs. A hypothesis is an explanation that allows you to predict what results you will get in an experiment or survey.
The next step is to state the hypothesis formally. A hypothesis must be "testable."

Example:

After reading about what other scientists have learned about frog deformities, you predict what you will find in your research. You construct a hypothesis that will help you answer your first question.

Any hypothesis needs to be written in a way that it can:
1. Be tested using evidence.
2. Provide measurable results.
3. Be supported or not supported by the results.

For example, the following hypothesis incorporates all three above guidelines:

“The percentage of deformed frogs in five ponds that are heavily polluted with a specific chemical X is higher than the percentage of deformed frogs in five ponds without chemical X.”

Test Your Hypothesis

The next step is to count the healthy and deformed frogs and measure the amount of chemical X in all the ponds. This study will test the hypothesis. The hypothesis will be either be supported or not supported by the results. A hypothesis is usually tested through a controlled experiment or modeling. Parts of the experiment need to be identified such as the constants or controlled variables in your experimental and controlled groups.

Variables are the parts of the experiment that are changing. There are two types of variables: independent variables and dependent variables. The independent variable is the part that is being manipulated by the experimenter. In the case of the deformed frogs it would be the water pollution, pesticides, or soil by the water (chemical X) that is being measured. A dependent variable is what may or may not respond to the independent variable—for example, the number of frogs with deformities.

A control group is a part of the experiment that all other groups are being compared to. For example you may use a pond in another town as the control to see if frogs are just born with extra legs.

An example of a hypothesis that is not testable would be: "The frogs are deformed because someone cast a magic spell on them." You cannot make any predictions based on the deformity being caused by magic, so there is no way to test a magic hypothesis or to measure any results of magic. There is no way to prove that it is not magic, so that hypothesis is untestable and therefore not relevant to a scientist.
**Analyze Data and Draw a Conclusion**

If a hypothesis and experiment are well designed, the experiment will produce measurable results or **data** that you can collect and analyze, and then develop a conclusion. Measurable results can be taken in two ways: **quantitative** (numerical) and **qualitative** (descriptive) data. The conclusion should tell you if the hypothesis is supported or not supported based on the data and contain an explanation of why.

*Example:*

Your results show that pesticide levels in the two sets of ponds are statistically different, but the number of deformed frogs is almost the same when you average all the ponds together. Your results demonstrate that your hypothesis is either not supported or the situation is more complicated than you thought. This gives you new information that will help you decide what to do next. Even if the results supported your hypothesis, you would probably ask a new question to try to better understand what is happening to the frogs and why. When you are satisfied that you have accurate information you share your results with others.

You will probably revise your hypothesis and design additional experiments along the way.

**Communicate Results**

Scientists communicate their findings in a variety of ways. For example, they may discuss their results with colleagues, talk to small groups of scientists, give speeches at large scientific meetings, and write articles for scientific journals. Scientific articles include the questions, methods, and conclusions from their research. Other scientists may try to repeat the experiments or change them. Scientists spend much time sharing and discussing their ideas with each other. Different scientists have different kinds of expertise they can use to help each other. When many scientists have independently come to the same conclusions, a scientific theory is developed. A scientific theory is a well-established explanation of an observation. It is generally accepted among the scientific community.

*Example:*

You eventually decide that you have strong results to share about frog deformities. You write an article and give talks about your research. Your results could contribute towards solutions.
Pure and Applied Science

Science can be "pure" or "applied." The goal of pure science is to understand how things work - whether it's why things fall on the floor or the structure of cells. Pure science is the source of most scientific theory and new knowledge. Applied science is using scientific discoveries to solve practical problems or to create new technologies.

Even though pure research is not intended to solve problems directly, pure research always provides the knowledge that applied scientists need to solve problems. For example, medicine and all that is known about how to treat patients is applied science based on pure research (Figure 1. 9).

Figure 1. 9: A healthy newborn being inspected by a doctor.
1.3 Tools and Measuring in Science

Objectives:

• Describe the growing number of tools available to investigate different features of the physical world.

• Describe how microscopes have allowed humans to view increasingly small tissues and organisms that were never visible before.

• Understand the history of measuring in science

• Recognize the prefixes of the metric system

• Convert from one prefix to another prefix when given a set of numbers.

Check Your Understanding

• What is the scientific method?

• What is an experiment?

• Where is the metric system used in the world?

Using Microscopes

Microscopes, tools that you may get to use in your class, are some of the most important tools in biology (Figure 1.10). Before microscopes were invented in 1595, the smallest things you could see on yourself were the tiny wrinkles in your skin. The magnifying glass, a simple glass lens, was developed about 1200 years ago. A typical magnifying glass may have doubled the size of an image. But microscopes allowed people to see objects as small as individual cells and even large bacteria. Microscopes let people see that all organisms are made of cells. Without microscopes, some of the most important discoveries in science would have been impossible.

Figure 1. 10: Basic light microscopes opened up a new world to curious people. 1. Ocular lens or eyepiece; 2. Nose piece; 3. Objective lenses; 4. Coarse adjustment knob; 5. Fine adjustment knob; 6. Object holder or stage; 7. Light (illuminator); 8. Diaphragm and condenser; 9. Stage clips
Microscopes are used to look at things that are too small to be seen by the unaided eye. Microscopy is a technology for studying small objects using microscopes. A microscope that magnifies something two to ten times (indicated by 2X or 10X on the side of the lens) may be enough to dissect a plant or look closely at an insect. Using even more powerful microscopes, scientists can magnify objects to two million times their real size.

Some of the very best early optical microscopes were made four hundred years ago by Antoine van Leeuwenhoek (Figure 1. 11), a man who taught himself to make his own microscopes. Robert Hooke, an English natural scientist of the same period of history, used a microscope to see and name the first "cells" (Figure 1. 12), which he discovered in plants.

![Figure 1. 11: Antoine van Leeuwenhoek, a Dutch cloth merchant with a passion for microscopy. Bacteria were discovered in 1683 when Antoine van Leeuwenhoek used a microscope he built to look at the plaque on his own teeth.](image)

![Figure 1. 12: Robert Hooke's early microscope.](image)

Some modern microscopes use light, as Hooke's and van Leeuwenhoek's did, but others may use electron beams or sound waves.

Researchers now use many kinds of microscopes. A light microscope allows biologists to see small details of biological specimens. Most of the microscopes used in schools and laboratories are compound light microscopes. Light microscopes use refractive lenses, typically made of glass or plastic, to focus light either into the eye, a camera, or some other light detector. The most powerful light microscopes can magnify images up to 2,000 times. Light microscopes are not as powerful as other higher tech microscopes but they are much cheaper—anyone can own one and see many amazing things.

**Metric system**

The metric system is an international system of measurement first adopted by France in 1791. Today it is the common system of unit of measurement used by most of the world; since the 1960s the International System of Units has been internationally recognized. Metric units are
universally used in scientific work, and widely used around the world for personal and commercial purposes. A standard set of prefixes in powers of ten may be used to derive larger and smaller units from the base units.

One goal of the metric system is to have a single unit for everything measured. Another goal is to avoid the need to convert from one unit to another. All lengths and distances, for example, are measured in meters, or thousandths of a meter (millimeters), or thousands of meters (kilometers). All liquids are measured in liters, and mass (weight) is measured in grams. Multiples and submultiples are factors of powers of ten, so that one can convert by simply moving the decimal place: 1.234 meters is 1234 millimeters, 0.001234 kilometers, etc.

The names of multiples and submultiples are formed with SI prefixes. They include kilo- (thousand, $10^3$), centi- (hundredth, $10^{-2}$) and milli- (thousandth, $10^{-3}$). The table below lists the most common metric prefixes and their relationship to the central unit that has no prefix. Length is used as an example to demonstrate the relative size of each prefixed unit.

Table 1.1:

### SI Prefixes

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<th>Unit Abbrev.</th>
<th>Meaning</th>
<th>Example</th>
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<td>k</td>
<td>1000</td>
<td>1 kilometer (km) = 1000 m</td>
</tr>
<tr>
<td>hecto</td>
<td>h</td>
<td>100</td>
<td>1 hectometer (hm) = 100 m</td>
</tr>
<tr>
<td>deca</td>
<td>da</td>
<td>10</td>
<td>1 decameter (dam) = 10 m</td>
</tr>
<tr>
<td>BASE m (eg. L, g)</td>
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<td>1 meter (m)</td>
<td></td>
</tr>
<tr>
<td>deci</td>
<td>d</td>
<td>1/10</td>
<td>1 decimeter (dm) = 0.1 m</td>
</tr>
<tr>
<td>centi</td>
<td>c</td>
<td>1/100</td>
<td>1 centimeter (cm) = 0.01 m</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>1/1000</td>
<td>1 millimeter (mm) = 0.001 m</td>
</tr>
<tr>
<td>micro</td>
<td>μ</td>
<td>1/1,000,000</td>
<td>1 micrometer (μm) = $10^{-6}$ m</td>
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<tr>
<td>nano</td>
<td>n</td>
<td>1/1,000,000,000</td>
<td>1 nanometer (nm) = $10^{-9}$ m</td>
</tr>
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1.4 What is Biology?

Biology is a natural science concerned with the study of life and living organisms, including their structure, function, growth, evolution, distribution, and taxonomy.

Unifying Principles of Biology

Four unifying principles form the basis of biology. Whether biologists are interested in ancient life, the life of bacteria, or how humans could live on the moon, they base their overall understanding of biology on these four principles:

1. cell theory
2. gene theory
3. homeostasis
4. evolution

The Cell Theory

According to the cell theory, three things are true: all living things are made up of cells, living cells always come from other living cells, and cells are the basic unit of life. In fact, each living thing begins life as a single cell. Some living things, such as bacteria, remain single-celled. Other living things, including plants and animals, grow and develop into many cells. Your own body is made up of an amazing 100 trillion cells! But even you—like all other living things—began life as a single cell (see Figure 1.13).

Figure 1.13: Tiny diatoms and whale sharks are all made of cells. Diatoms are about 20 µm in diameter and are made up of one cell, whereas whale sharks can measure up to 12 meters in length and are made up of billions of cells.
**The Gene Theory**

The gene theory is the idea that the characteristics of living organisms are controlled by genes, which are passed from parents to their offspring. A gene is a segment of DNA that has the instructions to encode a protein. Genes are located on larger structures, called chromosomes, which are found inside every cell. Chromosomes, in turn, contain large molecules known as DNA (deoxyribonucleic acid). Molecules of DNA are encoded with instructions that tell cells what to do. To see how this happens, see the animation titled *Journey into DNA* by clicking the following link: [http://www.pbs.org/wgbh/nova/genome/dna.html](http://www.pbs.org/wgbh/nova/genome/dna.html).

**Homeostasis**

Homeostasis, or maintaining a stable internal environment (keeping things constant), is not just a characteristic of living things. It also applies to nature as a whole. Consider the concentration of oxygen in Earth’s atmosphere. Oxygen makes up 21% of the atmosphere, and this concentration is fairly constant. What keeps the concentration of oxygen constant? The answer is living things. Most living things need oxygen to survive, and when they breathe, they remove oxygen from the atmosphere. On the other hand, many living things, including plants, give off oxygen when they make food, and this adds oxygen to the atmosphere. The concentration of oxygen in the atmosphere is maintained mainly by the balance between these two processes.

**Evolution**

Evolution is a change in the characteristics of living things over time. Evolution occurs by a process called natural selection. In natural selection, some living things produce more offspring than others, so they pass more genes to the next generation than others do. Over many generations, this can lead to major changes in the characteristics of living things. Evolution explains how living things are changing today and how modern living things have descended from ancient life forms that no longer exist on Earth. As living things evolve, they generally become better suited for their environment. This is because they evolve adaptations. An adaptation is a characteristic that helps a living thing survive and reproduce in a given environment.

**Characteristics of Life**

To be classified as a living thing, an object must have all eight of the following characteristics:

1. It responds to the environment - stimulus.
2. It grows and develops.
3. It produces offspring.
4. It maintains homeostasis.
5. It consists of cells.
6. It uses of energy.
7. It contains the universal genetic code.
8. As a group living things change over time - evolution

**Response to the Environment**

All living things detect changes in their environment and respond to them. What happens if you step on a rock? Nothing; the rock doesn’t respond because it isn’t alive. But what if you think you are stepping on a rock and actually step on a turtle shell? The turtle is likely to respond by moving—it may even snap at you!

**Growth and Development**

All living things grow and develop. For example, a plant seed may look like a lifeless pebble, but under the right conditions it will grow and develop into a plant. Animals also grow and develop. Look at the animals in Figure 1.14. How will the tadpoles change as they grow and develop into adult frogs?

![Tadpoles and Adult Frog](image)

**Figure 1.14: Tadpoles go through many stages to become adult frogs.**

**Reproduction**

All living things are capable of reproduction. Reproduction is the process by which living things give rise to offspring. Reproducing may be as simple as a single cell dividing to form two daughter cells. Generally, however, it is much more complicated. Nonetheless, whether a living thing is a huge whale or a microscopic bacterium, it is capable of reproduction.
**Keeping Things Constant**

All living things are able to maintain a more-or-less constant internal environment. They keep things relatively stable on the inside regardless of the conditions around them. The process of maintaining a stable internal environment is called homeostasis. Human beings, for example, maintain a stable internal body temperature. If you go outside when the air temperature is below freezing, your body doesn’t freeze. Instead, by shivering and other means, it maintains a stable internal temperature.

**Use of Energy**

All living things—even the simplest life forms—have complex chemistry. Living things consist of large, complex molecules, and they also undergo many complicated chemical changes to stay alive. All of these chemical changes that occur in an organism are known as metabolism. Complex chemistry is needed to carry out all the functions of life.

**Cells**

All forms of life are built of cells. A cell is the basic unit of the structure and function of living things. Living things may appear very different from one another on the outside, but their cells are very similar. Compare the human cells on the left in Figure 1.15 and onion cells on the right in Figure 1.15. How are they similar?

![Figure 1.15: Human cells (left) and onion cells (right). If you look under a microscope, this is what you might see.](image)

**Universal Genetic Code**

In living organisms there are nucleic acids that serve as a universal code. DNA and RNA work together to carry out the instructions found in cells. The DNA serves as a blueprint or recipe for how to build proteins. The three types of RNA work with the DNA to help convert the information in the DNA into a functional protein. This code composed of various genes found in DNA is universal and has been found in all living organisms.
Evolution

The idea of evolution has been around for centuries. In fact, it goes all the way back to the ancient Greek philosopher Aristotle. However, evolution is most often associated with Charles Darwin. Darwin published a book on evolution in 1859 titled *On the Origin of Species*. In the book, Darwin stated the theory of evolution by natural selection. He also presented a great deal of evidence that evolution occurs. As described by Darwin, evolution occurs by a process called natural selection. In natural selection, some members of a species produce more offspring than others, so they pass "advantageous traits" to their offspring. Over many generations, this can lead to major changes in the characteristics of the species. Evolution explains how living things are changing today and how modern living things have descended from ancient life forms that no longer exist on Earth. As living things evolve, they generally become better suited for their environment.

Evolution occurs in populations – not to individual organisms. Over time, populations can change as a result of environmental pressures. This changing nature of life is one of the defining characteristics of life. Evolutionary theory deals not with how life came into existence, but how it has changed since.

Review

1. Identify four unifying principles of modern biology.
2. How is gene theory related to the theory of evolution?
3. How are genes related to chromosomes?
4. Who was Charles Darwin and what did he study?

Vocabulary

- Applied science
- Controlled experiment
- Dependent variable (responding variable)
- Experimental group

- Controls
- Data
- Evidence
- Hypothesis
• Independent variable (manipulated variable)
• Models
• Predictions
• Qualitative Data
• Question

• Inference
• Observations
• Pure science
• Quantitative Data

Other State Standard Vocabulary to Know

• Analyses
• General trend
• Medium
• Negative relationship
• Positive relationship
• Procedural error
• Range
• Slope

• Frequency
• Mean
• Mode
• No relationship
• Probability
• Protocol
• Sample size
• Trials
CHAPTER 2: BIOCHEMISTRY

2.1 Carbon

Objectives:

- Explain why carbon is essential to life on Earth.
- Describe the structure and function of the four major types of organic compounds.

Carbon is the most important element to life. Without this element, life as we know it would not exist. As you will see, carbon is the central element in compounds necessary for life.

A compound found mainly in living things is known as an organic compound. Organic compounds make up the cells and other structures of organisms and carry out life processes. Carbon is the main element in organic compounds, so carbon is essential to life on Earth. Without carbon, life as we know it could not exist.

Compounds

A compound is a substance that consists of two or more elements. A compound has a unique composition that is always the same. The smallest particle of a compound is called a molecule. Consider water as an example. A molecule of water always contains one atom of oxygen and two atoms of hydrogen (Figure 2.1). The composition of water is expressed by the chemical formula H₂O. Water is not an organic compound because it does not contain any carbon.
What causes the atoms of a water molecule to “stick” together? The answer is chemical bonds. A chemical bond is a force that holds molecules together. Chemical bonds form when substances react with one another. A chemical reaction is a process that changes some chemical substances into others. A chemical reaction is needed to form a compound. Another chemical reaction is needed to separate the substances in a compound.

**Carbon**

Why is carbon so important to life? The reason is carbon’s ability to form stable bonds with many elements, including itself. This property allows carbon to form a huge variety of very large and complex molecules. In fact, there are nearly 10 million carbon-based compounds in living things! However, the millions of organic compounds can be grouped into just four major types: carbohydrates, lipids, proteins, and nucleic acids. You can compare the four types in Table 2.1 below. Each type is also described below.

<table>
<thead>
<tr>
<th>Table 2.1: Four types of carbon-based compounds.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Compound</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Carbohydrates</td>
</tr>
<tr>
<td>Lipids</td>
</tr>
<tr>
<td>Proteins</td>
</tr>
<tr>
<td>Nucleic Acids</td>
</tr>
</tbody>
</table>
Summary:

- Carbon is the main element in organic compounds. Carbon can form stable bonds with many elements, including itself.
- There are four major types of organic compounds: carbohydrates, lipids, proteins, and nucleic acids.

Practice:

Use the resource to answer the questions that follow.

1. What is an organic compound? Roughly how many organic compounds exist?
2. Describe the element carbon.
3. What is the chemical composition of aspirin? Is it a natural or synthetic compound?
4. Describe organic reactions.

Review:

1. Explain why carbon is essential to all known life on Earth.
2. Which type(s) of organic compounds provide energy?
3. Which organic compound stores genetic information?
4. Examples of proteins include ____________.
2.2 Carbohydrates

Sugar. Does this look like biological energy?

As a child, you may have been told that sugar is bad for you. Well, that's not exactly true. Essentially, carbohydrates are made of one single sugar molecule to thousands of sugar molecules attached together. Why? One reason is to store energy. But that does not mean you should eat it by the spoonful.

Carbohydrates are the most common type of organic compound. A carbohydrate is an organic compound such as sugar or starch, and is used to store energy. Like most organic compounds, carbohydrates are built of small, repeating units that form bonds with each other to make a larger molecule. In the case of carbohydrates, the small repeating units are called monosaccharides. Carbohydrates contain only atoms of carbon, hydrogen, and oxygen.

Monosaccharides and Disaccharides

A monosaccharide is a simple sugar such as fructose or glucose. Fructose is found in fruits, whereas glucose generally results from the digestion of other carbohydrates. Glucose (C₆H₁₂O₆) is used for energy by the cells of most organisms, and is a product of photosynthesis.

The general formula for a monosaccharide is:

- \((\text{CH}_2\text{O})_n\), where \(n\) can be any number greater than two. For example, in glucose \(n\) is 6, and the formula is: \(\text{C}_6\text{H}_{12}\text{O}_6\).

If two monosaccharides bond together, they form a carbohydrate called a disaccharide. An example of a disaccharide is sucrose (table sugar), which consists of the monosaccharides glucose and fructose. Monosaccharides and disaccharides are also called simple sugars. They provide the major source of energy to living cells.
Polysaccharides

A polysaccharide is a complex carbohydrate that forms when simple sugars bind together in a chain. Polysaccharides may contain just a few simple sugars or thousands of them. Complex carbohydrates have two main functions: storing energy and forming structures of living things. Some examples of complex carbohydrates and their functions are shown in Table 2.2 below. Which type of complex carbohydrate does your own body use to store energy?

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Example</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>Used by plants to store energy.</td>
<td><img src="image" alt="Starch Example" /></td>
<td>A potato stores starch in underground tubers.</td>
</tr>
<tr>
<td>Glycogen</td>
<td>Used by animals to store energy.</td>
<td><img src="image" alt="Glycogen Example" /></td>
<td>A human stores glycogen in liver cells.</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Used by plants to form rigid walls around cells.</td>
<td><img src="image" alt="Cellulose Example" /></td>
<td>Plants use cellulose for their cell walls.</td>
</tr>
<tr>
<td>Chitin</td>
<td>Used by some animals to form an external skeleton.</td>
<td><img src="image" alt="Chitin Example" /></td>
<td>A housefly uses chitin for its exoskeleton.</td>
</tr>
</tbody>
</table>

Table 2.2: Complex Carbohydrates.

Summary:
- Carbohydrates are organic compounds used to store energy.
- A monosaccharide is a simple sugar, such as fructose or glucose.
- Complex carbohydrates have two main functions: storing energy and forming structures of living things.
Practice:

Use these resources to answer the questions that follow.

1. What do carbohydrates provide to the cell?
2. Describe glucose.
3. What is an isomer? Give an example.
4. What is a disaccharide? Give an example.
5. What is the role of starch?

Review:

1. List three facts about glucose.
2. Assume that you are trying to identify an unknown organic molecule. It contains only carbon, hydrogen, and oxygen and is found in the cell walls of a newly discovered plant species. What type of organic compound is it? Why?
2.3 Proteins

You may have been told proteins are good for you. Do these look good to you?

To you, these may not look appetizing (or they might), but they do provide a nice supply of **amino acids**, the building blocks of proteins. Proteins have many important roles, from transporting, signaling, receiving, and catalyzing to storing, defending, and allowing for movement. Where do you get the amino acids needed so your cells can make their own proteins? If you cannot make it, you must eat it.

A **protein** is an organic compound made up of small molecules called amino acids. There are 20 different amino acids commonly found in the proteins of living organisms. Small proteins may contain just a few hundred amino acids, whereas large proteins may contain thousands of amino acids.

**General Structure of Amino Acids.**

Figure 2. 2 shows the general structure of all amino acids. Only the side chain, R, varies from one amino acid to another. The order of amino acids, together with the properties of the amino acids, determines the shape of the protein, and the shape of the protein determines the function of the protein.

A short video describing protein function can be viewed at:
As you view Protein Functions in the Body, focus on these concepts:

1. The amount of protein in each cell
2. The roles of different types of proteins

Summary

- Proteins are organic compounds made up of amino acids.

Practice

Use the resource to answer the questions that follow.

1. Give 3 examples of proteins.
2. What determines the primary structure of a protein?
3. What determines the protein's function?
4. How can a protein's conformation be disrupted?

Review

1. What determines the primary structure of a protein?
2. State two functions of proteins.
3. Proteins are made out of ___________.

Biomolecules - The Proteins:

2.4 Lipids

Oil. Does it mix with water? No. Biologically, why is this important?

Oil is a lipid. The property of being unable to chemically mix with water gives lipids some very important biological functions. Lipids form the outer membrane of cells. Why?

A lipid is an organic compound such as fat or oil. Organisms use lipids to store energy, but lipids have other important roles as well. Lipids consist of repeating units called fatty acids. Fatty acids are organic compounds that have the general formula \( \text{CH}_3(\text{CH}_2)_n\text{COOH} \), where \( n \) usually ranges from 2 to 28 and is always an even number. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.

![Saturated fatty acid](image1)

**Figure 2.3: Carbon bonding in saturated fatty acids**

**Saturated Fatty Acids**

In saturated fatty acids, carbon atoms are bonded to as many hydrogen atoms as possible. This causes the molecules to form straight chains, as shown in Figure 2.3. The straight chains can be packed together very tightly, allowing them to store energy in a compact form. This explains why
saturated fatty acids are solids at room temperature. Animals use saturated fatty acids to store energy.

**Fatty Acid Chains**

Saturated fatty acids have straight chains, like the three fatty acids shown in the upper left column of Figure 2.3. Unsaturated fatty acids have bent chains, like all the other fatty acids in the figure.

**Unsaturated Fatty Acids**

In unsaturated fatty acids, some carbon atoms are not bonded to as many hydrogen atoms as possible. These plant products in Figure 2.4 all contain unsaturated fatty acids.

---

**Summary:**

- Organisms use lipids to store energy. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.
- Animals use saturated fatty acids to store energy. Plants use unsaturated fatty acids to store energy.

**Practice:**

Use the resource to answer the questions that follow.

1. What is the defining property of a lipid?
2. Give 3 examples of lipids.
3. What are the roles of natural fats?
4. Describe the structure of phospholipid molecules.
5. What are the functions of cholesterol?

---

**Biomolecules - The Lipids:**

Review:

1. What is a lipid?

2. Butter is a fat that is a solid at room temperature. What type of fatty acid does butter contain? How do you know?

3. Explain why molecules of saturated and unsaturated fatty acids have different shapes.
2.5 Nucleic Acids

You may have heard that something is "encoded in your DNA." What does that mean?

Nucleic acids. Essentially the "instructions" or "blueprints" of life. Deoxyribonucleic acid, or DNA, is the unique blueprints to make the proteins that give you your traits. Half of these blueprints come from your mother, and half from your father. Therefore, every person that has ever lived - except for identical twins - has his or her own unique set of blueprints - or instructions - or DNA.

A nucleic acid is an organic compound, such as DNA or RNA, that is built of small units called nucleotides. The nucleic acid DNA (deoxyribonucleic acid) consists of two polynucleotide chains. The nucleic acid RNA (ribonucleic acid) consists of just one polynucleotide chain.

Structure of Nucleic Acids

Each nucleotide consists of three smaller molecules:

1. sugar
2. phosphate group
3. nitrogen base

If you look at Figure 2. 5, you will see that the sugar of one nucleotide binds to the phosphate group of the next nucleotide. These two molecules alternate to form the backbone of the nucleotide chain. This backbone is known as the sugar-phosphate backbone. The nitrogen bases in a nucleic acid stick out from the backbone. There are four different types of bases: cytosine
(C), adenine (A), guanine (G), and either thymine (T) in DNA or uracil (U) in RNA. In DNA, bonds form between bases on the two nucleotide chains and hold the chains together. Each type of base binds with just one other type of base: cytosine always binds with guanine, and adenine always binds with thymine. These pairs of bases are called complementary base pairs.

Figure 2.5: Sugars and phosphate groups form the backbone of a DNA strand. Hydrogen bonds between complementary bases hold the two DNA strands together.

The binding of complementary bases allows DNA molecules to take their well-known shape, called a double helix, which is shown in Figure 2.6 below. A double helix is like a spiral staircase. The double helix shape forms naturally and is very strong, making the two DNA strands difficult to break apart.
Figure 2. 6: How DNA winds into a chromosome.

DNA Molecules

Bonds between complementary bases help form the double helix of a DNA molecule. The sequence of the four bases in DNA is a code that carries instructions for making proteins. Shown in Figure 2. 6 is how the DNA winds into a chromosome.

An animation of DNA structure can be viewed at:

- http://www.youtube.com/watch?v=qy8dk5iS1f0&feature=related

Summary:

- DNA and RNA are nucleic acids. Nucleic acids are built of small units called nucleotides.
- The bases of DNA are adenine, guanine, cytosine and thymine. In RNA, thymine is replaced by uracil.
- In DNA, A always binds to T, and G always binds to C.
- The shape of the DNA molecule is known as a double helix.
Practice:

Use this resource to answer the questions that follow.

1. Why is DNA referred to as the “instructions”?  
2. Where is DNA located in the cell?  
3. What do A, C, G and T refer to? How can only four letters tell the cell what to do?  
4. What is a gene?

Review:

1. Identify the three parts of a nucleotide.  
2. What is DNA?  
3. What are complementary base pairs? Give an example.  
4. Describe the shape of DNA.  
5. How are DNA and RNA related to proteins?
2.6 Water

Dihydrogen oxide or dihydrogen monoxide. Does this chemical sound dangerous?

Another name for this compound is…water. Water can create some absolutely beautiful sights. Iguassu Falls is the largest series of waterfalls on the planet, located in Brazil, Argentina, and Paraguay. And, water is necessary for life. The importance of water to life cannot be emphasized enough. All life needs water. Life started in water. Essentially, without this simple three atom molecule, life would not exist.

Water, like carbon, has a special role in living things. It is needed by all known forms of life. Water is a simple molecule, containing just three atoms. Nonetheless, water’s structure gives it unique properties that help explain why it is vital to all living organisms.

Water, Water Everywhere

Water is a common chemical substance on planet Earth. In fact, Earth is sometimes called the "water planet" because almost 75% of its surface is covered with water. If you look at Figure 2.7, you will see where Earth’s water is found. The term water generally refers to its liquid state, and water is a liquid over a wide range of temperatures on Earth. However, water also occurs on Earth as a solid (ice) and as a gas (water vapor).
Most of the water on Earth consists of saltwater in the oceans. What percent of Earth’s water is fresh water? Where is most of the fresh water found?

**Figure 2. 7: Where is Earth's water?**

### Structure and Properties of Water

No doubt, you are already aware of some of the properties of water. For example, you probably know that water is tasteless and odorless. You also probably know that water is transparent, which means that light can pass through it. This is important for organisms that live in the water, because some of them need sunlight to make food.

### Chemical Structure of Water

To understand some of water’s properties, you need to know more about its chemical structure. As you have seen, each molecule of water consists of one atom of oxygen and two atoms of hydrogen. The oxygen atom in a water molecule attracts negatively-charged electrons more strongly than the hydrogen atoms do. As a result, the oxygen atom has a slightly negative charge, and the hydrogen atoms have a slightly positive charge.

A difference in electrical charge between different parts of the same molecule is called polarity, making water a polar molecule. The diagram in Figure 2. 8 to the right shows water’s polarity.

Opposites attract when it comes to charged molecules. In the case of water, the positive (hydrogen) end of one
water molecule is attracted to the negative (oxygen) end of a nearby water molecule. Because of this attraction, weak bonds form between adjacent water molecules, as shown in Figure 2. 9. The type of bond that forms between molecules is called a hydrogen bond. Bonds between molecules are not as strong as bonds within molecules, but in water they are strong enough to hold together nearby molecules.

Figure 2. 9: Hydrogen bonds form between nearby water molecules. How do you think this might affect water's properties?

Properties of Water

Hydrogen bonds between water molecules explain some of water’s properties. For example, hydrogen bonds explain why water molecules tend to stick together. Have you ever watched water drip from a leaky faucet or from a melting icicle? If you have, then you know that water always falls in drops rather than as separate molecules. The dew drops in Figure 2. 10 are another example of water molecules sticking together.

Can you think of other examples of water forming drops? (Hint: What happens when rain falls on a newly waxed car?)

Hydrogen bonds cause water to have a relatively high boiling point of 100°C (212°F). Because of its high boiling point, most water on Earth is in a liquid state rather than in a gaseous state. Water in its liquid state is needed by all living things. Hydrogen bonds also cause water to
expand when it freezes. This, in turn, causes ice to have a lower density (mass/volume) than liquid water. The lower density of ice means that it floats on water. For example, in cold climates, ice floats on top of the water in lakes. This allows lake animals such as fish to survive the winter by staying in the water under the ice.

**Water and Life**

The human body is about 70% water (not counting the water in body fat, which varies from person to person). The body needs all this water to function normally. Just why is so much water required by human beings and other organisms? Water can dissolve many substances that organisms need, and it is necessary for many biochemical reactions.

**Summary:**

- Water is needed by all known forms of life.
- Due to the difference in the distribution of charge, water is a polar molecule.
- Hydrogen bonds hold adjacent water molecules together.
- Water is involved in many biochemical reactions. As a result, just about all life processes depend on water.

**Practice:**

Use the resource to answer the questions that follow.

1. How do hydrogen and oxygen bind to form water?
2. Why is water a polar molecule?
3. Describe the bond between water molecules.
4. Describe two properties of water that make it important to life.
5. Why does ice float?

**Water:**

- [http://johnkyrk.com/H2O.html](http://johnkyrk.com/H2O.html)
- [http://www.hippocampus.org/Biology](http://www.hippocampus.org/Biology)
  - Go To: Non-Majors Biology
  - Search: Properties of Water
Review:

1. Where is most of Earth’s water found?
2. What is polarity? Describe the polarity of water.
3. How could you demonstrate to a child that solid water is less dense than liquid water?
4. Explain how water’s polarity is related to its boiling point.
5. Explain why metabolism in organisms depends on water.

Vocabulary

- Amino acid
- Carbohydrate
- DNA
- Lipid
- Monosaccharide
- Nucleic acid
- Organic compound
- Polysaccharide
- Protein
CHAPTER 3: CLASSIFICATION
3.1 Living Things

Objectives:

• Outline the Linnaean classification, and define binomial nomenclature.
• Describe phylogenetic classification, and explain how it differs from Linnaean classification.

Can two different species be related?

Of course they can. For example, there are many different species of mammals, or of one type of mammal, such as mice. And they are all related. In other words, how close or how far apart did they separate from a common ancestor during evolution? Determining how different species are evolutionarily related can be a tremendous task.

In biology, what would classification refer to?

When you see an organism that you have never seen before, you probably put it into a group without even thinking. If it is green and leafy, you probably call it a plant. If it is long and slithers, you probably call it a snake. How do you make these decisions? You look at the physical features of the organism and think about what it has in common with other organisms.

There are millions and millions of species, so classifying organisms into proper categories can be a difficult task. To make it easier for all scientists to do, a classification system had to be developed.

Linnaean Classification

The evolution of life on Earth over the past 4 billion years has resulted in a huge variety of species. For more than 2,000 years, humans have been trying to classify
the great diversity of life. The science of classifying organisms is called **taxonomy**. Classification is an important step in understanding the present diversity and past evolutionary history of life on Earth.

All modern **classification systems** have their roots in the Linnaean classification system. It was developed by Swedish botanist Carolus Linnaeus (1707-1778) in the 1700s (Figure 3.1). He tried to classify all living things that were known at his time. He grouped together organisms that shared obvious physical traits, such as number of legs or shape of leaves. He invented the way we name organisms today, with each organism having a two word name. For his contribution, Linnaeus is known as the “father of taxonomy.” The Linnaean system of classification consists of a hierarchy of groupings, called taxa (singular, taxon). Taxa range from the kingdom to the species (Figure 3.2). The kingdom is the largest and most inclusive grouping. It consists of organisms that share just a few basic similarities. Examples are the plant and animal kingdoms. The species is the smallest and most exclusive grouping. It consists of organisms that are similar enough to produce fertile offspring together. Closely related species are grouped together in a genus.

**Figure 3.2:** Linnaean Classification System: Classification of the Human Species. This chart shows the taxa of the Linnaean classification system. Each taxon is a subdivision of the taxon below it in the chart. For example, a species is a subdivision of a genus. The classification of humans is given in the chart as an example.
**Binomial Nomenclature**

Perhaps the single greatest contribution Linnaeus made to science was his method of naming species. This method, called **binomial nomenclature**, gives each species a unique, two-word Latin name consisting of the genus name and the species name. An example is *Homo sapiens*, the two-word Latin name for humans. It literally means “wise human.” This is a reference to our big brains. Why is having two names so important? It is similar to people having a first and a last name. You may know several people with the first name Michael, but adding Michael’s last name usually pins down exactly whom you mean. In the same way, having two names uniquely identifies a species.

**Revisions in Linnaean Classification**

Linnaeus published his classification system in the 1700s. Since then, many new species have been discovered. The biochemistry of many organisms has also become known. Eventually, scientists realized that Linnaeus’s system of classification needed revision. A major change to the Linnaean system was the addition of a new taxon called the domain. A domain is a taxon that is larger and more inclusive than the kingdom. Most biologists agree there are three domains of life on Earth: Bacteria, Archaea, and Eukaryota (Figure 3. 3). Both Bacteria and Archaea consist of single-celled prokaryotes. Eukaryota consists of all eukaryotes, from single-celled protists to humans. This domain includes the Animalia (animals), Plantae (plants), Fungi (fungi), and Protista (protists) kingdoms.

**Phylogenetic Classification**

Linnaeus classified organisms based on obvious physical traits. Basically, organisms were grouped together if they looked alike. After Darwin published his theory of evolution in the 1800s, scientists looked for a way to classify organisms that showed phylogeny. **Phylogeny** is the evolutionary history of a group of related organisms. It is represented by a phylogenetic tree, like the one in Figure 3. 4.
Cladistics is a method of comparing traits in related species to determine ancestor-descendant relationships. Clades are represented with cladograms, like the one in the Figure 3.5. This cladogram represents the mammal and reptile clades. The reptile clade includes birds. It shows that birds evolved from reptiles. Linnaeus classified mammals, reptiles, and birds in separate classes. This masks their evolutionary relationships.

**DNA and Biochemical Analysis**

Today, scientists prefer to use DNA and Biochemical analysis to classify organisms. They feel that it is more accurate in determining the evolutionary lineage of organisms. The closer two organisms are in their evolutionary descent, the closer they should be in our classification system. Our classification system is constantly changing and DNA and Biochemical analysis is being used to reclassify many organisms at this very moment. **DNA analysis** is when scientists analyze the DNA of an organism and compare it to other organisms. If the DNA is very similar, it is believed that the two organisms are more closely related in their evolutionary decent. If the DNA is very different, scientists believe that they are further away in their evolutionary decent. Biochemical Analysis analyzes other biochemicals in the organism, such as enzymes, proteins, chemical reactions, etc.
Again, the more similarities the two organisms have, the more closely related they are considered to be.

**A Changing System**

The current **classification system** is currently changing due to the discovery of new organisms as well as the discovery of new classification techniques. As long as humans strive to classify organisms, the classification of the organisms will continually change due to changes in human knowledge and technology. Linneaus with his classification system was the pioneer for the classification of organisms on Earth, however, cladistics seems to be fast overriding the old system because it is based more on DNA and biochemical analysis than embryology and morphology.

**Review:**

1. What is taxonomy?
2. Define taxon and give an example.
3. What is binomial nomenclature? Why is it important?
4. What is a domain? What are the three domains of life on Earth?
5. Create a taxonomy, modeled on the Linnean classification system, for a set of common objects, such as motor vehicles, tools, or office supplies. Identify the groupings that correspond to the different taxa in the Linnean system.
6. Who is the inventor of the modern classification system?
7. List the classification categories for organisms from the broadest category to the most specific.
8. (Optional) Nova: Classifying Life

**Vocabulary**

- Binomial nomenclature
- Classification system
- Phylogeny
- Cladistics
- DNA analysis
- Taxonomy
CHAPTER 4: CELLS

4.1 Tiny Structure, Big Function

Objectives:

- Recall the cell theory.
- What is a cell?
- Explain the levels of organization in an organism.
- Explain how cells are observed.
- Compare and contrast prokaryote and eukaryote cells.
- Compare and contrast plant and animal cells.

What are you made of?

Cells make up all living things, including your own body. Figure 4.1 shows a typical group of cells, but not all cells look alike. Cells can differ in shape and sizes. Recall that different shapes usually means different functions.

Introduction to Cells

A cell is the smallest structural and functional unit of an organism. Some organisms, like bacteria, consist of only one cell. Big organisms, like humans, consist of trillions of cells. Compare a human to a banana. On the outside, they look very different, but if you look close enough you’ll see that their cells are actually very similar.
**Observing Cells**

Most cells are so small that you cannot see them without the help of a microscope. It was not until 1665 that English scientist Robert Hooke invented a basic light microscope and observed cells for the first time. You may use light microscopes in the classroom. You can use a light microscope to see cells (See Figure 4. 2). But many structures in the cell are too small to see with a light microscope. So, what do you do if you want to see the tiny structures inside of cells?

**Cell Theory**

In 1858, after using microscopes much better than Hooke’s first microscope, Rudolf Virchow developed the hypothesis that cells only come from other cells. For example, bacteria, which are single-celled organisms, divide in half (after they grow some) to make new bacteria. In the same way, your body makes new cells by dividing the cells you already have. In all cases, cells only come from cells that have existed before. This idea led to the development of one of the most important theories in biology, the cell theory.

Cell theory states that:

1. All organisms are composed of cells.
2. Cells are alive and the basic living units of organization in all organisms.
3. All cells come from other cells.

As with other scientific theories, many hundreds, if not thousands, of experiments support the cell theory. Since Virchow created the theory, no evidence has ever been identified to contradict it.

**Organization of Living Things. What does this mean?**

We know it all starts with the cell and for some species it ends with the cell. For others, the cells come together to form tissues, tissues form organs, organs form organ systems, and organ systems combine to form an organism.

**Levels of Organization**

The living world can be organized into different levels. For example, many individual organisms can be organized into the following levels:

- **Cell:** Basic unit of all living things.
- **Tissue**: Group of cells of the same kind.
- **Organ**: Structure composed of one or more types of tissues.
- **Organ system**: Group of organs that work together to do a certain job.
- **Organism**: Individual living thing that may be made up of one or more organ systems.

Examples of these levels of organization are shown in Figure 4.3 below.

![Figure 4.3: An individual mouse.](image)

An individual mouse is made up of several organ systems. The system shown here is the digestive system, which breaks down food into a form that cells can use. One of the organs of the digestive system is the stomach. The stomach, in turn, consists of different types of tissues. Each type of tissue is made up of cells of the same type.

There are also levels of organization above the individual organism. These levels are illustrated in Figure 4.4 below.

- Organisms of the same species that live in the same area make up a **population**. For example, all of the goldfish living in the same area make up a goldfish population.

- All of the populations that live in the same area make up a **community**. The community that includes the goldfish population also includes the populations of other fish, coral, and other organisms.

- An **ecosystem** consists of all the living things in a given area, together with the nonliving environment. The nonliving environment includes water, sunlight, and other physical factors.
• A group of similar ecosystems with the same general type of physical environment is called a **biome**.

• The **biosphere** is the part of Earth where all life exists, including all the land, water, and air where living things can be found. The biosphere consists of many different biomes.

![Figure 4.4](image)

**Figure 4.4:** This picture shows the levels of organization in nature, from the individual organism to the biosphere.

---

**Specialized Cells**

Although cells share many of the same features and structures, they also can be very different. Each cell in your body performs a specific task. In other words, the cell's function is partly based on the cell's structure. The cells pictured in Figure 4.5 below are just a few examples of the many different shapes that cells may have. Each type of cell in the figure has a shape that helps it do its job. For example, the job of the nerve cell is to carry messages to other cells. The nerve cell has many long extensions that reach out in all directions, allowing it to pass messages to many other cells at once. Do you see the tail-like projections on the algae cells? Algae live in water, and their tails help them swim. Pollen grains have spikes that help them stick to insects such as bees. How do you think the spikes help the pollen grains do their job? *(Hint: Insects pollinate flowers.)*
Cells come in many different shapes. How are the shapes of these cells related to their functions?

How many different types of cells are there?

There are many different types of cells. For example, in you there are blood cells, skin cells, bone cells, and even bacteria. However, all cells - whether from bacteria, human, or any other organism - will be one of two general types. In fact, all cells other than bacteria will be one type, and bacterial cells will be the other. It all depends on how the cell stores its DNA.

Four Common Parts of a Cell

Although cells are diverse, all cells have certain parts in common. The parts include a plasma membrane, cytoplasm, ribosomes, and DNA.

1. The plasma membrane (also called the cell membrane) is a thin coat of lipids that surrounds a cell. It forms the physical boundary between the cell and its environment, so you can think of it as the “skin” of the cell.
2. Cytoplasm refers to all of the cellular material inside the plasma membrane, other than the nucleus. Cytoplasm is made up of a watery substance called cytosol, and contains other cell structures such as ribosomes.
3. Ribosomes are structures in the cytoplasm where proteins are made.
4. DNA is a nucleic acid found in cells. It contains the genetic instructions that cells need to make proteins.

These parts are common to all cells, from organisms as different as bacteria and human beings. How did all known organisms come to have such similar cells? The similarities show that all life on Earth has a common evolutionary history.
Two Types of Cells

There is another basic cell structure that is present in many but not all living cells: the nucleus. The **nucleus** of a cell is a structure in the cytoplasm that is surrounded by a membrane (the nuclear membrane) and contains DNA. Based on whether they have a nucleus, there are two basic types of cells: prokaryotic cells and eukaryotic cells. To view a short animation for prokaryotic and eukaryotic cells go to the following site:

- [http://www.youtube.com/watch?feature=player_embedded&v=yWy4o_UfZ4A](http://www.youtube.com/watch?feature=player_embedded&v=yWy4o_UfZ4A)

**Prokaryotic Cells**

Prokaryotic cells are cells without a nucleus. The DNA in prokaryotic cells is in the cytoplasm rather than enclosed within a nuclear membrane. Prokaryotic cells are found in single-celled organisms, such as bacteria, like the one shown in [Figure 4. 6](#). Organisms with prokaryotic cells are called prokaryotes. They were the first type of organisms to evolve and are still the most common organisms today.

![Diagram of a typical prokaryotic cell](#)

**Figure 4. 6:** The structure of a typical prokaryotic cell, a bacterium. Like other prokaryotic cells, this bacteria cell lacks a nucleus but has other cell parts, including a plasma membrane, cytoplasm, ribosomes, and DNA. Identify each of these parts in the diagram.

**Eukaryotic Cells**

Eukaryotic cells are cells that contain a nucleus. A typical eukaryotic cell is shown in [Figure 4. 7](#). Eukaryotic cells are usually larger than prokaryotic cells, and they are found mainly in multicellular organisms. Organisms with eukaryotic cells are called **eukaryotes**, and they range from fungi to people. Eukaryotic cells also contain other organelles besides the nucleus. An **organelle** is a structure within the cytoplasm that performs a specific job in the cell. Organelles called **mitochondria**, for example, provide energy to the cell, and organelles called vacuoles store substances in the cell. Organelles allow eukaryotic cells to carry out more
functions than prokaryotic cells can. Ribosomes, the organelle where proteins are made, are the only organelles in prokaryotic cells.

**Figure 4.7:** Compare and contrast the eukaryotic cell shown here with the prokaryotic cell. What similarities and differences do you see?

In some ways, a cell resembles a plastic bag full of Jell-O. Its basic structure is a plasma membrane filled with cytoplasm. Like Jell-O containing mixed fruit, the cytoplasm of the cell also contains various structures, such as a nucleus and other organelles.

A nice, 20-minute introduction to the cell is available at:

- [http://www.youtube.com/watch?v=Hmwvj9X4GNY&list=EC7A9646BC5110CF64&index=35](http://www.youtube.com/watch?v=Hmwvj9X4GNY&list=EC7A9646BC5110CF64&index=35)
Plant Cells

Even though plants and animals are both eukaryotes, plant cells differ in some ways from animal cells as shown in Figure 4. 8. Plant cells have a large central vacuole, are surrounded by a cell wall, and have chloroplasts, which are the organelles of photosynthesis.

![Diagram of a plant cell](image)

**Figure 4. 8:** A plant cell has several features that make it different from an animal cell, including a cell wall, huge vacuoles, and photosynthesizing chloroplasts.

**Vacuoles**

First, plant cells have a large central vacuole that holds a mixture of water, nutrients, and wastes. A plant cell's vacuole can make up 90% of the cell's volume. The large central vacuole essentially stores water. What happens when a plant does not get enough water? In animal cells, vacuoles are much smaller.

**Cell Wall**

Second, plant cells have a cell wall, while animal cells do not. The cell wall surrounds the plasma membrane but does not keep substances from entering or leaving the cell. A cell wall gives the plant cell strength and protection.

**Plastids**

A third difference between plant and animal cells is that plants have several kinds of organelles called plastids. And there are several different kinds of plastids in plant cells. For
example, **Chloroplasts** are needed for photosynthesis, leucoplasts can store starch or oil, and brightly colored chromoplasts give some flowers and fruits their yellow, orange, or red color. It is the presence of chloroplasts and the ability to photosynthesize, that is one of the defining features of a plant. No animal or fungi can photosynthesize, and only some protists are able to. The photosynthetic protists are the plantlike protists, represented mainly by the unicellular algae.

To view a short 3-minute video comparing animal and plant cells go to the following site:


**Review:**

- What are the three basic parts of the cell theory?
- Cells come in many different shapes. Cells with different functions often have different shapes.
- Although cells come in diverse shapes, all cells have certain parts in common. These parts include the plasma membrane, cytoplasm, ribosomes, and DNA.
- What are the four common parts of a cell?
- Compare and contrast prokaryotic cells and eukaryotic cells.
- What are three structures that are found in plant cells but not in animal cells?
- What is biodiversity?

**Vocabulary**

- Cell wall
- Cell
- Community
- DNA
- Eukaryotic cells (eukaryotic)
- Nucleus
- Organ
- Organism
- Plasma membrane
- Prokaryotic cells (prokaryotic)
- Tissue
- Chloroplast
- Cell theory
- Cytoplasm
- Ecosystem
- Mitochondria (mitochondrion)
- Organelle
- Organ system
- Photosynthesis
- Population
- Ribosomes
- Vacuole
CHAPTER 5: EVOLUTION
5.1 Evidence for Evolution

Objectives:

- Describe how fossils help us understand the past.
- Explain how evidence from living species gives clues about evolution.
- State how biogeography relates to evolutionary change.

Introduction

In his book *On the Origin of Species*, Darwin included a lot of evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin’s time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

Fossil Evidence

Fossils are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called paleontologists. How do they use fossils to understand the past? Consider the example of the horse, shown in Figure 5.1. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses phenotype changed.
• They became taller, which would help them see predators while they fed in tall grasses.
• They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
• Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea. A brief animation of this process can be viewed at:


In order for fossils to tell us how life changed over time, we must be able to date them. The two methods include relative dating and absolute dating. Relative dating determines which of two fossils is older or younger than the other, but not their age in years. Relative dating is based on the positions of fossils in the strata, or rock layers. Lower layers were laid down earlier, so they are assumed to contain older fossils. Absolute dating determines about how long ago a fossil organism lived. This gives the fossil an approximate age in years.

**Does The Fossil Record Support Evolution?**

This video can be seen at:

• http://www.youtube.com/watch?v=QWVoXZPOCGk (9:20).

**Evidence from Living Species**

Just as Darwin did, today’s scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

Homologous structures are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. Figure 5.2 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However,
their forelimbs now have different functions. Analogous structures are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in Figure 5.3, look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

Comparative Embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails, as shown in Figure 5.4. All of the animals in the figure, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tailbone. Thus, similarities organisms share as embryos may be gone by adulthood. This is why it is valuable to compare organisms in the embryonic stage.

Vestigial Structures are structures like the human tailbone. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism’s fitness?

Comparing DNA is a modern technique for the study of evolution. Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. Look at the cladogram in Figure 5.5. It shows how humans and apes are related based on their DNA sequences.
Using various types of information to understand evolutionary relationships is discussed in the following videos:

- [http://www.youtube.com/watch?v=aZc1t2Os6UU](http://www.youtube.com/watch?v=aZc1t2Os6UU) (3:38)

**KQED: The Reverse Evolution Machine**

In search of the common ancestor of all mammals, University of California Santa Cruz scientist David Haussler is pulling a complete reversal. Instead of studying fossils, he's comparing the genomes of living mammals to construct a map of our common ancestors' DNA. His technique holds promise for providing a better picture of how life evolved.

For more information see:


**Evidence from Biogeography**

Biogeography is the study of how and why plants and animals live where they do. It provides more evidence for evolution. The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (see Figure 5. 6). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. An adaptation is a feature that is found in a population because it provides increased fitness for an individual organism and it can be passed from parent to offspring (an inheritable trait). Adaptations can be: behaviors such as escaping predators, a protein that better functions at higher temperatures, or an anatomical characteristic that allows the individual to access a valuable, new resource. **Speciation** is a process by which a single
species evolves into many new species to fill available niches. Adaptive radiation is a type of speciation.

Figure 5.6: Galapagos Finches differ in beak size and shape, depending on the type of food they eat.

**Eyewitness to Evolution**

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin’s finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place. While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (see Figure 5.7). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.

Figure 5.7: Evolution of Beak Size in Galapagos Finches. The top graph shows the beak size of the entire finch population studied by the Grants in 1976. The bottom graph shows the beak sizes of the survivors in 1978. In just two years, beak size increased.
Review Questions

1. How do paleontologists learn about evolution?

2. Describe what fossils reveal about the evolution of the horse.

3. What are vestigial structures? Give an example.

4. Define biogeography.

5. Describe an example of island biogeography that provides evidence of evolution.

6. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.

7. Compare and contrast homologous and analogous structures. What do they reveal about evolution?

8. Why does comparative embryology show similarities between organisms that do not appear to be similar as adults?
5.2 Evolution by Natural Selection

![Figure 5.8](image)

Figure 5. 8: This is the only illustration in Charles Darwin’s 1859 book *On the Origin of Species*, depicting his ideas about the divergence of species from a common ancestor.

How Do Species Form?

**Darwin’s Theory of Evolution by Natural Selection**

Darwin spent many years thinking about the works of Lamarck, Lyell, and Malthus, what he had seen on his voyage, and artificial selection. What did all this mean? How did it all fit together? It fits together in Darwin’s theory of evolution by natural selection. It’s easy to see how all of these influences helped shape Darwin’s ideas.

For a discussion of the underlying causes of natural selection and evolution see the following video (19:51):

- [http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/5/DuArVnTl-E](http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/5/DuArVnTl-E)
- Select the Biology Tab to explore the several videos about Natural Selection.

**Evolution of Darwin’s Theory**

It took Darwin years to form his theory of evolution by natural selection. His reasoning went like this:
1. Just as Lamarck discussed, Darwin assumed that species can change over time. The fossils he found helped convince him of that.

2. From Lyell, Darwin saw that Earth and its life were very old. Thus, there had been enough time for evolution to produce the great diversity of life Darwin had observed.

3. From Malthus, Darwin knew that populations could grow faster than their resources. This “overproduction of offspring” led to a “struggle for existence,” in Darwin’s words.

4. From artificial selection, Darwin knew that some offspring have variations that occur by chance, and that can be inherited. In nature, offspring with certain variations might be more likely to survive the “struggle for existence” and reproduce. If so, they would pass their favorable variations to their offspring.

5. Darwin coined the term fitness to refer to an organism’s relative ability to survive and produce fertile offspring. Nature selects the genetic variations that are most useful. Therefore, he called this type of selection natural selection.

6. Darwin knew artificial selection could change domestic species over time. He inferred that natural selection could also change species over time. In fact, he thought that if a species changed enough, it might evolve into a new species.

Wallace’s paper not only confirmed Darwin’s ideas. It also pushed him to finish his book, On the Origin of Species. Published in 1859, this book changed science forever. It clearly spelled out Darwin’s theory of evolution by natural selection and provided convincing arguments and evidence to support it.

Applying Darwin’s Theory

The following example applies Darwin’s theory. It explains how giraffes came to have such long necks (see Figure 5.9).

- In the past, giraffes had short necks. But there was chance variation in neck length. Some giraffes had necks a little longer than the average.

Figure 5.9: Giraffes feed on leaves high in trees. Their long necks allow them to reach leaves that other ground animals cannot.

- The leaves became scarcer thus creating a limiting factor in the environment. There would be more giraffes than the trees could support. Thus, there would be a “struggle for existence.”
• Giraffes with longer necks had an advantage. They could reach leaves other giraffes could not. Therefore, the long-necked giraffes were more likely to survive and reproduce. They had greater fitness.

• These giraffes passed the long-neck trait to their offspring. Each generation, the population contained more long-necked giraffes. Eventually, all giraffes had long necks.

As this example shows, chance genetic variations may help a species survive if the environment changes. This genetic variability among species helps ensure that at least one will be able to survive environmental change. Genetic variability arises through mutations, or changes in the DNA sequence, and genetic recombination, or the exchange of genetic material. The process of natural selection, working over billions of years, has led to the present day biodiversity we can observer around us.

The components of natural selection that can lead to speciation:

1. Potential for species to increase its numbers;
2. Genetic variability and inheritance of traits;
3. Finite supply of the required resources for life;
4. Selection by the environment of those individuals better able to survive and produce offspring (those that are most fit).

Evolution continuing today:


A summary of Darwin's ideas are presented in the video (13:29) "Natural Selection and the Owl Butterfly":
- [http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/3/dR_BFmDMRaI](http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/3/dR_BFmDMRaI)

Review Questions

1. Apply Darwin’s theory of evolution by natural selection to a specific case. For example, explain how Galápagos tortoises could have evolved saddle-shaped shells.

2. Explain how the writings of Charles Lyell and Thomas Malthus helped Darwin develop his theory of evolution by natural selection.

Article about the evolution of a mouse population in Nebraska:

Vocabulary

- Adaptation
- Genetic recombination
- Inheritable (inherited) trait
- Mutations
- Phenotype
- Biodiversity
- Genetic variability
- Limiting factor
- Natural selection
- Speciation
CHAPTER 6: ECOLOGY
6.1 Energy Flow

Objectives:

• Describe and diagram how energy flows through an ecosystem.
• Interpret and construct a food chain, food web, and ecological pyramids.
• Classify the type of relationship between organisms as competitive, predatory, or symbiotic.
• List the correct order and give examples of ecological levels (i.e. cells through biosphere).

![Image of a forest with sunlight shining through]

**Figure 6.1:** Energy enters an ecosystem from the sun, and travels through the organisms.

**What is happening inside each leaf and blade of grass?**

Photosynthesis. Maybe the most important biochemical reaction of Earth. As sunlight shines down on this forest, the sunlight is being absorbed, and the energy from that sunlight is being transformed into chemical energy. That chemical energy is abiotic (non living) and is distributed to all other biotic (living) organisms in the ecosystem.
To survive, ecosystems need a constant influx of energy. Energy enters ecosystems in the form of sunlight or chemical compounds. Some organisms use this energy to make food. Other organisms obtain energy by eating the food.

**Producers**

Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. The stability of producers is vital to ecosystems because all organisms need organic molecules. Producers are also called autotrophs. There are two basic types of autotrophs: photoautotrophs use light for energy and chemoautotrophs use chemical compounds.

**Consumers**

Consumers are organisms that depend on other organisms for food. They take in organic molecules by essentially “eating” other living things. They include all animals and fungi. (Fungi don't really “eat”; they absorb nutrients from other organisms.) They also include many bacteria and even a few plants. Consumers are also called heterotrophs. Heterotrophs are classified by what they eat:

- **Herbivores** consume producers such as plants or algae. They are a necessary link between producers and other consumers. Examples include deer, jackrabbits, mice, mustangs and toros.
- **Carnivores** consume animals. Examples include coyotes, mountain lions, polar bears, salmon, spiders, and war eagles. Carnivores that are unable to digest plants and must eat only animals are called obligate carnivores. Other carnivores can digest plants but do not commonly eat them.
- **Omnivores** consume both plants and animals. They include brown bears, crows, gulls, some species of fish, and of course, humans.

** Decomposers**

When organisms die, they leave behind energy and matter in their remains. Decomposers break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds. The stability of decomposers is essential to every ecosystem. Decomposers are classified by the type of organic matter they break down:

- Scavengers consume the soft tissues of dead animals. Examples of scavengers include vultures, raccoons, and blowflies.
Detritivores consume detritus—the dead leaves, animal feces, and other organic debris that collects on the soil or at the bottom of a body of water. On land, detritivores include earthworms, millipedes, and dung beetles. In water, detritivores include “bottom feeders” such as sea cucumbers and catfish.

For more information about banana slugs, a type of detritovore:


**Practice**

Use this resource to answer the questions that follow:

1. Describe the role of autotrophs.
2. Is energy recycled?
3. What is the role of photosynthesis?
4. What is the difference between primary productivity and secondary productivity?
5. What is the relationship between gross primary productivity and net primary productivity?
6. What is biomass?
7. How much energy is lost at each trophic level?

**Review Questions**

1. Identify three different types of consumers. Name an example of each type.
2. What can you infer about an ecosystem that depends on chemoautotrophs for food?
3. What is the original source of almost all energy in most ecosystems?
4. Identify examples of biotic and abiotic factors in a desert biome.
6.2 Food Chains and Food Webs

Who eats whom?

Describing the flow of energy within an ecosystem essentially answers this question. To survive, one must eat. Why? To get energy. Food chains and webs describe the transfer of energy within an ecosystem, from one organism to another. In other words, they show who eats whom.

Food chains and food webs are diagrams that represent feeding relationships. Essentially, they show who eats whom. In this way, they model how energy and matter move through ecosystems.

Food Chains

A food chain represents a single pathway by which energy and matter flow through an ecosystem. An example is shown in Figure 6.2. Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.

A musical summary of food chains (2:46) can be heard at:

- http://www.youtube.com/watch?v=TE6wqG4nb3M

Figure 6.2: This food chain includes producers and consumers. How could you add decomposers to the food chain?
**Food Webs**

A food web represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species. An example is shown in Figure 6.3 below.

**Figure 6.3:** This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

**Practice**

Use the resource to answer the questions that follow:

1. What are trophic levels?
2. Describe primary producers.
3. Differentiate between primary, secondary, and tertiary consumers.
4. Define detritus and detritivore.
5. What is a food chain? What is a food web?

- [http://www.hippocampus.org/Biology](http://www.hippocampus.org/Biology)
  - Go to: Biology for AP*
  - Search: Feeding Relationships
Review

1. Draw a desert food chain that includes four feeding levels.
2. Describe the role of decomposers in food webs.
6.3 Trophic Levels

**Why are pyramids important in ecology?**

The classic example of a pyramid is shown here in Figure 6. 4. But the pyramid structure can also represent the decrease in a measured substance from the lowest level on up. In ecology, pyramids model the use of energy from the producers through the ecosystem.

**Figure 6. 4: Pyramids of Giza**

The feeding positions in a food chain or web are called **trophic levels**. The different trophic levels are defined in Table 6. 1 **below**. Examples are also given in the table. All food chains and webs have at least two or three trophic levels. Generally, there are a maximum of four trophic levels.

<table>
<thead>
<tr>
<th>Trophic Level</th>
<th>Where It Gets Food</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Trophic Level: Producer</td>
<td>Makes its own food</td>
<td>Plants make food</td>
</tr>
<tr>
<td>2nd Trophic Level: Primary Consumer</td>
<td>Consumes producers</td>
<td>Mice eat plant seeds</td>
</tr>
<tr>
<td>3rd Trophic Level: Secondary Consumer</td>
<td>Consumes primary consumers</td>
<td>Snakes eat mice</td>
</tr>
<tr>
<td>4th Trophic Level: Tertiary Consumer</td>
<td>Consumes secondary consumers</td>
<td>Hawks eat snakes</td>
</tr>
</tbody>
</table>

**Table 6. 1: Trophic levels in a food chain or food web.**

Many consumers feed at more than one trophic level. Humans, for example, are primary consumers when they eat plants such as vegetables. They are secondary consumers when they eat cows. They are tertiary consumers when they eat salmon.

**Trophic Levels and Energy**

Energy is passed up a food chain or web from lower to higher trophic levels. However, generally only about 10 percent of the energy at one level is available to the next level. This is represented by the **ecological pyramid** in Figure 6. 5.
What happens to the other 90 percent of energy? It is used for metabolic processes or given off to the environment as heat. This loss of energy explains why there are rarely more than four trophic levels in a food chain or web. Sometimes there may be a fifth trophic level, but usually there’s not enough energy left to support any additional levels.

Ecological pyramids can demonstrate the decrease in energy, biomass or numbers within an ecosystem.

Energy pyramids are discussed in this video (1:44):
- [http://www.youtube.com/watch?v=8T2nEMzk6_E&feature=related](http://www.youtube.com/watch?v=8T2nEMzk6_E&feature=related)

**Trophic Levels and Biomass**

With less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers result in less biomass. Biomass is the total mass of organisms at a trophic level. The decrease in biomass from lower to higher levels is also represented by Figure 6.6.

**Practice**

Use the first resources to answer the questions that follow:

1. Define trophic level.
2. What is the role of organisms in the first trophic level?

3. What are the main primary producers in aquatic ecosystems?

4. Give examples of primary consumers and secondary consumers.

Use the second resource to answer the questions that follow:

1. Discuss the importance of primary producers.
2. Define biomass.
3. What is meant by ecological efficiency?
4. Compare a pyramid of productivity to a biomass pyramid and a pyramid of numbers.
5. What is shown in each type of ecological pyramid?

**Review Questions**

1. What is a trophic level?

2. Draw a terrestrial food chain that includes four trophic levels. Identify the trophic level of each organism in the food chain.

3. Explain how energy limits the number of trophic levels in a food chain or web.
6.4 Human Population

How do humans adapt to their environment?

It could be said that the human population does not have to adapt to its environment, but forces the environment to change to suit us. We can live practically anywhere we want, eat all types of food, and build all types of housing. Because of all of these "adaptations," our population has grown, after a slow start, considerably fast.

Humans have been called the most successful "weed species" Earth has ever seen. Like weeds, human populations are fast growing. They also disperse rapidly. They have colonized habitats from pole to pole. Overall, the human population has had a pattern of exponential growth, as shown in Figure 6. 7. The population increased very slowly at first. As it increased in size, so did its rate of growth.

Figure 6. 7: Growth of the Human Population. This graph gives an overview of human population growth since 10,000 BC. It took until about 1800 AD for the number of humans to reach 1 billion. It took only a little over 100 years for the number to reach 2 billion. The human population recently passed the 7 billion mark! Why do you think the human population began growing so fast?
Early Population Growth

*Homo sapiens* arose about 200,000 years ago in Africa. Early humans lived in small populations of nomadic hunters and gatherers. They first left Africa about 40,000 years ago. They soon moved throughout Europe, Asia, and Australia. By 10,000 years ago, they had reached the Americas. During this long period, birth and death rates were both fairly high. As a result, population growth was slow. Humans invented agriculture about 10,000 years ago. This provided a bigger, more dependable food supply. It also let them settle down in villages and cities for the first time. The death rate increased because of diseases associated with domestic animals and crowded living conditions. The birth rate increased because there was more food and settled life offered other advantages. The combined effect was continued slow population growth.

**Practice**

1. Use this resource to answer the questions that follow:
2. What was the human population 2,000 years ago? Where did most people live?
3. Describe the growth rate over the next 1,000 years.
4. What was the population around the year 1800? Where did most people live?
5. When did the population reach 2 billion?
6. What changed in the mid-1900s that profoundly affected the growth rate?
7. How long did it take the population to grow from 2 billion to 3 billion people?
8. How long did it take the population to grow from 3 billion to 4 billion people? Why?
9. As of 1999, what percentage of the population lived in Asia?
10. What will the population be like in 2050?

**Review**

1. Describe human population growth rates.
2. How did the invention of agriculture affect human birth and death rates? How did it affect human population growth?

**Human Numbers Through Time:**

6.5 Limiting Factors to Population Growth

What happened during the Irish Potato Famine?

In the 1800s, a disease called potato blight destroyed much of the potato crop in Ireland. Since many Irish people depended on potatoes as their staple food, mass starvation and emigration resulted. This caused Ireland's population to dramatically decrease. Lack of food is one factor that can limit population growth.

For a population to be healthy, factors such as food, nutrients, water, and space must be available. What happens when there are not resources to support the population?

Limiting factors are resources or other factors in the environment that can lower the population growth rate. Limiting factors include a low food supply and lack of space. Limiting factors can lower birth rates, increase death rates, or lead to emigration. Most populations do not live under ideal conditions. Therefore, most do not grow exponentially. Certainly, no population can keep growing exponentially for very long. Many factors may limit growth. Often, the factors are density dependent (known as density-dependent factors). These are factors that are influential when the population becomes too large and crowded. For example, the population may start to run out of food or be poisoned by its own waste. As a result, population growth slows and population size levels off. Factors that are influential regardless of population size are known as density-independent factors (often these are abiotic factors). For example: drought, flooding, extreme weather, and earthquakes.

When organisms face limiting factors, they show logistic growth (S-shaped curve, curve B: Figure 6.8). Competition for resources like food and space cause the growth rate to stop increasing, so the population levels off. This flat upper line on a growth curve is the carrying capacity. The carrying capacity (K) is the maximum population size that can be supported in a particular area without destroying the habitat. Limiting factors determine the carrying capacity of a population. Recall that when there are no limiting factors, the population grows exponentially. In exponential growth (J-shaped curve, curve A: Figure 6.8), as the population size increases, the growth rate also increases.
Food Supply as Limiting Factor

If there are 12 hamburgers at a lunch table and 24 people sit down at a lunch table, will everyone be able to eat? At first, maybe you will split hamburgers in half, but if more and more people keep coming to sit at the lunch table, you will not be able to feed everyone. This is what happens in nature. But in nature, organisms that cannot get food will die or find a new place to live. It is possible for any resource to be a limiting factor, however, a resource such as food can have dramatic consequences on a population.

In nature, when the population size is small, there is usually plenty of food and other resources for each individual. When there is plenty of food and other resources, organisms can easily reproduce, so the birth rate is high. As the population increases, the food supply, or the supply of another necessary resource, may decrease. When necessary resources, such as food, decrease, some individuals will die. Overall, the population cannot reproduce at the same rate, so the birth rates drop. This will cause the population growth rate to decrease.

When the population decreases to a certain level where every individual can get enough food and other resources, and the birth and death rates become stable, the population has leveled off at its carrying capacity.

Other Limiting Factors

Other limiting factors include light, water, nutrients or minerals, oxygen, the ability of an ecosystem to recycle nutrients and/or waste, disease and/or parasites, temperature, space, and predation. Can you think of some other factors that limit populations?

Weather can also be a limiting factor. Whereas most plants like rain, an individual cactus-like *Agave americana* plant actually likes to grow when it is dry. Rainfall limits reproduction of this plant which, in turn, limits growth rate. Can you think of some other factors like this?
Human activities can also limit the growth of populations. Such activities include use of pesticides such as DDT, use of herbicides, habitat destruction, and affluence.

Summary

- Limiting factors, or things in the environment that can lower the population growth rate, include low food supply and lack of space.
- When organisms face limiting factors, they show logistic type of growth (S-curve).

Practice

Use the resource below to answer the questions that follow:

1. What type of growth is characterized by a consistent increase in growth rate? How often is this type of growth actually seen in nature?
2. What factors keep populations from reaching their carrying capacity?
3. Think of the environmental variations in weather we are currently witnessing today. How do you think these conditions will affect a species' ability to reach its carrying capacity?
4. How do you think the length of an organism's life span will affect the species' ability to reach carrying capacity?
5. What would the growth equation look like for sessile populations (i.e. populations where individuals are fixed in space)? Think carefully about all possibilities before answering this question.

Review

1. What are some examples of limiting factors?
2. When organisms face limiting factors, what type of growth do they show?
6.6 Predation

What may be the most common way different species interact?

Biomes as different as deserts and wetlands share something very important. All biomes have populations of interacting species. Species interact in the same basic ways in all biomes. For example, all biomes have some species that prey on others for food.

Predation is a relationship in which members of one species (the predator) consume members of another species (the prey). The lions and buffalo in Figure 6.9 are classic examples of predators and prey. In addition to the lions, there is another predator in this figure. Can you spot it? The other predator is the buffalo. Like the lion, it consumes prey species, in this case species of grass. However, unlike the lions, the buffalo does not kill its prey. Predator-prey relationships such as these account for most energy transfers in food chains and food webs.

Figure 6.9: Two lions feed on the carcass of a South African cape buffalo.
Predation and Population

A predator-prey relationship tends to keep the populations of both species in balance. This is shown by the graph in Figure 6. 10. As the prey population increases, there is more food for predators. So, after a slight lag, the predator population increases as well. As the number of predators increases, more prey are captured. As a result, the prey population starts to decrease. What happens to the predator population then?

Keystone Species

Some predator species are known as keystone species. A keystone species is one that plays an especially important role in its community. Major changes in the numbers of a keystone species affect the populations of many other species in the community. For example, some sea star species are keystone species in coral reef communities. The sea stars prey on mussels and sea urchins, which have no other natural predators. If sea stars were removed from a coral reef community, mussel and sea urchin populations would have explosive growth. This, in turn, would drive out most other species. In the end, the coral reef community would be destroyed.

Adaptations to Predation

Both predators and prey have adaptations to predation that evolved through natural selection. Predator adaptations help them capture prey. Prey adaptations help them avoid predators. A common adaptation in both predator and prey is camouflage. Several examples are shown in Figure 6. 11. Camouflage in prey helps them hide from predators. Camouflage in predators helps them sneak up on prey.

Figure 6. 10: Predator-Prey Population Dynamics. As the prey population increases, why does the predator population also increase?
Figure 6.11: Camouflage in Predator and Prey Species. Can you see the crab in the photo on the left? It is camouflaged with algae. The preying mantis in the middle photo looks just like the dead leaves in the background. Can you tell where one zebra ends and another one begins? This may confuse a predator and give the zebras a chance to run away.

Practice

Use this resource to answer the questions that follow.

1. Define intraspecific competition.
2. Describe predator-prey interactions.
3. What is mimicry? Give an example.
4. Give an example of camouflage.

Review

1. Describe the relationship between a predator population and the population of its prey.
2. What is a keystone species? Give an example.
6.7 Competition

Does there have to be a winner when animals compete?

Yes. Animals, or other organisms, will compete when both want the same thing. One must "lose" so the winner can have the resource. But competition doesn't necessarily involve physical altercations.

**Competition** is a relationship between organisms that strive for the same resources in the same place. The resources might be food, water, or space. There are two different types of competition:

1. **Intraspecific competition** occurs between members of the same species. For example, two male birds of the same species might compete for mates in the same area. This type of competition is a basic factor in natural selection. It leads to the evolution of better adaptations within a species.

2. **Interspecific competition** occurs between members of different species. For example, predators of different species might compete for the same prey.

**Interspecific Competition and Extinction**

Interspecific competition often leads to **extinction**. The species that is less well adapted may get fewer of the resources that both species need. As a result, members of that species are less likely to survive, and the species may go extinct.
Interspecific Competition and Specialization

Instead of extinction, interspecific competition may lead to greater specialization. Specialization occurs when competing species evolve different adaptations. For example, they may evolve adaptations that allow them to use different food sources.

Practice:

Use this resource to answer the questions that follow.

1. What are the three general types of interactions within a community?
2. Define competition.
3. What are some of the resources organisms compete for?
4. What is the main outcome of competition? (Hint: affects the niche)
5. Describe an example of interspecific competition.
6. Why might intraspecific competition occur?

Competition: http://www.concord.org/activities/competition.

Review:

1. What is competition?

2. Compare and contrast the evolutionary effects of intraspecific and interspecific competition.
6.8 Symbiosis

Figure 6.12: A commensal shrimp on another sea organism, possibly a sea cucumber. As commensal shrimp they neither bring a benefit nor have a negative effect on their host.

Do interactions between species always result in harm?

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be positive, negative, or neutral. There are three basic types of symbiosis: mutualism, commensalism, and parasitism.

Mutualism

Mutualism is a symbiotic relationship in which both species benefit. An example of mutualism involves goby fish and shrimp (see Figure 6.13). The nearly blind shrimp and the fish spend most of their time together. The shrimp maintains a burrow in the sand in which both the fish and shrimp live. When a predator comes near, the fish touches the shrimp with its tail as a warning. Then, both fish and shrimp retreat to the burrow until the predator is gone.

Figure 6.13: The multicolored shrimp in the front and the green goby fish behind it have a mutualistic relationship.
From their relationship, the shrimp gets a warning of approaching danger. The fish gets a safe retreat and a place to lay its eggs.

**Commensalism**

**Commensalism** is a symbiotic relationship in which one species benefits while the other species is not affected. One species typically uses the other for a purpose other than food. For example, mites attach themselves to larger flying insects to get a “free ride.” Hermit crabs use the shells of dead snails for homes.

**Parasitism**

**Parasitism** is a symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed. Many species of animals are parasites, at least during some stage of their life. Most species are also hosts to one or more parasites. Some parasites live on the surface of their host. Others live inside their host. They may enter the host through a break in the skin or in food or water. For example, roundworms are parasites of mammals, including humans, cats, and dogs (see Figure 6.14). The worms produce huge numbers of eggs, which are passed in the host’s feces to the environment. Other individuals may be infected by swallowing the eggs in contaminated food or water.

![Figure 6.14: Canine Roundworm. The roundworm above, found in a puppy's intestine, might eventually fill a dog's intestine unless it gets medical treatment.](image)

Some parasites kill their host, but most do not. It’s easy to see why. If a parasite kills its host, the parasite is also likely to die. Instead, parasites usually cause relatively minor damage to their host.

**Practice**

Use this resource to answer the questions that follow.

1. What are the three types of symbiotic relationships?
2. Describe the three symbiotic relationships.
3. Describe an example of a symbiotic relationship involving humans.

- [http://www. hippocampus.org/Biology](http://www. hippocampus.org/Biology)
- Go to: Non-Majors Biology
- Search: Interactions Within Communities
4. Describe a symbiotic relationship involving plants and bacteria.

**Review**

1. Define mutualism and commensalism.

2. Explain why most parasites do not kill their host. Why is it in their own best interest to keep their host alive?
6.9 Population Growth

What would old luggage have to do with population growth?

Moving into an area, or immigration, is a key factor in the growth of populations. Shown above in Figure 6.15 is actual vintage luggage left by some of the millions of immigrants who came through Ellis Island and into the United States.

Populations gain individuals through births and immigration. They lose individuals through deaths and emigration. These factors together determine how fast a population grows.

Population Growth Rate

Population growth rate \( r \) is how fast a population changes in size over time. A positive growth rate means a population is increasing. A negative growth rate means it is decreasing. The two main factors affecting population growth are the birth rate \( b \) and death rate \( d \). Population growth may also be affected by people coming into the population from somewhere else (immigration, \( i \)) or leaving the population for another area (emigration, \( e \)). The formula for population growth takes all these factors into account.

\[
r = (b + i) - (d + e)
\]

- \( r \) = population growth rate
- \( b \) = birth rate
- \( i \) = immigration rate
- \( d \) = death rate
- \( e \) = emigration rate
Two lectures on demography are available at:

- http://www.youtube.com/watch?v=3diw1Hu3auk (50:36)

**Dispersal**

Other types of movements may also affect population size and growth. For example, many species have some means of dispersal. This refers to offspring moving away from their parents. This prevents the offspring from competing with the parents for resources such as light or water. For example, dandelion seeds have “parachutes.” They allow the wind to carry the seeds far from the parents (see Figure 6.16).

![Dandelion Seeds](image)

**Figure 6.16:** Dandelion Seeds. These dandelion seeds may disperse far from the parent plant. Why might this be beneficial to both parents and offspring?

**Migration**

Migration is another type of movement that changes population size. **Migration** is the regular movement of individuals or populations each year during certain seasons. The purpose of migration usually is to find food, mates, or other resources. For example, many Northern Hemisphere birds migrate thousands of miles south each fall. They go to areas where the weather is warmer and more resources are available. Then they return north in the spring to nest. Some animals, such as elk, migrate vertically. They go up the sides of mountains in spring as snow melts. They go back down the mountain sides in fall as snow returns.
Practice

Use this resource to answer the questions that follow.

1. What is meant by unlimited population growth?
2. Why might growth slow down?

Review:

1. Define immigration and emigration.
2. What is migration? Give an example.
3. Write the formula for the population growth rate. Identify all the variables.
4. State why dispersal of offspring away from their parents might be beneficial.

Vocabulary

- Abiotic factors
- Autotroph
- Biome
- Biotic factors
- Carrying capacity
- Competition
- Death rate
- Drought
- Ecological pyramid
- Energy flow
- Immigration
- Flooding
- Food web
- Mutualism
- Parasitism
- Predation
- Symbiosis
- Urban development

- Affluence
- Biodiversity
- Biosphere
- Birth rate
- Commensalism
- Consumer
- Decomposer
- Earthquakes
- Emigration
- Extreme weather
- Fires
- Food chain
- Heterotroph
- Natural ecosystem
- Pollution
- Producer
- Trophic level
- Urban sprawl