Unit 1
Introduction to Biology

South Dakota Science Standards

9-12.N.1.1. Students are able to evaluate a scientific discovery to determine and describe how societal, cultural, and personal beliefs influence scientific investigations and interpretations.
9-12.N.1.2. Students are able to describe the role of observation and evidence in the development and modification of hypotheses, theories and laws.
9-12.N.2.1. Students are able to apply science process skills to design and conduct student investigations.
9-12 S.1.2 Students are able to evaluate and describe the impact of scientific discoveries on historical events and social, economic, and ethical issues.
9-12 N.2.2 Students are able to practice safe and effective laboratory techniques.
9-12 L.1.3 Students are able to identify structures and function relationships within major taxa.

Prefix or Suffix	Definition
bio-	Living or life
a-	Not, without
centi-	1/100th
milli-	1/1000th
kilo-	1000
micro-	Small in scale
zoo-	Animal
homeo-	Constant or same
therm-	Heat
-stasis	Staying
-ology	Study of

Top Vocabulary Terms

1. **Theory**
2. **Biology**
3. **Organism**
4. **Cell**
5. **Variables**
6. **Homeostasis**

I. Lab Safety

Introduction

There are some very serious safety risks in scientific research. Research can involve many different kinds of risks. Yet, if science were as dangerous as some horror movies make it look, not many people would become scientists. Since the life sciences deal with living organisms, some research may have risks not found in other fields. Safety practices are needed to work with any potentially hazardous situation, such as:

- **pathogens**
- parasites
- wild animals
- radioactive materials
- pollutants in air, water, or soil
- toxins
- **carcinogens**
- radiation

The kinds of risks that scientists face depend on the kind of research they perform. For example, a botanist working with plants or algae in a laboratory faces different risks than a zoologist studying the behavior of lions in Africa. Think back to the deformed frogs discussed earlier, the ones in the pond with extra limbs or extra eyes. If there is something in the frogs' environment causing these deformities, could there be a risk to a researcher in that environment? Perhaps a disease is causing the deformities? Infectious agents such as viruses and bacteria are called **biohazards** (Figure 1) Biohazards include any material such as medical waste that could possibly transmit an infectious disease. A used hypodermic needle or a vial of bacteria can both be considered biohazards.

Figure 1*-The Biohazard symbol*

Safety Practices

Most laboratories are safe places to visit. If you plan to work in a scientific **laboratory**, ask someone to tell you about the safety rules they are required to follow. Scientists must follow regulations set by federal, state, and private institutions. For example, scientists cannot work with hazardous materials or equipment without:

- Getting approval to do the specific research.
- Using safety equipment, such as hoods and fans
- Demonstrating that they are familiar with risks, know how to respond to problems, and can follow safety regulations.
- Accepting laboratory inspections by safety officers at any time.

In some laboratories, conditions are no more dangerous than in any other room. In many labs, though, additional hazards are present. Laboratory hazards are as varied as the subjects of study in laboratories, and might include poisons, infectious agents, flammable, explosive, or radioactive materials, moving machinery, extreme temperatures, or high voltage. The hazard symbols for corrosive, explosive, and flammable substances are shown in figure 2. In laboratories where conditions might be dangerous, safety precautions are important. Lab safety rules and proper **lab techniques** minimize a person's risk of getting hurt, and safety equipment is used to protect the lab user from injury or to help in responding to an emergency.

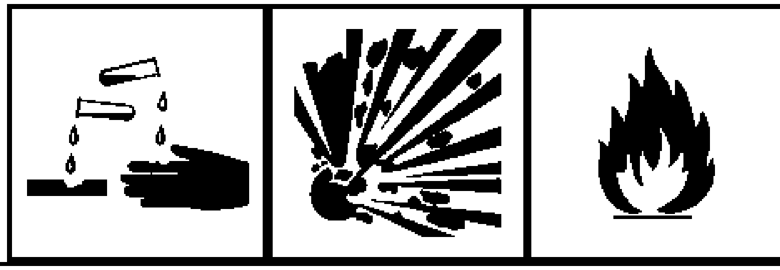


Figure 2*-The hazard symbols for corrosive, explosive, and flammable substances.*

What is a biohazard?

What kinds of hazards might be found in biology laboratories, but not physics laboratories?

What are some of the precautions you might take if you were collecting frogs in water you think might be polluted?

Safety Equipment

Some **safety equipment** that you might find in a biology lab includes:

Sharps/Broken Glass Containers: Containers that are filled with used medical needles and other sharp instruments such as blades or broken glass. Needles that have been used and broken glass are dropped into the container without touching the outside of the container. Objects should never be pushed or forced into the container, as damage to the container or injuries may result.

Gloves: Gloves protect the wearers' hands and skin from getting contaminated by microorganisms or stained or irritated by chemicals.

Lab Apron: A knee-length apron that is usually worn while working in the lab. The apron helps to protect the researcher's clothes from splashes or contamination.

Goggles: tight-fitting eyewear worn to protect the eyes

Eye-wash Station: a piece of equipment specifically made to flush water continuously over the eyes; used for any chemical or biological splashes that may hit the eye

Safety Shower: a piece of equipment specifically made to cascade water over the entire body should a chemical spill occur

Fire Blanket: a piece of cloth made of fire resistant material which is used to extinguish small fires

Fire Extinguisher: a hand-held piece of equipment that sprays a powder-based fire retardant; meant for small contained fires in emergency situations only

Safe Laboratory Practice

Safety precautions are in place to help prevent accidents. Always wear personal protective equipment such as goggles and gloves when recommended to do so by your teacher.

- Tell your teacher immediately if an accident happens.
- Wear enclosed toe shoes, instead of sandals or flip flops, or thongs. Your feet and toes could easily get hurt or broken or if you dropped something.
- Do not wear loose, floppy clothes in the lab; they can get caught in or knock over equipment, causing an accident.
- If you have long hair, tie it up for the same reasons listed above.
- Do not eat or drink in the lab.
- Do not use cell phones in the lab. You can easily contaminate your phone with whatever you have been working with. Consider where your hands have been, and where your face will be the next time you talk on the phone.
- Immediately notify the teacher of any broken glass so that it may be disposed of properly in the broken glass container.
- Always listen carefully to your teacher's instructions.
- Never conduct experiments alone in the laboratory.

Material Safety Data Sheets

Information on hazardous materials is provided by the materials safety data sheet. A bound copy of this information is found on the back bookcase. These should be referred to if you are curious about any chemical you are working worth.

When working in a lab, which of the following would be an important lab safety skill to remember?

a. Perform additional experiments as new questions arise.
b. Wear safety goggles at all times during all experiments.
c. Use lab equipment to obtain a drink when thirst while performing your lab.
d. Only refer to written directions or verbal instructions when you can not figure out how to do the lab yourself.

II. The Nature of Biological Science

Introduction

Before proceeding through this class, you need to realize a number of fundamental concepts of science. You need to:

• Know that **science** is a way of knowing about the physical world, based on observable evidence, testing predictions, and reasoning
• Understand that, in science, theories and knowledge are constantly tested and questioned.
• Know that, science is not static and is constantly changing in response to new evidence.
• Understand that principles of philosophy and religion usually cannot be tested scientifically, because they are not based on observable evidence.
• Identify what the life sciences are and some of the main fields of study.
• Know the difference between scientific theory and fact.

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. 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.

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 lightening, thunder, and storms?

Throughout time, different cultures have created hundreds of different myths and stories and even gods to explain what they saw. Ancient Greeks explained that lightening was a show of their god Zeus' anger. Scandinavians claimed that their god of thunder, Thor, was responsible for the rumbling and bolts of lightning. Without any formal science, many cultures have also blamed diseases, such as epilepsy, on evil spirits and other imaginary entities. For example, there is evidence that many different cultures drilled holes in the skulls of patients who had seizures or other maladies, thinking that they were releasing evil spirits. Throughout time, **cultural beliefs** such as those listed above, have attempted to explain of a variety of natural events.

How do cultural beliefs influence the explanation of natural events?

Science as a Way of Knowing

During yours and your parents' lifetimes, advances in medicine, 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 **personal beliefs** 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. However, science cannot scrutinize what is good versus what is bad (morality), because these are values, ideas that lack measurable evidence. Science is not used to examine philosophy or supernatural entities, such as the existence or nonexistence of a god. However, science can be used to examine the effects of these experiences. The most important message from this chapter is that science is not only a way of knowing, it is 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, 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.

Can science explain everything? Why or why not?

Science is based upon what type of knowledge?

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.

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

Based on **scientific investigation**, scientists discovered that the answer turned out to be no. The researchers treated used cutting boards with different kinds of germs and then washed the boards. They found, much to their surprise, 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 seemed to vanish. On plastic, the germs sit on the surface in cuts in the plastic where they are difficult to clean out but can 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 disprove 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.

Scientific 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.

What makes science different than common sense?

What Are the Life Sciences?

The **life sciences** are the study of living organisms and how they interact with each other and their environment. These include all the biological sciences. Life sciences deal with every aspect of living organisms. The life sciences are so complex that most scientists focus on just one or two subspecialties.

Fields of Studies:

Botany: plants

Zoology: animals

Microbiology: The study of what occurs at the smallest levels of biology; includes
  Molecular Biology (study of what occurs at the level of atoms and molecules) **and**
  Cell Biology (study of what occurs at the level of the cell).

Taxonomy: the classification of organisms

Anatomy: the structures of animals

Physiology: the physical and chemical functions of tissues and organs

Developmental biology and embryology: the growth and development of plants and animals

Genetics: the genetic make up of all living organisms (heredity)

Epidemiology: How diseases arise and spread throughout populations.

Ecology: how various organisms interact with their environments

Pathology: a study of the symptoms and effects of a disease in an organism.

III. The Scientific Method

Introduction

The scientific method is an inquiry process used to investigate the physical world using observable evidence and testing. This method allows scientists to "conduct" science in a uniform process. This process allows the information collected to be reproduced by other scientists, and most importantly, this process allows the information to be accepted and trusted.

Observations, Data, Hypotheses, and Experiments

Imagine that you are scientist who wants to know something like, "Why do whales migrate?" or "Why do some people get more colds than others do?" Two hundred years ago you could have come up with theories without necessarily thoroughly testing your ideas. But there were many exceptional scientists who made outstanding contributions.

As a modern scientist today, you would use the scientific method, collecting evidence to test your hypothesis and answer your questions. The scientific method presents a general idea of how science is conducted; it is not a strict pattern for doing research. Scientists use many different variations of the scientific method to meet their specific needs. Almost all versions of the scientific method include the following steps, though not always in the same order:

- Make **observations**
- Identify a question you would like to answer about the observation
- Research: find out what is already known about your observation
- Form a hypothesis
- Conduct experiment
- Analyze your results and revisit hypothesis
- Communicate your results

A **hypothesis** is a proposed explanation that allows you to make predictions about what ought to happen if the hypothesis is true. If the predictions are accurate, that provides support for the hypothesis. If the predictions are incorrect, that suggests the hypothesis is wrong.

What is the purpose of a hypothesis?

Make Observations

Observe something in which you are interested. Here is an example of a real observation made by students in Minnesota (Figure 3). Imagine that you are one of the students who discovered this strange frog.

Figure 3*-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.

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.

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.

How is an observation different than research?

Construct a Hypothesis

A hypothesis is a proposed explanation of an observation. Scientists use hypotheses to make **predictions.** A prediction is a statement that tells what will happen under specific conditions. 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. Be **falsified** (found false/wrong).
3. Provide measurable results.
4. Provide yes or no answers.

For example, the following hypothesis can be tested and provides yes or no answers:
"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."

What does it mean to be 'testable'?

What does it mean to have measurable results?

How is a hypothesis different than a guess?

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 true or false.

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 since 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 interesting to a scientist.

Collecting Data

One of the steps in the scientific method is observation. Observation involves recording data about the phenomenon we wish to investigate. There are two different types of observations which are called qualitative and quantitative. **Qualitative** observations are those involving words only while **quantitative** observations are those involving both words and numbers. Although all the observations we can make on a phenomenon are valuable, quantitative observations are more helpful than qualitative. Qualitative observations are somewhat more vague in nature because they involve comparative terms.

For example, a qualitative observation would be “The attendance clerk is a small woman.” If the observer was 6 feet 4 inches tall, he/she might refer to a woman who is 5 feet 8 inches tall as “small”. But if the observer reported this observation to a person who was 5 feet 2 inches tall, the listener would not acquire a good idea of the height of the attendance clerk because they would not think that a woman who is 5 feet 8 inches tall was small.

The description “a small woman” could refer to any woman whose height was between 2 feet and 6 feet tall depending on who did the observing. Similarly, “a small car” could refer to anything from a compact car to a child’s toy car. The word small is a comparative term. The same is true of words like tall, fast, slow, hot, and cold. These words do not have exact meanings. Quantitative observations on the other hand, have numbers and units associated with them and are, therefore, more exact. Even if the number is only an estimate, it is more valuable than no number at all.

You can see that even if the number is an estimate, a quantitative observation contains more information because of the number associated with the observation. (Some people might not think that a walk of one mile was short even though the speaker in the above case did. If an actual measuring instrument is not available, the observer should always try to estimate a measurement so the observation will have a number associated with it.

Analyze Data and Draw a Conclusion

If a hypothesis and experiment are well designed, the experiment will produce measurable results that you can collect and analyze. The analysis should tell you if the hypothesis is true or false. 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 false or the situation is more complicated than you thought. This **scientific interpretation** 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. A **scientific discovery** belongs to the entire scientific community, therefore the knowledge reaches its maximum impact when shared.

If research data does not support a hypothesis, what are two conclusions a scientist could reach?

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 talks at large scientific meetings, and write articles for scientific journals. Their findings may also be communicated to journalists.

Drawing Conclusions and Communicating Results

If a hypothesis and experiment are well designed, the results will indicate whether your hypothesis is true or false. If a hypothesis is supported by the results of a study, scientists will often continue testing the hypothesis in new ways to learn more.

If a hypothesis is false, the results may be used to construct and test a new hypothesis. The next step is to analyze your results and to communicate them to other scientists. Scientific articles include the questions, methods and the 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. In is generally accepted among the scientific community. A **scientific law** is equally accepted among the scientific community but makes no effort to explain the causes of the phenomon, it only describes the event.

Scientific Theories

Science 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 (discussed in the Scientific Method lesson).

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. The idea that matter is made up of atoms, evolution, and gravity are all scientific theories about how the world works that scientists accept as fundamental principles of basic science. However, any theory may be altered or revised to make it consistent with new evidence.

What makes a scientific theory different from 'just a hunch'?

In science, what is a primary characteristic of a theory?

A. It is a possible explanation that can be tested by experimentation.
B. It is an experimental result used to support a conclusion.
C. It is a well-tested explanation based on observation, experimentation and reasoning.
D. It is a generalization used to explain natural phenomenon that cannot be tested.

IV. Experimental Design

Introduction

A scientific experiment must have the following features:

- a control, so variables that could affect the outcome are reduced
- the variable being tested reflects the phenomenon being studied
- the variable can be measured accurately, to avoid experimental error
- the experiment must be reproducible.

An **experiment** is a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains. The experiment is a cornerstone in the scientific approach to gaining deeper knowledge about the physical world. Scientists use the principles of their hypothesis to make predictions, and then test them to see if their predictions are confirmed or rejected.

Scientific experiments involve **controls**, or subjects that are not tested during the investigation. In this way, a scientist limits the factors, or *variables* that can cause the results of an investigation to differ. A **variable** is a factor that can change over the course of an experiment. **Independent variables** are factors whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable). **Dependent variables** change in response to the independent variable. **Controlled variables** are also important to identify in experiments. They are the variables that are kept constant to prevent them from influencing the effect of the independent variable on the dependent variable. During experiments it is important to keep all other factors consistent throughout the experiment. These factors are referred to as **constants**. An example of a constant is temperature of the room and amount of sunlight in a day

For example, if you were to measure the effect that different amounts of fertilizer have on plant growth, the independent variable would be the amount of fertilizer used (the changing factor of the experiment). The dependent variables would be the growth in height and/or mass of the plant (the factors that are influenced in the experiment). The controlled variables include the type of plant, the type of fertilizer, the amount of sunlight the plant gets, the size of the pots you use. The controlled variables are controlled by you, otherwise they would influence the dependent variable.

In summary:

- The independent variable answers the question "What do I change?"
- The dependent variables answer the question "What do I observe?"
- The controlled variables answer the question "What do I keep the same?"

You conduct an experiment to measure how tall plants grow when given either water or Mt. Dew. Which is the dependent variable, plant height or Mt. Dew/water? Explain.

Why does a good experiment require controls?

Types of Experiments

Controlled Experiments

To demonstrate a cause and effect hypothesis, an experiment must often show that, for example, a phenomenon occurs after a certain treatment is given to a subject, and that the phenomenon does not occur in the absence of the treatment.

One way of finding this out is to perform a controlled experiment. In a **controlled experiment,** two identical experiments are carried out side-by-side. In one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.

A controlled experiment generally compares the results obtained from an experimental sample against a control sample. The control sample is almost identical to the experimental sample except for the one variable whose effect is being tested. A good example would be a drug trial. The sample or group receiving the drug would be the experimental group, and the group receiving the placebo would be the control. A **placebo** is a form of medicine that does not contain the drug that is being tested.

Controlled experiments can be conducted when it is difficult to exactly control all the conditions in an experiment. In this case, the experiment begins by creating two or more sample groups that are similar in as many ways as possible, which means that both groups should respond in the same way if given the same treatment.

Once the groups have been formed, the experimenter tries to treat them identically except for the one variable that he or she wants to study (the independent variable). Usually neither the patients nor the doctor know which group receives the real drug, which serves to isolate the effects of the drug and allow the researchers to be sure the drug does work, and that the effects seen in the patients are not due to the patients believing they are getting better. This type of experiment is called a **double blind** experiment.

Why would a researcher ever use a placebo?

Experiments Without Controls

The term **experiment** usually means a controlled experiment, but sometimes controlled experiments are difficult or impossible to do. In this case researchers carry out natural experiments. When scientists conduct a study in nature instead of the more controlled environment of a lab setting, they cannot control variables such as sunlight, temperature, or moisture. Natural experiments therefore depend on the scientist's observations of the system under study rather than controlling just one or a few variables as happens in controlled experiments.

For a natural experiment, researchers attempt to collect data in such a way that the effects of all the variables can be determined, and where the effects of the variation remains fairly constant so that the effects of other factors can be determined. Natural experiments are a common research tool in areas of study where controlled experiments are difficult to carry out.

In astronomy it is impossible, when testing the hypothesis "suns are collapsed clouds of hydrogen", to start out with a giant cloud of hydrogen, and then carry out the experiment of waiting a few billion years for it to form a sun. However, by observing various clouds of hydrogen in various states of collapse, and other phenomena related to the hypothesis, researchers can collect data they need to support (or maybe falsify) the hypothesis.

Natural Experiments

There are situations where it would be wrong or harmful to carry out an experiment. In these cases, scientists carry out a natural experiment, or an investigation without an experiment. For example, alcohol can cause developmental defects in fetuses, leading to mental and physical problems, through a condition called fetal alcohol syndrome.

Certain researchers want to study the effects of alcohol on fetal development, but it would be considered wrong or *unethical* to ask a group of pregnant women to drink alcohol to study its effects on their children. Instead, researchers carry out a natural experiment in which they study data that is gathered from mothers of children with fetal alcohol syndrome, or pregnant women who continue to drink alcohol during pregnancy. The researchers will try to reduce the number of variables in the study (such as the amount or type of alcohol consumed), which might affect their data. It is important to note that the researchers do not influence or encourage the consumption of alcohol; they collect this information from volunteers.

Field Experiments

Field experiments are so named to distinguish them from lab experiments. Field experiments have the advantage that observations are made in a natural setting rather than in a human-made laboratory environment. However, like natural experiments, field experiments can get contaminated, and conditions like the weather are not easy to control. Experimental conditions can be controlled with more precision and certainty in the lab.

Researchers want to study why bee populations worldwide are declining. This phenomenon is referred to as Colony Collapse Disorder. In order to examine this disorder, researchers take data from existing bee colonies. They need to account for changing weather patterns, increasing pollution, and other unseen factors. Field experiments are much harder to control than lab experiments.

Why is it important for scientists to publish the results of experimental investigations?

a. It allows other scientists to review the experimental design to make sure it is without flaw.
b. It enables scientists to become more respected in the scientific community.
c. It allows major companies to prove new scientific discoveries.
d. It allows scientists to make large amounts of money from their discoveries.

V. Tools of Science

Using Microscopes

Microscopes, tools that you get to use in your class, are some of the most important tools in biology. Before microscopes were invented in 1595, the smallest things you could see on yourself were the tiny lines 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.

Microscope*s* 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 Antony van Leeuwenhoek, a man who taught himself to make his own microscopes. When he looked at a sample of scum from his own teeth, Leeuwenhoek discovered bacteria. In rainwater, he saw tiny protozoa. Imagine his excitement when he looked through the microscope and saw this lively microscopic world. Van Leeuwenhoek discovered the first one-celled organisms (protists), the first bacteria, and the first sperm. Robert Hooke, an English natural scientist of the same period of history, used a microscope to see and name the first "cells", which he discovered in plants.

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, two of which are:

1. ***Light microscopes (***Figure 4***)*** allow biologists to see small details of biological specimens. Most of the microscopes used in schools and laboratories are 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, easier to use, allow the viewing of living organisms and can display true color.

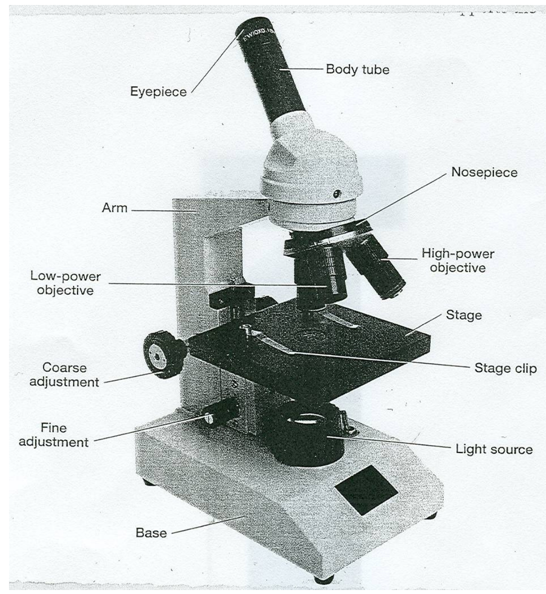
2. ***Electron microscopes*** allow scientists to map the surfaces of extremely small objects. These microscopes slide a beam of electrons across the surface of specimen, producing detailed maps of the shapes of objects.

If using the 10X objective, what would be the total magnification?

When would a scanning electron microscope be more helpful than a light microscope?

If you were on high power, what adjustment knob would you use?

Figure 4- *Light Microscope*



Other Life Science Tools

What other kinds of tools and instruments would you expect to find in a biologist's laboratory or field station? Other than computers and lab notebooks, biologists use very different instruments and tools for the wide range of life science specialties. For example, biologists rely on simple tools to give basic information about living things. **Thermometers** measure temperature which is measured in degrees. Biologists also use probes to gather multiple types of data. A **probe** is an instrument used to take measurements and is supported by data-gathering software like a computer. Tools like these are used to gather quantitative data, which helps aids in the scientific process.

Using Maps and Other Models

Researchers use models for many purposes. A volcano model is not the same as a volcano, but it is useful for thinking about real volcanoes. A model of planets may show the relationship between the positions of planets in space. Biologists use many different kinds of models to simulate real events and processes. Models are often useful to explain observations and to make scientific predictions.

Some models are used to show the relationship between different variables. For example, the model in figure 5 says that when there are few coyotes, there are lots of rabbits (left side of the graph) and when there are only a few rabbits, there are lots of coyotes (right side of the graph). You could make a prediction, based on this model, that removing all the coyotes from this system would result in an increase in rabbits. That's a prediction that can be tested.

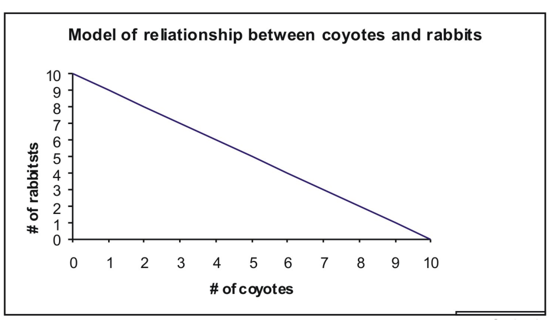


Figure 5*- This graph shows a model of a relationship between a population of coyotes (the predators) and a population of rabbit, which the coyotes are known to eat (the prey).*

According to the graph, what happens to the rabbit population as the coyote population increases?

According to the graph, if there are 3 coyotes, approximately how many rabbits are there?

Graphing Relationships

Graphs are used to show relationships. A graph is a great way to show the data that is collected during an experiment. However, reading a graph is very important also. There are many types of graphs. A line graph is a great way to demonstrate a relationship between two groups. Line graphs can show two different types of relationships.

The first is directly proportional. A **directly proportional** relationship is one in which the manipulated variable and responding variable remains constant. In other words, they have a constant ratio. In math terms, this means that the slope is positive. For example: As the number of students at Brandon Valley High School increases, the number of teachers at BVHS increases.

The other relationship is inversely proportional. An **inversely proportional** relationship is one in which the manipulated variable and responding variable remains constant but is inversely related. In math terms, this means that the slope is negative. For example: As the numbers of coyotes increases in a population, the population of rabbits declines.
Line graphs do not always need to show direct relationships. Sometimes the graph does not have a straight line but instead has a curved line. This is called an **exponential graph**. In this graph, the slope of the line increases as the x values increase. This results in a J-shaped curve.

In the case of an exponential graph, the slope will increase as x-values increase. As a result, an exponential graph will not have a straight line but rather a J-shaped line. Consider the case of a bacterium capable of splitting each hour. After one hour, you would have two bacteria. After two hours, each of the new cells will split, resulting in four new cells. After three hours, there will be eight, etc. While the independent variable (X-axis) increased from one to two to three, the dependent variable (y-axis) went from two to four to eight.

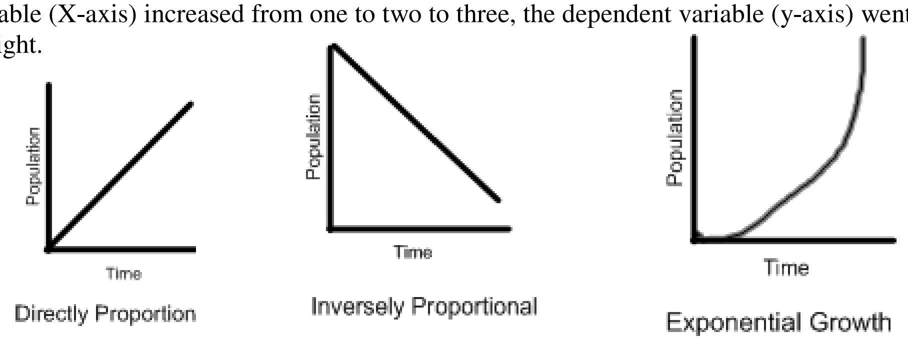


Figure 6- *Three types of graphs that are typically used to show biological data.*

Measurements

Accurate measurements are vital to science. There are many measurement systems used in the world but only one that is used consistently in science. That system is called the International System of Units and is abbreviated as SI units. You are probably already familiar with part of the SI system because part of the SI system is called the **Metric System.**

Why is the metric system useful in science?

Mass and Its SI Unit

When you step on a bathroom scale, you are most likely thinking that about determining your *weight*, right? You probably aren't wondering if you have gained mass. Is it okay then to use either term?

Although we often use mass and weight interchangeably, each one has a specific definition and usage. The **mass** of an object does not change; whether the object is on the earth's equator, on top of Mt. Everest, or in outer space, the mass will always be the same. Because mass measures how much matter the object contains, it has to be a constant value.

Weight, on the other hand, is a measure of the force with which an object is attracted to the earth or body upon which it is situated. Since the force of gravity is not the same at every point on the earth's surface, the weight of an object is not constant. For example, an object weighing 1.0000 lb in Panama weighs 1.00412 lb in Iceland. For large objects this difference may not be significant. However, since we will often be working with extremely tiny pieces of matter – atoms, molecules, etc. – we need to use mass and not weight.

The basic unit of mass in the metric system is the gram. A gram is a relatively small measurement compared to, for instance, one pound. 454 grams equals one pound. While pounds are helpful in measuring the mass of a package that needs to be mailed, grams are much more useful in science.

One gram is equal to 1,000 milligrams or 0.001 kilograms; there are numerous intermediate measurements between each of these mass units as well as ones that are even larger and smaller that may be appropriate to the application at hand.

Length and its SI Unit

When the four minute mile was achieved on May 6, 1954 by Roger Bannister, it was an international sensation. Today, many runners have broken that record. Only a few countries measure length or distance using miles, feet or inches. For instance, if you live in the US, you probably know your height in feet and inches, right? Or, if there is a mountain or even a hill near where you live, you probably know its height in feet. And when you discuss how far school is from your home, you probably try to figure out the distance in miles.

However, most of the world measures distances in meters and kilometers; for shorter lengths, millimeters and centimeters will be used. 1 kilometer is equal to 1,000 meters. For a student in Germany, she will state how many kilometers her school is from home, and the height of the mountain she is thinking of climbing will be given in meters. Because the metric system is a decimal system, changing between the various measurements simply becomes a matter of moving a decimal point to the right or left.

If you live 1.5 kilometers from school, how many meters do you have to travel to get to school?

Volume: A Derived Unit

In biological experiments, scientists often need to measure specific amounts of liquid. Liquid is best measured in terms of volume. **Volume** is used to measure how much space an object takes up. The metric unit for volume is the liter (L), which is equal to 1,000 milliliters. In most cases, liquid volume will be given in terms of milliliters.

If you buy a 2 liter bottle of soda, how many milliliters of soda do you get?

Temperature: Celsius Scale

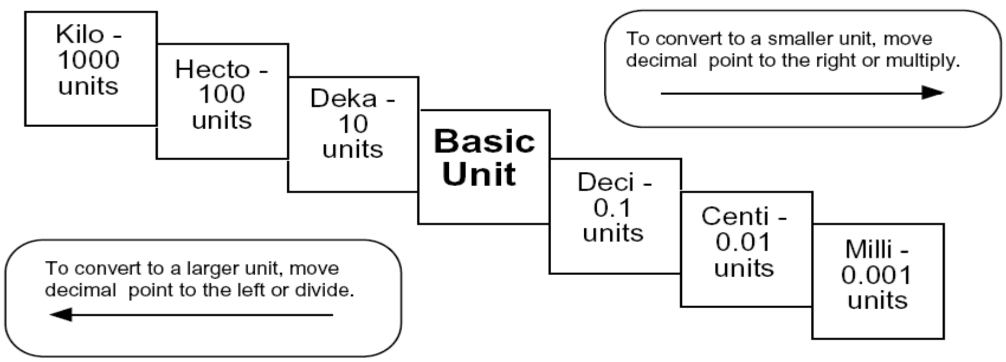
In the sciences, temperatures should be reported in degrees Celsius. Here are some common references for the Celsius scale:

Freezing point of water- 0ºC

Boiling Point of Water- 100 ºC

Normal Body Temperature-37 ºC

***Figure 7**-This chart shows how to convert metric units. The prefixes below are used for all units of measure in the metric system.*



VI. Introduction to living organisms

Introduction

How would you define a living thing? In other words, what do mushrooms, daisies, cats, and bacteria have in common? All of these are living things, or **organisms.** It might seem hard to think of similarities among such diverse organisms, but there are actually many similarities. The chemical processes inside all organisms are the same. For example, all living things encode their genetic information in the same way. And many organisms share the same needs, such as the need for energy and materials to build their bodies. Living things have so many similarities because all living things have evolved from the same common ancestor that lived billions of years ago.

All living organisms:

- Need energy to carry out life processes
- Are composed of one or more cells (the cell theory)
- Evolve and share an evolutionary history

- Respond to their environment
- Grow, reproduce themselves, and pass on information to their offspring in the form of genes
- Maintain a stable internal environment (homeostasis)

Life on Earth is very diverse, yet all these forms of life share some characteristics. Forms of life include: Bacteria, Algae, Fungi, Plants, and Animals.

What are some criteria for determining if something is living?

Living Things Maintain Stable Internal Conditions

All living things have some ability to maintain a stable internal environment. The inside of an organism is separate and different from the outside world. Maintaining that separation and difference is known as **homeostasis**. For example, many animals work hard to keep their temperature within a certain range. If the animal gets too hot or too cold, it will die. As a result, many animals have evolved behaviors that regulate their internal temperature. A lizard may stretch out on a sunny rock to increase its internal temperature, and a bird may fluff its feathers to stay warm

Why is the ability to maintain homeostasis essential for living things?

Living Things Grow and Reproduce

All living things reproduce. Organisms that do not reproduce go extinct, every time. As a result, there are no species that do not reproduce.

Reproduction, the process of creating a new organism, is different for different organisms. Many organisms reproduce ***sexually***, where an egg and sperm go together to form a new individual. Other organisms can reproduce without sex ("***asexually***"). For example, bacteria can simply split in two, producing two identical new cells. But it's not just bacteria that can reproduce without sex. Some lizards can produce clones of themselves. In such species, all individuals are female and simply lay their eggs when they are ready to reproduce.

How is sexual reproduction different from asexual reproduction?

Living Things are Composed of Cells

All living things are composed of ***cells***, the tiny units that are the building blocks of life. Cells are the smallest possible unit of life that is still considered living. Most cells are so small that they are usually visible only through a microscope. Some organisms, like the tiny plankton that live in the ocean, are composed of just one cell. Other organisms have many millions of cells that make up different body tissues and organs. On the other hand, eggs are some of the biggest cells around, including chicken eggs and ostrich eggs. But most cells are tiny.

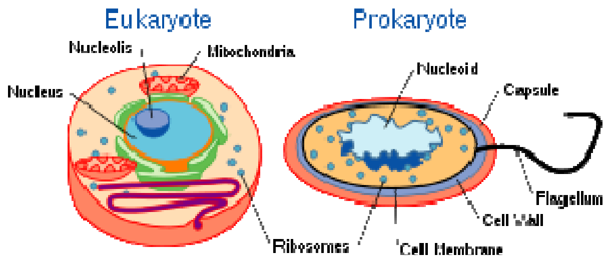


Figure 8- Cells *Not all cells are the same. The two cells above are from different organisms.*

Living Things Need Resources and Energy

In order to grow, reproduce, and maintain homeostasis, living things need energy. The work you do each day, from walking to writing and thinking, is fueled by energy in your cells. But where does this energy come from?

The source of energy differs for each type of living thing. In your body, the source of energy is the food you eat. All animals must eat plants or other animals in order to obtain energy and building materials. This process is called ***cellular respiration***. Plants themselves don't eat; they use the energy of the sun to make their "food" through the process of ***photosynthesis***. Like animals, mushrooms and other fungi obtain energy from other organisms. That's why you often see fungi growing on a fallen tree; the rotting tree is their source of energy. Although the means of getting energy might be different, all organisms need some source of energy. And since plants harvest energy from the sun and other organisms get their energy from plants, nearly all the energy of living things ultimately comes from the sun.

What is the ultimate source of energy on Earth? Explain.

Vocabulary

Biohazard: Any biological material, such as infectious material that poses a potential to human health, animal health, or the environment.
Carcinogen: A cancer-causing agent
Cell: The smallest living unit of life; the smallest unit of structure of living organisms.
Cellular respiration: The process by which cells harvest energy from food.
Control: Subjects that are not tested during an experiment.
Controlled experiment: Two identical experiments, carried out with everything held constant except for one variable.
Constant: Factors that need to stay constant during an experiment.
Controlled variable: Variables that are kept constant to prevent them from influencing the effect of the independent variable on the dependent variable.
Cultural beliefs: Views based on religion or race.
Dependent variable: The variable that changes in response to the independent variable.
Directly proportional relationship: the manipulated variable and responding variable remains constant.
Double blind: An experiment where neither the researchers nor the subjects are informed of which group is the control set and which group is variable set.
Electron microscopes: A microscope that scans the surfaces of objects with a beam of electrons to produce detailed images of the surfaces of tiny things.
Experiment: a test that is used to eliminate one or more of the possible hypotheses until one remains.
Exponential graph: The slope of the line increases as x-values increase.
Evidence: Something that gives us grounds for knowing of the existence or presence of something else.
Falsifiable: Testable. If a hypothesis generates predictions that can be shown to be true or false by experiment or observation, the hypothesis is "falsifiable" or "testable."
Homeostasis: Maintaining a stable internal environment despite changes in the environment.
Hypothesis: A proposed explanation for something that is testable.

Independent Variable: The variable that is not affected by the dependent variable; Usually affected by experimenter in a controlled experiment.
Inversely proportional relationship: the manipulated variable and responding variable remains constant but in inversely related.
Laboratory: A place that has controlled conditions in which scientific research, experiments, and measurement may be carried out.
Lab techniques: The procedures used in science to carry out an experiment.
Life science: The study of living organisms and how they interact with each other and their environment.
Light microscopes: A microscope that focuses light, usually through a glass lens; used by biologists to small details of biological specimens.
Mass: The amount of matter an object contains.
Metric system: The international measurement system used in science.
Microscopes: A set of lenses used to look at things too small to be seen by the unaided eye.
Microscopy: All the methods for studying things using microscopes.
Observation: Information gathered by uses of senses and instruments.
Organism: A living thing.
Pathogen: A disease causing agent.
Personal belief: The views and values held by an individual.
Photosynthesis: The process of turning light energy into chemical energy.
Placebo: A treatment or substance that does not contain an active drug but subject is not aware of lack of active treatment or drug.
Prediction: A statement that tells what will happen under specific conditions. A scientific prediction is different from an everyday prediction, like predicting the weather before it happens. A scientific prediction is related to a specific hypothesis.
Probe: An instrument used to take measurements supported by data-gathering software
Qualitative data: Observation of physical characteristics that are described in words.
Quantitative data: Observations involving words and numbers.
Reproduction: The process by which an organism makes a new organism with at least some of its own genes.

*__Sexual:__ Offspring are not genetically identical to either parent but are a combination of both.
*__Asexual:__ Offspring are genetically identical to the parent.

Safety equipment: Tools or equipment used/worn by an individual for protection
Science: A way of knowing about the physical world, based on observable evidence, testing predictions, and reasoning.
Scientific discovery: A finding based on experiments.
Scientific evidence: A direct, physical observation of a thing, a group of things, or of a process over time.
Scientific interpretation: Explanation of what experimental results mean.
Scientific investigation: Experiments designed to find out about something.
Scientific law: A rule that describes but does not explain a pattern in nature and predicts what will happen under specific conditions.
Scientific method: A careful way of asking and answering questions to learn about the physical world that is based on reason and observable evidence.
Science theories: Well established and tested explanations of observations; produced through repeated studies, usually performed and confirmed by many individuals.
Societal beliefs: Opinions of people living together.
Thermometer: An instrument for measuring temperature.
Variable: A condition or value that is changed in the course of an experiment.
Volume: The amount of space an object occupies.
Weight: The measure of the gravitational force acting on an object.

Works Cited

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http://www.ck12.org
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