Grade 8
Physical Science

Oak Meadow
Coursebook

Oak Meadow, Inc.
Post Office Box 1346
Brattleboro, Vermont 05302-1346
oakmeadow.com

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Lesson 1

Measurements and Quantitative Data

ASSIGNMENT SUMMARY

- ☐ Complete the reading selections.
- ☐ Reflect on how knowledge is built upon the work of others.
- ☐ Identify objective and subjective observations.
- ☐ Record qualitative and quantitative observations.
- ☐ Measure and describe household objects.
- ☐ Optional activity: Scientists and Scientific Discoveries
- ☐ Complete lesson 1 test.

MATERIALS

- ☐ metric ruler or tape measure

Learning Objectives

At the end of this lesson you will be able to:

- Demonstrate objective observations.
- Differentiate between subjective, objective, qualitative, and quantitative observations.
- Identify the basic components of a scientific argument.

Reading

Read the following sections (found in Reading Selections at the end of this lesson).

- The Flow of Discovery
- Scientific Inquiry
- Measurements and Quantitative Data
- Scientific Argument

Before you begin reading, glance over the length of the reading selections in this week's lesson. This is a good habit to get into—at the beginning of each lesson, scan all the work ahead of you. If you find a lot of reading material in a lesson, try to read one or two sections and then take a break before reading more. That way, you are more likely to remember what you read rather than if you had rushed through it.

In addition to the reading selections in this coursebook, you are encouraged to learn more about topics you are interested in by visiting the library, reading newspapers and scientific journals, and doing research online. You'll find a list of online resources at www.oakmeadow.com/curriculum-links/. You can use these links to learn more about lesson topics.

Assignments

At the beginning of each lesson, read the assignments, lab investigations, and activities to see what you'll be doing that week. Yes, this will take a little time, but it will help you get a good sense of how long things will take so you can manage your time better. You have a full week to complete each lesson, so there's no rush.

1. Think of a time when you have built on the knowledge of someone who came before you, and consciously taken it to the next step. Was this next step an improvement or a better design? Perhaps an activity you do is now more efficient. Write about one or two of your experiences.
2. Identify which of the following observations are objective and which are subjective.

Statement	**Objective**	**Subjective**
The cat is 20 inches long.		
Its tail is striped orange and white.		
It is friendly.		
The cat is fat.		
It weighs 20 pounds.		
Its whiskers are white.		
The fur on its paws is orange.		
It enjoys lying in the sun.		

3. Practice careful and objective observation. Choose something to observe, either outdoors or indoors. Consider what you might need to do for the observation to be repeatable. If you're observing your dog playing in your backyard, you need to record the dog's actions as well as the time of day, the weather, the sounds around you, who else is there, etc. All these things are important and helpful information. For example, if you don't note that a thunderstorm comes up, and you just say, "The dog suddenly stopped chasing the stick and hid under a bush," we're not getting the full picture. You will need to use all your senses and record your data carefully and thoroughly. Be sure to be objective. Instead of saying, "My dog kept jumping up happily," you should say, "My dog jumped two feet off the ground six times in ten seconds while wagging his tail." That way the reader decides if the dog seems happy or not. Use clear and precise language when describing your observations. Make sure to include both qualitative and quantitative data.

4. Find five objects in your house that are rectangular or square. The objects should be different sizes. At least one should be smaller than your hand, and at least one should be larger than a chair (such as an appliance). Take careful measurements using a metric ruler or tape measure and complete the table below. After measuring the item (quantitative data), write down one objective qualitative observation.

Object	Dimensions (length, height, and width)	Volume (length × height × width)	Qualitative observation

Activities

All the activities in this course are optional. Although these activities are not required, you are encouraged to choose any that interest you to help you gain a better understanding of the course material.

Activity: Scientists and Scientific Discoveries

In this lesson, you've been introduced to a few scientists whose work changed the world. Find a scientist or a scientific discovery that interests you. Do a little research, and write a paragraph highlighting the work of this scientist or the significance of the discovery.

Test

Answer the following questions using the knowledge you have gained in this lesson. Use correct terminology and refer to scientific concepts to support your answer whenever possible.

1. Explain the difference between an objective observation and a subjective observation.
2. Give three examples of quantitative observations.
3. Give three examples of qualitative observations.
4. List and define the steps of a scientific argument.

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Learning Checklist

This learning checklist can be filled out by either you or the adult who is supervising your work. This checklist will help you keep track of how your skills are progressing and what you need to work on. You or your home teacher can also add notes about where you'd like help.

Here is what the different headings mean:

Developing: You still need to work on this skill.

Consistent: You use this skill correctly most of the time.

Competent: You show mastery of this skill.

Please remember that these skills continue to develop over time so you aren't expected to be able to do all of them yet. The main goal is to be aware of which skills you need to focus on.

SKILLS	Developing	Consistent	Competent	Notes
Differentiate between subjective and objective observations				
Define quantitative and qualitative data				
Record accurate measurements				
Use scientific terminology in explanations				

FOR ENROLLED STUDENTS

You will be sending your work from this lesson to your Oak Meadow teacher at the end of lesson 2. In the meantime, feel free to contact your teacher if you have any questions about the assignments or the submission process.

Reading Selections

The Flow of Discovery

Roughly 2,500 years ago, two Greeks, Aristotle and (a hundred years later) Archimedes, made discoveries because they were curious about why certain things in their world behaved as they did. Aristotle observed natural phenomena and tried to come up with logical explanations about them, testing his observations through organized scientific inquiry. This changed everything! Until then, people had explained natural phenomena through myths and stories. Archimedes was a noted mathematician who introduced mathematical reasoning into scientific inquiry.

Like Aristotle and Archimedes, Isaac Newton (1642–1727) challenged ideas that had dominated scientific thinking for thousands of years. Newton developed the laws of motion of bodies, and

Portrait of Isaac Newton by Godfrey Kneller (1689)

the laws of gravitation and optics. Much of what we'll be learning about in this physical science course is what is known as "Newtonian physics."

Some 300 years later, *Time* magazine chose German-born physicist Albert Einstein as "the most important person of the 20th century." When Einstein published his Theories of Relativity in 1905 and 1915, he dramatically altered the way we understood the world. Throughout his life, Einstein acknowledged his debt to scientists who had gone before him. Though it was their individual brilliance that led to scientific breakthroughs, both Newton and Einstein saw themselves as part of a flow of discovery.

When Einstein advanced his Theory of Relativity, it overturned Newton's idea of absolute space and time. About the same time, Max Planck introduced the basis for the Quantum Theory. These two concepts—Relativity Theory and Quantum Theory—have provided the foundation for most of modern physics, which includes ideas such as the big bang, black holes, antimatter, and quarks.

However, scientific theories often come into question as new theories are advanced. That is what science is all about! It's all about hypothesizing, testing theories, making mistakes, adjusting your hypothesis, and trying again.

Many scientists today are deeply involved in developing a Unified Field Theory, also known as the Theory of Everything. It ties together all known phenomena to explain the nature of all energy and matter in existence. So far it has defied expression; there are some things that just don't fit into the equation. The current search for a Unified Field Theory has led to the Superstring Theory, which says that all matter and energy in the universe is composed of incredibly tiny vibrating "strings." This idea offers a lot of promise.

Perhaps during your lifetime an entirely new concept of space and time will emerge, rendering what we know today obsolete. We hope this course will make it easier for you to accept new ideas. Perhaps, one day, you will help discover one of those new ideas.

Throughout the course, you'll find short biographies of notable people in the scientific world. Each one has made a significant contribution and helps us remember that science is about people. It's easy to forget that! The biographies highlight people who devoted their lives to searching for answers to scientific questions, and to those who stumbled upon a scientific discovery by accident.

Keep in mind, as you move through this course, that *people* accomplished all the great achievements you will read about. People who had homes and families, hopes and ideals. They got sick, got angry, felt frustrated, and lived from day to day, just like everyone else does. For many scientists, it is their passionate curiosity that spurs them to action.

Scientific Inquiry

Science focuses on observing, understanding, and explaining the world around us. Scientific inquiry attempts to gather information that is free of opinion or bias. In order to do that, scientific explorations have three particular things: ***measurable observation***, ***repeatable results***, and ***objective analysis***.

Every scientific observation that is made must be measurable. The ancient Greeks explained observations with myths. If there was a thunderstorm, it was assumed that the god Zeus was causing the lightning because of his anger. That's not a scientific explanation—there is no way to measure or test that assumption. We now know, through observation and measurements, that atmospheric conditions create the static charge that we know as lightning.

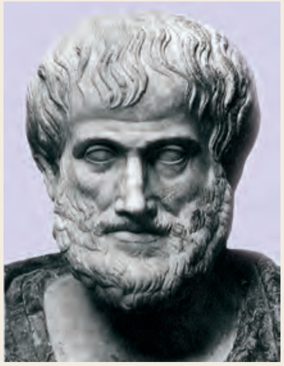
Let's say you notice that when you wake at 7:30 each morning, the day seems a little darker than it did the day before. This is a measurable observation. You can record the time the sun comes up each day for two weeks and note that the sun really does come up later each day. Your measurable observations are the specific time measurements you made for 14 days. With this specific data, other people can verify your results by repeating what you did.

The basis of scientific inquiry is careful observation. This means being aware of the world around us. ***Objectivity*** is the desire to observe things as they are, without personal opinions or feelings influencing the observation. Sometimes we really want a process to turn out a certain way, and we'll want to adjust our way of looking at it (or worse yet, adjust the results themselves) to mesh with our desire. This is not science!

En Hedu'anna (circa 2354 BCE)
Sumerian Astronomer

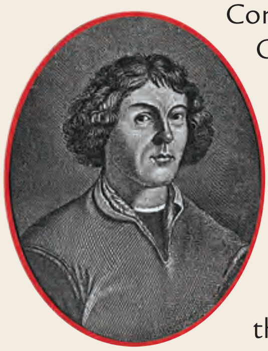
En Hedu'anna lived in Sumeria over 4,000 years ago. She was the daughter of the ruler Sargon, who established the Argonian Dynasty in Babylon. As Priestess of the Moon Goddess, her position was very powerful. She was the head of a sacred temple where priests and priestesses monitored the movements of the stars from a network of observatories. They created a calendar that is still in use for determining religious holy days.

Aristotle (384–322 BCE)
Greek Philosopher



Aristotle was a Greek philosopher who founded the science of logic. Both of Aristotle's parents died when he was a boy. When he was 18, he began studying at the Academy of Plato in Athens, where he stayed for 20 years. Plato called him the "intelligence of the school." Aristotle later formed his own school in Athens, the Lyceum (335 BCE). He was known for walking around with his students while teaching them. In his writings, Aristotle covered almost every area of human knowledge. He emphasized that rationality was essential in politics and thinking. He adhered to a strict moral code, believing if a man practiced behaving morally and ethically, it would soon become his natural behavior.

Nicolaus Copernicus (1473–1543)
Polish Astronomer



Considered the founder of modern astronomy, Copernicus challenged the ancient yet popular ideas of a Greek astronomer and geographer named Ptolemy who believed the sun, moon, and planets circled around Earth. Because Ptolemy's work was so respected, for almost 1,500 years astronomers believed this was true. However, Copernicus set out to prove how Earth's movements explained the movement of other heavenly bodies with the Sun as the center of the Universe. Copernicus's theory laid the foundation for Johannes Kepler to use mathematics to develop the three laws of planetary motion. In turn, Kepler's laws were crucial to Galileo's discoveries, based on telescopic investigation. Following the path of discovery, Sir Isaac Newton was later able to determine the principle of gravity based on the combined works of all three: Copernicus, Kepler, and Galileo.

Galileo Galilei (1564–1642)
Italian Astronomer

Galileo, who lived one hundred years after Copernicus, made observations of the moon, and the planet Jupiter and its moons, that convinced him Copernicus was right. His ideas disagreed with the teachings of the powerful Catholic Church, so the Church declared him a heretic and forced him to renounce his views. He had to spend the rest of his life being watched over by officers from the Church. It took another hundred years of careful research and determination on the part of scientists around the world for Copernicus's theory to enjoy universal acceptance.

All observations are potentially influenced by experience, beliefs, or worldview. For example, if you and a friend go for a walk in the park, the two of you might notice different things. Afterwards, if asked to describe what you observed, you might have noticed all the people there—what they are doing, what they are wearing, where they are in relation to you. Your friend might have observed all the plants and animals—trees, flowers, squirrels, birds, and bees. Your observations were somewhat subjective because you only paid attention to what you were interested in. If you had taken a video camera with you and recorded everything while you walked around, you would be able to replay the video and each of you would be able to see the things that you missed. A video camera recording is like an objective observer because it records everything in its field of vision.

Objective scientific observation attempts to be like a video camera, recording everything. Scientists record everything they notice, even when they don't think that it is important and even when the observations that they are making are different from what they expected or when they disagree with the results. Scientists strive for objective observation.

The easiest way to tell if an observation is subjective or objective is whether someone else could disagree with you. If they could disagree because they have a different opinion or view, then the observation is ***subjective***. For instance, if you and a friend sat on a park bench and saw a group of three squirrels nearby, you both would agree on the number of squirrels. That's an objective observation. If asked, "Were the squirrels friendly or shy?" you might say they acted friendly but your friend might say they acted shy. These are subjective observations, based on your opinions or feelings. However, if asked, "Did the squirrels approach when you sat on the bench?" it's likely your answers would agree because the question asks for an objective observation.

An objective observation is an example of good science if it contains the three features of scientific observation: it is measurable, repeatable, and objective.

Measurements and Quantitative Data

Physical science focuses on the physical properties of energy and matter, and how they interact with each other. Why does the skateboard roll downhill? What makes your computer run? Why does salt dissolve in water? What happens to light as it comes through the window? All these questions have to do with the physical objects and how they move or change.

Measuring is an integral part of all scientific exploration. ***Quantitative data*** is anything that can be measured or counted. Quantitative measurements involve numbers. In physical science, commonly measured things include temperature, time, area, volume, sound, weight, speed, and distance. These are all measured with numbers.

Qualitative data involves characteristics that relate to appearance or behavior. It describes the qualities of whatever is being observed. Qualitative measurements include color, texture, smell, taste, sound, movement, and other characteristics that can't be measured with numbers. Accuracy of detail is extremely important in both qualitative and quantitative observations.

All quantitative measurements are expressed in units. For example, when you weigh yourself, you may express your weight in pounds. A pound is the unit of measure. Other units include grams, ounces, millimeters, inches, seconds, miles, and kilometers.

Measurements can record different types of data:

Linear distance measures the distance from one point to another.

Area is the amount of flat (or two-dimensional) space, and includes length and width. Area is measured in square units, such as square meters.

Volume is the amount of three-dimensional space taken up by a solid, and includes length, width, and height. Volume is measured in cubic units, such as cubic meters.

Liquid volume differs from solid volume since liquids change shape depending on the container. Liquid volume is measured in liters (or related measurements).

The volume of a liquid is generally measured using a ***graduated*** container, which means that there are units marked on the container at regular intervals. A measuring cup is an example of a graduated container.

There is a certain technique involved in measuring liquids. If you put water in a glass measuring cup, you'll see that the water clings to the sides of the container, so that the edge of the liquid is curved. This curve is called the ***meniscus***. Because of this curved surface, you need to have your eyes level with the top of the liquid to get an accurate volume measurement.

Originally every culture had its own system of measurement. Today, the standard system of weights and measures used by the scientific community and most of the world is the metric system, also known as Système International (SI). The metric system is based on units of 10. The name of each unit tells you how many 10s (or 100s or 1,000s) there are. For example, if you add the prefix *centi-* to the word *meter*, you get centimeter. The prefix *centi-* means one hundredth, so a centimeter is one hundredth of a meter. If you add the prefix *kilo-*, you get kilometer. The prefix *kilo-* means one thousand, so a kilometer is one thousand meters.

Metric System Prefix	**Meaning**	**Example**	**Equivalency**
Mega-	one million	1 megaliter is 1,000,000 liters	1,000,000 liters = 1 megaliter
Kilo-	one thousand	1 kilogram is 1,000 grams	1,000 grams = 1 kilogram
Hecto-	one hundred	1 hectogram is 100 grams	100 grams = 1 hectogram
Deca-	ten	1 decameter is 10 meters	10 meters = 1 decameter
Deci-	one tenth	1 deciliter is one tenth (1/10) of a liter	10 deciliters = 1 liter
Centi-	one hundredth	1 centimeter is one hundredth (1/100) of a meter	100 centimeters = 1 meter
Milli-	one thousandth	1 milliliter is one thousandth (1/1,000) of a liter	1,000 milliliters = 1 liter
Micro-	one millionth	1 microgram is one millionth (1/1,000,000) of a gram	1,000,000 micrograms = 1 gram

Common Abbreviations of Metric Measurements

Meter	Meter	m
	Kilometer	km
	Centimeter	cm
	Millimeter	mm
Gram	Gram	g
	Kilogram	kg
	Milligram	mg
Liter	Liter	l
	Milliliter	mL (or ml)

Sometimes volume is given in cubic centimeters (cc). This is often used in medicine to measure dosage. A cubic centimeter is exactly the same volume as a milliliter. They are used interchangeably. If you were measuring a volume of water, 1 mL (1 cc) weighs exactly one gram (at a water temperature of 4°C)! This works out because a liter is the same volume as a cubic decimeter (a decimeter is one tenth of a meter, or 10 centimeters). If you had a cube that was 10 cm on each side, the volume of it is exactly one liter.

Scientific Argument

In addition to making careful measurements and objective observations, scientists also strive to draw conclusions based on the data collected. Any claims made based on results should be supported by data. Presenting a scientific argument lets scientists "argue" or prove their claims or conclusions using measurable, replicable, and objective data.

Here are the steps to making a scientific argument:

- **Make a claim based on research.**

A claim is a statement that suggests or infers a relationship (correlation) between factors, or draws a conclusion about what the data indicates. It's important to be careful with how a claim is stated because one experiment or data set doesn't prove something conclusively. Scientific claims often use phrases like "this suggests," "it appears," or "it seems likely" to indicate whatever the observations or results might show.

- **Provide evidence (data) to support the claim.**

Observations (both quantitative and qualitative) form the data that become evidence to support a claim. Usually this data is assembled into an easy-to-read form, such as a chart, graph, or table. The data should directly relate to the claim or conclusion in a logical way. If the claim is sound, others who see the data are likely to agree with the statement.

- **Use reasoning to explain how the data supports the claim.**

The bulk of a scientific argument is explaining how the data relates to and supports the initial claim. It clearly presents the logical flow of reasoning that led to the claim or conclusion. The argument explains what the data shows so that others can judge the accuracy of the claim for themselves.

Scientists, like everyone else, have personal opinions, feelings, beliefs, and biases. However, they try very hard to remain objective when making observations, interpreting data, making claims, and providing scientific argumentation. Throughout this course, you'll be practicing these essential scientific habits.

Lesson 2

Controlled Experiments and the Scientific Method

ASSIGNMENT SUMMARY

- ☐ Complete the reading selections.
- ☐ Make a list of variables and how they can be controlled.
- ☐ Lab Investigation: Sink or Float?
- ☐ Complete lesson 2 test.

MATERIALS

☐ Lab Investigation: Sink or Float?

clay (about the size of a baseball)

bucket of water

Learning Objectives

At the end of this lesson you will be able to:

- Identify the variable factors in an experiment.
- Design an experiment that controls all variables but one.
- Write a conclusion based on experiment results.
- Differentiate between causation and correlation.

Reading

Read the following sections (found in Reading Selections at the end of this lesson).

- Scientific Method
- Variable and Constant Factors
- Controlled Versus Uncontrolled Environments
- Using the Scientific Method
- Causation and Correlation

Look over the amount of reading before you begin, and make a plan to divide it up so you aren't trying to absorb too much information at once. If you have any questions about the reading, ask for help or do some extra research on your own.

Assignments

Before you begin your assignments, read through them to get a sense of what you'll be doing and how long it will take. This will help you manage your time better.

1. Take some time to make an observation around your home. Perhaps you notice that your cat naps in different places at different times of day. Or maybe you see that the temperature on one side of your house generally feels colder than on the other. Then make a list of variable factors that you might consider if you were to design an experiment. After each variable you list, explain how you might control that variable to make it a constant in your experiment.

Lab Investigation

Complete the following lab investigation.

- **Lab Investigation: Sink or Float?**

All lab investigations are found in the physical science lab manual. Read the instructions carefully and assemble all your materials before you begin. Use good scientific habits by taking careful observations and measurements, recording your data in an organized way, and using precise, detailed language.

Test

Answer the following questions using scientific terminology. Refer to scientific concepts to support your answer whenever possible.

1. In your own words, explain the steps of the scientific method.
2. What is the difference between a variable and a constant? How many variables are normally in a scientific experiment? How many constants? Why are both part of every experiment? Give an example of each.
3. Define controlled environment and give an example.
4. What does the phrase "correlation does not imply causation" mean? Make sure to define *correlation* and *causation* in your answer.

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Learning Checklist

Use this learning checklist to keep track of how your skills are progressing. Include notes about what you need to work on. Please remember that these skills continue to develop over time.

SKILLS	Developing	Consistent	Competent	Notes
Describe the steps of the scientific method				
Write a concise, testable hypothesis				
Identify variable and constant factors				
Write a step-by-step procedure for an experiment				
Record data with accuracy				
Write a conclusion based on results				
Describe a controlled environment				
Differentiate between causation and correlation				

FOR ENROLLED STUDENTS

When you have completed this lesson, please send lessons 1 and 2 to your Oak Meadow teacher. Include any additional notes about the lesson work or anything you'd like your teacher to know. Feel free to include any questions you have—your teacher is eager to help.

If you have any questions about what to send or how to send it, please refer to your parent handbook and your teacher's welcome letter. Your teacher will respond to your submission of student work with detailed feedback. In the meantime, proceed to the next lesson.

Reading Selections

Scientific Method

The ***scientific method*** is an organized way of testing observed phenomena. However, it is not the only way that scientific progress is made! Scientists observe the world like children do: exploring every new thing, being curious, asking questions. This observation and questioning is scientific inquiry. Sometimes you cannot create experiments around the observed phenomena. If a shower of meteors falls to Earth, how can you devise an experiment to test what happened and why? You can't recreate the event, but you can observe carefully and relate it to what is already known. This is the way science works.

We are all scientists. We ask questions, we guess what the answer will be, and we watch to see what happens. Our minds record the results and then we decide what the results mean. We take this knowledge and use it to guide our future actions or explorations. In the scientific method, observations are made about the world, and then experiments are conducted to explain the observation. How carefully the experiment is designed and conducted determines how accurate the results will be. If the factors influencing the experiment are not controlled, then the experiment will not give us reliable results and an accurate explanation of what was observed. Often a scientist will repeat an experiment, changing different elements each time, in order to gain a clearer understanding of a phenomenon.

When drawing conclusions about what happened and why, it's important to consider the many different factors that may influence the results. Scientists try to keep these influences under control by following very specific procedures of the scientific method:

Ask a question: Questions often arise from observations. The question should be brief, concise, and testable. For example, "Why does my dog eat so fast?" is a question that would be hard to test—it is too open-ended. There could be many factors influencing how fast the dog eats. However, "Does the type of food influence how fast my dog eats?" is a question that is easy to test. There is one factor that is being looked at: the type of food.

Form a hypothesis: A hypothesis is an educated guess about what the answer to the question might be, based on what you already know. The hypothesis forms the focus of your experiment, which will attempt to prove or disprove the statement. For instance, you might hypothesize, "My dog will eat cooked meat faster than dry dog food, fresh fruit, or fresh vegetables."

Conduct an experiment (procedure): An experiment is designed and conducted to test the hypothesis. The experiment will try to isolate a single factor to test, controlling all other influences. Often procedure is performed multiple times to see if the results can be repeated.

Record the results: Observations are carefully recorded, and these become the results of the experiment. Results, which can be qualitative or quantitative or both, are recorded as objectively as possible.

Draw a conclusion: The data (results or observations) is compiled and interpreted as you look for patterns and cause-and-effect relationships, and make inferences about what happened and why. The conclusion states whether the hypothesis was proved or disproved.

The conclusion is where you compare your hypothesis with what actually happened:

- Did what you think would happen actually happen?
- Did something unexpected happen?
- Describe the variables and which ones may have impacted your results.
- Consider possible explanations for what happened in your experiment.

The conclusion is a chance to reflect on the experiment and how it might be altered or expanded to produce more accurate or helpful information. Is there an influencing factor that was not properly controlled? Would more trials or a longer time period reveal more patterns of behavior? Is there another factor that needs to be taken into account or tested? When writing a conclusion, scientists will often discuss questions such as these, and propose a relevant follow-up experiment.

Variable and Constant Factors

When we make observations about the world, it is important to understand the factors that may be influencing what we are observing. In an experiment, a ***variable factor*** (or variable) is an aspect of the experiment that can be varied or changed. For instance, temperature might be a variable factor in a plant growth experiment, or the amount of water might be a variable factor. Usually an experiment will have only one variable factor. The variable in the dog food experiment is the type of food.

Factors that are controlled and do not change are called ***constant factors*** (or constants). In a plant growth experiment, you might control the amount and type of soil, the type and number of seeds, how deep the seeds are planted, and the amount of sunshine each plant gets. These constant factors are the same for each plant in the study. The constants in the dog food experiment might be the amount of food, the time of day, the number of people present when the dog is eating, the noise level, the location of the food, and the shape and size of dish the dog eats from. These constant factors are the same throughout the experiment. The only thing that changes is the type of food.

Let's suppose you notice that sometimes the ice cream in your freezer is really hard and sometimes it is a little soft. What are some of the variable factors that could explain this?

- The temperature of the freezer
- The placement or location of the ice cream in the freezer
- The type of ice cream
- How long the ice cream has been in the freezer
- How many times the freezer door has been opened
- How much ice cream is left in the container

If you wanted to conduct an experiment to try to figure out why the ice cream changes its form, you might start by identifying the variables, such as temperature, placement, type of ice cream, and length of time in freezer. To determine which variable is causing the ice cream to be hard or soft at different times, you would have to conduct a series of experiments to look at the influence of each variable, one at a time.

You might put some ice cream in a certain spot in the freezer and then two hours later you test it for hardness. After another two hours, you go to test the ice cream again, but you realize that someone ate it all, and there is another kind of ice cream right in the same spot. Since it is in the same place in the freezer, you do another hardness test and find it much softer than the previous ice cream. When you think about why the ice cream was soft the second time, you come up with several possible reasons:

- The ice cream was a different kind, and it is normally softer than the first kind of ice cream.
- The ice cream had not been in the freezer for very long, and might have been placed there after sitting in the car on the way home from the grocery store.
- The temperature in the freezer rose because someone left the door open while eating the remainder of the first ice cream.

Your hardness tests of the ice cream didn't really prove anything because there were too many variable factors in your experiment.

This is an example of an ***uncontrolled experiment***—there was not enough control over the variables to find an explanation for the observation. If you really want to find out what causes the ice cream to be harder or softer at different times, you will need to limit the variables. Remember:

- Only one variable factor in each experiment.
- All other factors should be controlled or constant.

How might you design your ice cream experiment to test only one variable? Let's say you want to test the placement of the ice cream in the freezer. That is your one variable. That means you need to control all the other influencing factors.

Here are some things you might do:

- Make sure no one opens the freezer door while your experiment is being conducted. This also means nothing is added or taken out of the freezer. This controls the temperature element and how many items are in the freezer.
- Buy three containers of the same ice cream, all in the same size container. This controls the amount and type of ice cream.
- Place each of the three ice cream containers in the freezer at the same time and make a note of the time you put them into the freezer. You will test the hardness of each at the same time, and the same number of times (say, one time per hour for three hours). This controls the element of time.

Since you are varying the location of the ice cream in the freezer, you will place each container in a different spot. You then conduct the experiment by checking the hardness in each of the three containers on a set schedule and you write your results down each time. As you do the experiment, you are careful not to change the location of any of the three containers.

If the results showed that the ice cream in one of the containers was soft and the ice cream in the other two containers was hard, then the placement of the ice cream in the freezer affects the hardness of the ice cream. If the results were that the ice cream in all the containers was equally hard or soft in all locations, then the placement of the ice cream in the freezer is not the variable that affects the hardness and softness of the ice cream. You will have to design another experiment that has a different factor as a variable, and where the placement of the ice cream in the freezer is a constant. You would continue to test different variables, one at a time, until your question was answered.

Controlled Versus Uncontrolled Environments

The environment or circumstances in which an experiment is conducted has an effect on the outcome of a scientific experiment. It is important to control the environmental factors (the variables), or you will not get reliable results or an accurate explanation for your observation or question.

A ***controlled environment*** is an environment where there is only one variable factor (or at most, a few). Most scientists, when they are working to explain an observation they have made, strive to design and conduct experiments in a controlled environment and to limit the variable factors as much as possible. An example of a controlled environment is a science laboratory where the scientist can control the temperature, the humidity, and the materials that are used.

An ***uncontrolled environment*** is an environment where there are many variable factors or factors that are hard to control. For example, when dealing with experiments in a natural setting, such as a forest, it is impossible to isolate a single variable—there are simply too many environmental factors that can influence the experiment. Good, careful scientific experiments can still be conducted, however, by having scientists do their best to notice and take into account the many varying influences.

Sometimes variables work together, and isolating them doesn't give you an accurate assessment. This has been the case when studying the human body. Scientists have isolated different organs and studied them individually and made conclusions, only to find later that each organ is quite connected to the whole body/mind system. They interact with the system in many complex ways, and controlled systematic study of each organ separately can give an incomplete picture.

It is always important to remember that your observations and/or experiment may have variable factors that are affecting your results. Try to limit the number of variables so you can figure out what you are actually measuring.

Remember that scientific observations must be measurable, repeatable, and objective. Whenever you use the scientific method for a controlled experiment, it should be written clearly so that others can repeat exactly what you did. You need to document your method or procedure precisely! This allows other scientists to verify your results, and it is how scientific theories are proven.

A repeatable experiment doesn't mean that the same results will be observed each time. We do experiments to see what the results will be rather than expecting them to be one way or another. If someone else repeats the experiment exactly and gets different results, you have a new question: Why did the results differ? You'd probably want to repeat the experiment many more times, and have others repeat it, to see if the data begins to show a pattern. If not, perhaps there is another variable influencing the results that hasn't yet been taken into account or controlled. Science is all about asking questions and looking for answers!

Using the Scientific Method

Let's look at an example of the scientific method in action. Pretend that you are washing the dishes in the sink one day, and you notice something about them. This is how the scientific method would be used to make a conclusion about your observation:

National Weather Service observation platform being installed at the lighthouse in Saginaw Bay, Michigan (Image credit: NOAA)

1. **Observation:** You have noticed that some objects sink when put in water, and that others float. You decide to test several items to see if you can figure why certain things sink and others don't.
2. **Hypothesis:** There are several variables that you need to identify, so that you can test one of them at a time. Some variables that might affect whether an object sinks or floats are shape, size, weight, and density. You decide to test density (which is mass per unit volume). You need to state your hypothesis quite specifically: "Objects that are the same shape and size, but different densities, will act differently in water. Objects that are less dense will float, and the more dense objects will sink. Wood will float and clay will sink."
3. **Experiment:** Now you need to clearly document your method, identifying how you will control each variable: "I will take a small block of wood and a lump of clay. I will form the clay to be the exact shape and size as the block of wood. I will put each of them in a sink with water in it and observe whether they sink or float. Both are exposed to the exact same conditions in the room and the water. The only difference is the material they are made of."
4. **Results:** Write your results in detail: "When dropped into the water, the block of wood went under the water and then immediately bobbed back to the surface. The clay object sank to the bottom in less than one second, and landed on its side."
5. **Conclusion:** First review your original observation (that some objects sink and others float), and your hypothesis. Your results indicate that what you predicted did actually happen. But what is your conclusion? Basically, all you can conclude from this is that wood floats and clay sinks. You would like to make the theory that objects that are less dense will float and those that are more dense will sink. As you think about it more, though, you wonder whether this is always true. "Less dense" and "more dense" are vague terms. Less dense than what? What about ships that sail on the ocean? They are metal and quite dense, but they don't sink. Will

clay always sink, no matter what shape it's in? There are many more questions raised by this experiment than answers obtained—this is the way science works!

Your experiment is an important start. Information was learned, and now further testing can be done. You see that you need to clarify your hypothesis even more, perhaps adding that those objects that are more dense than water will sink, and those less dense than water will float. But what about the ships that float? You might consider that there is more than one variable that determines whether an object will float. There could be variables that you haven't thought of yet. It's important to remain inquisitive and keep questioning.

Causation and Correlation

When scientists draw conclusions or make statements based on data, they are often looking for a connection or cause-and-effect relationship between factors. However, proving that one thing causes another can be harder than it sounds. Just because two things happen together or under the same circumstances doesn't mean that one caused the other. In fact, science studies are often misunderstood by the public because of the confusion between correlation and causation.

Imagine that you trip on the sidewalk every time you wear a certain pair of shoes. You notice a correlation because the two events—wearing that pair of shoes and tripping on the sidewalk—seem to always happen together. This might lead you to believe that the shoes are the cause of your stumbles. But hold on—that's a big assumption to make. Perhaps you only wear those shoes to walk to your grandmother's house, and the sidewalk near her house is cracked and broken. Or perhaps you only wear those shoes in the rain and the sidewalk is always slippery in the rain, or you only wear those shoes at night, and you are more likely to trip in the dark. On the other hand, maybe the shoes are new and stiff or uncomfortable or too large, and they actually are the cause of all that tripping! However, without a comprehensive experiment, it's hard to prove it—there are just too many other factors involved. You can't say for certain that one thing (the shoes) causes another (tripping), so you can't claim causality. There is not enough evidence to prove it.

"Correlation does not imply causation" is a well-known phrase in science, and it is repeated often with good reason. Many people think correlation and causation are the same thing. If two things always seem to happen together, ask yourself, "Does *A* always lead to *B*?" And then try to answer the question through careful, methodical scientific inquiry and repeated trials.

This is how scientists try to determine cause and effect. When experiment results seem to indicate causation (one thing causing another), scientists look carefully at whether uncontrolled variables might have influenced the results.

Lesson 6 Types of Mixtures

ASSIGNMENT SUMMARY

- ☐ Complete the reading selections.
- ☐ Identify homogeneous and heterogeneous substances.
- ☐ Create a graphic showing different types of matter.
- ☐ List soluble and insoluble substances.
- ☐ Answer questions about temperature and solubility of gases.
- ☐ Identify compounds and mixtures.
- ☐ Lab Investigation: Chocolate Solution
- ☐ Lab Investigation: Mixtures and Solutions
- ☐ Lab Investigation: Saturation of Sugar Solution
- ☐ Optional activities:

  Activity A: Soda Shake

  Activity B: Oil Marble

  Activity C: Ocean in a Bottle
- ☐ Complete lesson 6 test.

MATERIALS

☐ Lab Investigation: Chocolate Solution

3 small pieces of chocolate (uniform in size) or other candy

☐ Lab Investigation: Mixtures and Solutions

8 glass jars with lids

hot water

spoon

vinegar

rubbing alcohol

solid (powdered) laundry soap

liquid soap (hand, dish, or laundry soap)

flour

ground-up chalk

dirt

cooking oil

☐ Lab Investigation: Saturation of Sugar Solution

granulated sugar

3 glass jars with lids (all the same size)

measuring spoons

cold, warm, and hot water

thermometer

☐ Activity A: Soda Shake

2 unopened cans of soda or seltzer water

☐ Activity B: Oil Marble

rubbing alcohol

cooking oil

eyedropper

blue or green food coloring

small glass or jar

water

☐ Activity C: Ocean in a Bottle

clear plastic bottle with tight-fitting cap

cooking oil

food coloring

water

Learning Objectives

At the end of this lesson you will be able to:

- Demonstrate mixtures, solutions, and saturated solutions.
- Explain the variables that influence solubility.
- Differentiate between compounds and different types of mixtures.

Reading

Read the following sections (found in Reading Selections at the end of this lesson).

- Different Types of Solutions
- Solubility, Concentration, and Saturation
- Solutions, Colloids, and Suspensions
- Separating Mixtures

Assignments

1. Look for homogeneous and heterogeneous substances in your refrigerator or food cupboard. Make a list of what you find.
2. Create a graphic or visual representation to show how matter is either an element, a compound, or a mixture. Also on your graphic, show that a mixture can be either a solution, a colloid, or a suspension. You might draw a concept map or Venn diagram to show this information (look up what these are if you aren't familiar with them).
3. List three soluble substances and three insoluble substances.

4. Thermal pollution is caused when warm water is released into rivers from power plants and factories, raising the temperature of the river in that location and far downstream. All aquatic life depends on the oxygen that is in solution in the water (known as *dissolved oxygen*). What happens to the dissolved oxygen level if the water is warmed up, and how would this affect the aquatic life?

5. Indicate if the following items are compounds or mixtures, and for the mixtures, indicate which type.

Item	**Compound**	**Mixtures (solution, colloid, or suspension?)**
air		
seltzer water		
mayonnaise		
salt		
salad dressing		
bronze		
baking soda		
sweetened iced tea		
vegetable soup		
whipped cream		
strawberry ice cream (with real strawberries throughout)		
mud		
iron oxide (rust)		
butter		

Lab Investigation

Complete all three of the following lab investigations.

- **Lab Investigation: Chocolate Solution**
- **Lab Investigation: Mixtures and Solutions**
- **Lab Investigation: Saturation of Sugar Solution**

All lab investigations are found in the lab manual.

Activities

Complete one or more of the following optional activities to learn more about the topics in this lesson.

- Activity A: Soda Shake
- Activity B: Oil Marble
- Activity C: Ocean in a Bottle

Activity A: Soda Shake

Explore how temperature affects the solubility of gas in this simple but exciting activity. You can do this activity with a partner or by yourself.

MATERIALS

- 2 unopened cans of soda or seltzer water

Procedure

1. Soda (solvent) contains dissolved carbon dioxide (solute). Place one can in the refrigerator for the night and the other in a warm place for the night.
2. The next day, take the two cans outside and shake each one 10 times. If you do this by yourself, do one can at a time; if you have a partner, you can shake and open the cans simultaneously.
3. Pointing the can away from you and any nearby objects, open it.
4. Measure how far the soda shoots out of the can. Compare the warm soda to the cold soda. Which soda went the farthest?
5. Pour what's left in each can into two separate glasses. Compare how they look. Which one is more bubbly?
6. Write a summary of your results and explain what you think happened. What do your results indicate about the relationship between the solubility of a gas and the temperature of the liquid solvent?

Activity B: Oil Marble

In this activity, you'll make a "marble" out of cooking oil.

MATERIALS

- rubbing alcohol
- cooking oil
- eyedropper
- blue or green food coloring
- small glass or jar
- water

Procedure

1. Fill the glass about halfway with water and add food coloring. Stir until the color is evenly distributed.
2. Pour in about 2 tablespoons of oil, enough to make a thin layer on the water.
3. Add rubbing alcohol with the eyedropper (or pour it in very slowly, a little at a time).
4. Watch what happens to the shape of the oil. Keep adding alcohol until the oil layer becomes a perfect sphere.

Activity C: Ocean in a Bottle

In this activity, you'll experiment with immiscible liquids.

MATERIALS

- clear plastic bottle with tight-fitting cap
- cooking oil
- food coloring
- water

Procedure

1. Fill the bottle halfway with water and add food coloring to make a deep, rich color.
2. Pour in about a one-inch layer of oil. Put the cap on tightly.
3. Tip the bottle over on its side. Tip the bottle back and forth, making waves with the water. Watch what happens.
4. Turn the bottle upside down. What happens?

5. Give the bottle one good shake, and then let it stand still. What happens, and how long does it take?
6. Give the bottle ten strong shakes, and let it stand still again. How long does it take this time?
7. Do you think you could ever make a solution with this mixture? Why or why not?

Test

1. List the three types of mixtures and explain the similarities and differences between them.
2. Define solute and solvent.
3. Give an example of a homogeneous mixture and a heterogeneous mixture, and explain the difference between them.
4. What are immiscible liquids? How do they differ from miscible liquids? Give an example of each.
5. Explain how temperature influences the solubility of gases in liquids.

Learning Checklist

Use this learning checklist to track how your skills are developing over time and identify skills that need more work.

SKILLS	Developing	Consistent	Competent	Notes
Identify similarities and differences between types of mixtures				
Differentiate between homogeneous and heterogeneous substances				
Differentiate between miscible and immiscible liquids				
Use scientific terminology in writing lab results and conclusions				
Record observations with accuracy and clear language				

FOR ENROLLED STUDENTS

Submit lessons 5 and 6 to your Oak Meadow teacher. Make sure to include the conclusions from your lab investigations. If you chose to complete any activities, please include information about them as well. Let your teacher know if you made any adjustments to the assignment or the workload.

Reading Selections

Different Types of Solutions

Have you ever mixed sugar into a cup of tea, or salt into warm water? When a substance ***dissolves*** in a liquid, it seems to disappear. But you know it is still there because if you were to taste the cup of tea or water, you would taste the sugar or salt.

The mixture of salt and water is an example of a ***solution***. Solutions are a type of mixture in which one substance dissolves in another substance. They do not make a compound because there are different types of molecules—the components have not chemically bonded.

Solutions can be mixtures of solids, liquids, or gases. The substance that dissolves is called the ***solute***. The substance in which the solute dissolves is called the ***solvent***. In the example above, the salt or sugar is the solute and the water is the solvent. Solvents can be water or any other substance that dissolves a solute. The solvent is the part of the solution that is in the greater quantity, and the solute is the smaller portion of the solution.

Liquid solutions are formed when solids, liquids, or gases dissolve in a liquid. When a solid dissolves in a liquid (such as sugar dissolving in tea), it is called a ***solid-liquid solution***. When a liquid is dissolved in a solvent, the result is a ***liquid-liquid solution***. For instance, alcohol (solute) dissolves in water (solvent). However, if the amount of alcohol is greater than the amount of water, the water becomes the solute, and the alcohol is the solvent. A gas can also dissolve in a liquid to form a ***gas-liquid solution***, such as seltzer or soda water. Carbon dioxide (solute) is dissolved in water (solvent) to make soda water. This is the carbonation that makes soda fizz. In nature, oxygen and carbon dioxide from the air dissolve in fresh water and seawater. Fish and other aquatic animals depend on that dissolved oxygen. Plants depend on dissolved carbon dioxide, and help to add oxygen to the water through photosynthesis.

Liquid solutions are always clear. They can be colored (as tea or coffee are), but there are no floating particles in them. This is how you can determine the difference between a mixture that is a solution and a mixture that is not a solution.

Liquids that can be mixed together to form a solution are called ***miscible liquids***. Liquids that do not dissolve when mixed together are called ***immiscible liquids***. Oil and water are immiscible because they do not form a solution when mixed—one does not dissolve into the other.

Balsamic vinegar and oil are immiscible liquids because they do not dissolve into a solution when mixed together. (Image credit: Ewan Munro)

Gas solutions are formed when solids, liquids, or gases dissolve in a gas. An example of a solid dissolving in a gas solution is when iodine (solute) dissolves in air (solvent) to make iodine vapor. When water (solute) dissolves in air (solvent) through the process of evaporation to make water vapor, this is an instance where liquid dissolves into a gas solution. Gas dissolves in a gas to make a solution when nitrogen, oxygen, and other gases mix together to form the air that we breathe. Air is a solution (a mixture, not a compound) because each type of gas in air keeps its own properties.

Solid solutions are formed when solids, liquids, or gases dissolve in a solid. Many metal alloys (such as steel, sterling silver, brass, and bronze) are mixtures of solids forming solid solutions. The metals are dissolved into each other at high temperatures, when the metals are in a liquid state, and then they revert to their solid state once they have cooled. Although it may look like a new substance, the elements retain their original chemical properties and they can be separated again by physical means (melting).

Solubility, Concentration, and Saturation

Some substances dissolve completely in another substance, such as salt or sugar dissolving in water to make a solution. This means sugar and salt are ***soluble*** in water. Some substances are not soluble in water. For example, if you put some sand in water, it would not dissolve. Sand is ***insoluble*** in water, so you can make a mixture of sand and water but you cannot make a solution.

What is happening to the molecules in a mixture that is a solution? The solute is broken down by the solvent into pieces the size of molecules. That is why liquid solutions are transparent. The particles of the solute are so small that you can't see them, and all you can see is the solvent. When you make a solution by dissolving salt in water, the water breaks the salt down into pieces the size of molecules.

Solutions are always ***homogeneous***, meaning that the solution is consistent or uniform throughout. The solution is mixed very well so each part of the liquid is the same as every other part. Mixtures can be homogeneous or ***heterogeneous*** (not the same throughout), but to be a solution, the mixture must be homogeneous.

To understand the term *homogeneous*, think of mixing paints. When you first start to mix blue and yellow paints you can see bits of yellow paint, bits of blue paint, and bits of green paint. As you keep mixing though, eventually the paint becomes thoroughly mixed and the same throughout. Now all you see is green, and the mixture is now homogeneous. The blue and yellow have been mixed up completely to make the same green throughout.

If you dissolve one teaspoon of sugar or honey in a cup of tea, your drink becomes somewhat sweet. If it isn't sweet enough for your taste, you add more sugar or honey to make it sweeter. As you add more sweetener, your solution becomes more ***concentrated***. A concentrated solution has a large amount of solute dissolved in it. A ***dilute*** solution has a small amount of solute dissolved in it.

If you were to keep adding more and more sugar to the tea, would there ever be a point when you had added so much sugar that it could no longer dissolve? Yes! When a solution is so concentrated that it cannot dissolve any more of the solute it is ***saturated***. A solution that can still dissolve solute is called ***unsaturated***.

Temperature can affect the saturation point of a solution. Usually liquid solutions that are warm or hot can dissolve more of the solute than solvents that are cool or cold. The amount of a solute that can be dissolved in a solvent is called its ***solubility***. The solubility of a solid generally goes up with the temperature of the solvent. However, the opposite is true when you try to dissolve a gas in water. The solubility of a gas in liquid increases as the temperature of the liquid goes down.

Solutions, Colloids, and Suspensions

There are three main types of mixtures. The size of the particles determines what type of mixture it is. In a solution, the particles are broken down or dissolved by the solvent into the size of molecules. The molecules are evenly mixed together so that the substance is homogeneous and clear.

In mixtures that are not solutions, the substances break down into smaller pieces but not to the size of molecules. Think of mixing clay with water. You can stir the clay around and around until you get a liquid. The clay has been broken down into smaller pieces than you started with, but the liquid is not clear. You can see little pieces of clay floating around. The clay has not been broken down into pieces the size of molecules and the mixture is not a solution.

In a ***suspension***, you can easily see particles of the components floating around. When you mix dirt with water, or shake up a salad dressing, or see dust particles floating in the air, you are looking at a suspension. A pot of vegetable soup is another example of a suspension. There are particles of one thing (vegetables) suspended in another (broth), so the substance is heterogeneous, not homogeneous. If the suspension is allowed to rest, the particles will either float to the top or sink to the bottom.

In a ***colloid***, a substance is broken down into microscopic particles so it can mix well with another substance, but the particles are insoluble. This means they won't dissolve but they remain suspended. Whipped cream and Jell-O are examples of colloids.

How can you tell the difference between a colloid and a solution or suspension? One difference between a colloid and a solution is that a colloid involves insoluble materials and a solution involves soluble materials; another difference is that it is hard to see through a colloidal mixture but a solution is clear. One difference between a colloid and a suspension is that a colloid involves microscopic particles and a suspension involves particles that can be seen without a microscope; another difference is that a suspension is heterogeneous and will "settle" into its component parts and a colloid is often homogeneous and will not separate into its parts.

Separating Mixtures

Compounds are the result of chemical reactions causing different elements or molecules to bond. Compounds form new substances that have different properties than the original components, and they cannot be separated except by chemical means—you have to actually break the chemical bond. Once different elements or molecules are chemically joined into a compound, every molecule of that compound is identical. The different elements and molecules that went into the compound have been transformed into something new.

Mixtures are different than compounds because when different substances are mixed together, the molecules in the mixture are not all alike. This means they can be physically separated again. Mixtures do not have chemical formulas, nor do they have definite chemical compositions, because they consist of so many different molecules. Since the component molecules still retain their original properties, the substances in a mixture can be separated by physical means.

Here's an example: Imagine you were to prepare a mixture of salt and pepper. The properties of the salt and pepper are not changed by being next to each other in the mixture. You could actually separate them again—if you had a lot of time and patience! If you picked out a grain of salt and a grain of pepper and ate them, they would still taste just like they did before you mixed them. To make a mixture of salt and pepper, you don't need to use a specific amount of salt and a specific amount of pepper. You can use however much of each as you like. Some of the molecules in your mixture will be salt molecules and some will be pepper molecules. The molecules are not all alike so mixing them together did not create a compound.

Compounds can only be separated by chemical means, but mixtures can be separated by physical means. How a mixture can be separated depends on its properties. The size of the particles in the mixture, its density, or its boiling point are properties that affect how something can be separated into its component parts. Separation techniques include filtering, flotation and sedimentation (particles float to the top or sink to the bottom), evaporation, using a magnet, and using a strong rotational force, like a centrifuge. There are many reasons for wanting to separate a mixture into its components. For instance, taking the salt out of seawater transforms it into drinkable water. Separating a blood sample into its parts can help doctors determine a person's health.

Lesson 7 Temperature and Pressure

ASSIGNMENT SUMMARY

- ☐ Complete the reading selections.
- ☐ Experience and explain the concept of thermal transfer.
- ☐ Apply knowledge of convection currents to weather.
- ☐ Research why popcorn pops.
- ☐ Predict how a change in water properties would affect aquatic life.
- ☐ Calculate metric temperature conversions.
- ☐ Lab Investigation: Insulators and Conductors
- ☐ Lab Investigation: Thermal Expansion and Contraction of a Gas
- ☐ Lab Investigation: Water Depth and Pressure
- ☐ Optional activity: Sensing Temperature
- ☐ Complete lesson 7 test.

MATERIALS

☐ Lab Investigation: Insulators and Conductors

ice cubes

2 metal baking pans

2 ceramic plates

2 paper towels

☐ Lab Investigation: Thermal Expansion and Contraction of a Gas

glass bottle (such as a soda or juice bottle)

cooking pot

small balloon

☐ Lab Investigation: Water Depth and Pressure

small can (such as a soup can)

large can (such as a large juice can)

can opener

hammer

nail

ruler

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Learning Objectives

At the end of this lesson you will be able to:

- Explain thermal transfer and equilibrium.
- Identify thermal conductors and insulators.
- Perform metric temperature conversions.

Reading

Read the following sections (found in Reading Selections at the end of this lesson).

- Thermal Energy and Heat Transfer
- Conduction, Convection, and Radiation
- Conductors and Insulators
- Thermal Expansion and Contraction
- Special Properties of Water
- Temperature as a Measurement of Thermal Energy
- Increasing and Decreasing Pressure

Assignments

1. With bare feet, stand with one foot on a rug, and the other foot on a tile, linoleum, or wood floor. Which one feels colder? Which one is really colder? Explain what is going on.
2. Land masses heat up and cool down faster than bodies of water. When land heats up (by the sun's radiation), the heat travels by conduction to the air above the land, which then moves by convection. Knowing this, if you are near the ocean on a sunny day, which way will the breeze be blowing, toward the shore (onshore breeze) or away from the shore toward the water (offshore breeze)? Which way will it be blowing in the middle of the night? Why?
3. What causes popcorn to pop? Research popcorn and find out how it relates to this lesson. Write a brief explanation or draw a diagram showing what happens when popcorn kernels pop.
4. Think about the fact that water is most dense at 4°C, and ice is much less dense than water. What would happen to a lake or a pond in the winter (in a cold climate) if this wasn't the case? What if the solid form (ice) was more dense than liquid water? How would this affect the life in the lake?

5. Complete the following conversion:
   a. Convert the following Fahrenheit temperatures to Celsius (you may use a calculator):
      - 98.6°F (normal body temperature)
      - 68°F (room temperature)
      - 23°F (a cold day)
   b. Convert the following Celsius temperatures to Fahrenheit:
      - 10°C
      - 35°C
      - –40°C (that's cold!)

Lab Investigation

Complete the following lab investigations (found in the lab manual).

- **Lab Investigation: Insulators and Conductors**
- **Lab Investigation: Thermal Expansion and Contraction of a Gas**
- **Lab Investigation: Water Depth and Pressure**

Read the instructions carefully and assemble all your materials before you begin. Use good scientific habits by taking careful observations and measurements, recording your data in an organized way, and using precise, detailed language.

Activities

This optional activity explores the concept of heat transfer.

Activity: Sensing Temperature

Try this experiment to see how reliable your hands are for determining temperature. You will need three bowls of water: one hot, one cold, and one lukewarm.

1. Put your right hand in the hot water and your left hand in the cold water. Hold them in the water for several seconds.
2. Take your right hand out of the hot water and put it in the lukewarm water. How does it feel?
3. Take your right hand out and put your left hand in the lukewarm water. How does it feel?
4. Put your right hand back in the hot water and your left hand back in the cold water, leaving each hand in the water for several seconds.

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5. Now quickly put the right hand in the cold water and the left hand in the hot water (switching places). How do they feel?
6. Record your observations and write an explanation. How does the change in speed of the molecules on your hands affect how they feel?

Test

Answer the following questions using scientific terminology and concepts in your responses.

1. Explain what is happening, in terms of heat transfer, when you take an ice cube out of the freezer and let it melt.
2. What is thermal equilibrium? Give an example that shows how this happens.
3. Explain each of the three ways that heat energy can be transferred.
4. What is the difference between a heat conductor and an insulator? Give an example of material that is a good conductor and material that is a good insulator.
5. Does insulation help keep your house warm or cool? Explain your answer.
6. Why do things expand as the temperature increases and contract when the temperature decreases?
7. Imagine you have two identical buckets of water. One is filled with liquid water and one is frozen solid into a block of ice. Which one would be heavier to carry? Why?

Learning Checklist

Use this learning checklist to track how your skills are developing over time and identify skills that need more work.

SKILLS	Developing	Consistent	Competent	Notes
Explain methods of thermal transfer				
Differentiate between thermal conductors and insulators				
Explain molecular activity related to thermal expansion and contraction				
Identify unique properties of water related to thermal expansion and contraction				
Perform calculations to convert between temperature units (C and F)				

FOR ENROLLED STUDENTS

Use the learning checklist to make a note of areas that need work and let your teacher know if you need help with the materials or lab investigations.

Reading Selections

Thermal Energy and Heat Transfer

We've been looking at the structure of molecules in matter, but molecules don't just sit still—they move! In fact, atoms and molecules are always moving. And when they move, they generate ***kinetic energy*** in the form of heat. Kinetic energy is the energy of motion.

When two or more things rub or move against each other, it causes ***friction***, which creates heat. The faster molecules of a substance move, the more ***heat energy*** it generates, and the warmer it becomes. All matter contains heat. Some things contain more heat than others, but everything contains heat because heat is energy in motion, and molecules are always in motion.

Heat energy (also called ***thermal energy***) moves through solids, liquids, and gases, and it always moves from a warm object to a cold object. The thermal energy keeps moving until the cold object is warmed up and the two objects are the same temperature. Heat flows spontaneously and constantly from an object of higher temperature to an object of lower temperature in a process called ***heat transfer***. Heat energy cannot flow from a cooler object to a warmer one.

Once two objects reach the same temperature, there is no more heat energy flowing between them. At this point, they are in ***thermal equilibrium***. For example, if you feel cold, you can snuggle up to someone else to get warm. The heat from that other person will flow into you until you are both the same temperature. Because of this, while you are warming up, the other person cools off until eventually you are the same temperature. So why doesn't your heat flow out of you, making you even colder and the other person warmer? It doesn't work that way because heat always flows from the warmer object to the cooler one. The heat would only flow out of you if you were the warmer object.

Conduction, Convection, and Radiation

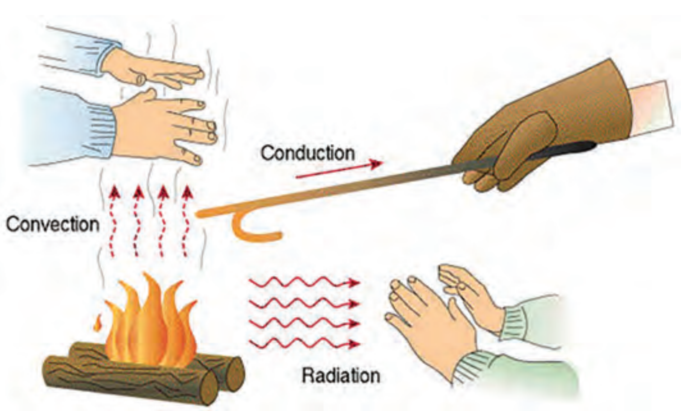
There are three ways that heat is transferred. Heat travels through metal and other solid objects by a process called ***conduction***. Think about heating some food on the stove using a metal or glass pan. One of the chemical properties of metallic elements is that they are good heat conductors. The stove heats the bottom of the pan, and the heat travels through the solid pan to reach the food, warming it up.

Conduction is the main way heat is transferred in solids. But how does it work? In the example above, the thermal energy from the stove is transferred to the molecules in the metal pan. The molecules in the pan vibrate back and forth faster and faster, causing more heat. Molecules nearest the heat source (the gas flame or electric burner) vibrate the fastest, bumping into those neighboring molecules, causing them to move faster. Those molecules in turn bump into other molecules, causing them to vibrate. In this way, kinetic energy is transferred from the faster, warmer molecules to the cooler ones with each collision. The heat energy is transferred in a pattern spreading outward from the hottest part of the pan. Eventually the thermal energy moves through the solid metal into the liquid in the pan or the air (gas) around it. Conduction is only really noticeable in solids where the molecules vibrate but can't move freely.

Another way that heat travels is through ***convection***. Convection occurs in fluids, which includes both gases and liquids. It cannot occur in solids because convection depends on all the molecules in a substance moving in a particular direction, not just vibrating back and forth (like they do in conduction). The rule behind it all is quite simple: things that are less dense rise and things that are more dense sink. When a liquid or gas warms up, the molecules move around more and more quickly. This causes the fluid to expand, which makes it less dense, so it rises.

As the warm fluid rises (because it is less dense), the cooler, denser fluid sinks. This motion of rising and falling produces a ***convection current***. You can see a convection current when you heat a pot of water on a stove. The water nearest the flame or the burner heats up, rises, and is replaced by cooler water that falls toward the base of the pot. The moving water creates currents. If you were to add a small amount of dye to the water, you would be able to see the circular movements of the convection currents. The currents continue until all the water is hot. Can you imagine how long it would take to heat a pot of water if we relied only on conduction for the heat transfer? The water nearest to the hot pan bottom would heat quickly while the water on top would take a very long time to warm up.

Another example of a convection current is found outside. Winds are the result of the unequal heating of air by the sun. The sun warms some areas of Earth more than others, depending on things like Earth's tilt, bodies of water, large land masses such as mountain ranges, ice or snow, and vegetation. The warm air rises and is replaced by sinking cooler air until all the air reaches the same temperature and ceases to continue to move and mix. Winds are the currents caused by this unequal heating. Convection currents have a strong influence on the weather. Have you ever seen hawks soaring along mountain ridges? They are riding on ***thermals***, which are convection currents of warm air that rise up the slope from the valley, which is heated by the sun. Hang gliders take advantage of these same thermals.



Heat is transferred through conduction, convection, and radiation. (Image credit: Kmedfiunit)

Radiation is the third type of heat transfer. Any warm object gives off ***infrared radiation***, also called ***heat radiation*** or ***thermal radiation***. "Warm," however, is a relative term; an ice cube is warmer than liquid nitrogen and so gives off more infrared radiation than the liquid nitrogen. Infrared radiation is a type of ***electromagnetic wave*** that is experienced by our bodies as heat (we'll look at electromagnetic waves in another lesson). Radiation travels along waves and can transfer heat even in the absence of solids or fluids (liquids or gases). Conduction and convection both need matter to work, but radiation can travel through matter as well as through the void of space. Imagining the heat radiating from a fire can help you understand thermal transfer by radiation. The sun, of course, is the best example of ***radiant energy***. Radiation does not rely on contact to transfer heat between the source and an object.

How can you identify the type of heat transfer?

- Conduction heat is transferred through a direct point of contact with a heat source (and is most obvious in solids).
- Convection heat is transferred through the movement of fluids (gases and liquids).
- Radiation heat is transferred by electromagnetic waves that travel outward even in the absence of matter.

Conductors and Insulators

Some solids transfer heat quickly and easily, making them good ***conductors*** of heat. Most metals are good conductors of heat, although some are better than others. For example, copper and silver are more efficient heat conductors than steel or iron.

Some materials do not transfer heat very well. They are poor conductors of heat and are called heat ***insulators***. If you hold the bottom part of a long, lighted candle, you do not feel much heat coming through to your fingers. Wax, wood, air, and paper are all poor conductors of heat and therefore good heat insulators.

There are many types of insulation designed for building construction and other uses. Some are more effective than others, and some have more environmental and health concerns to be aware of. For instance, fiberglass insulation is inexpensive and is effective, but there are serious health and environmental concerns associated with it. Cotton batts are more expensive and not as widely available, but they have the same rating as fiberglass and have a high percentage of recycled material. Polystyrene, a type of plastic, is easy to install but emits a toxic smoke when burned and debris from installation can end up in waterways. Each type of insulation has its advantages and drawbacks, so it is important to carefully select the right type of insulation for a particular project.

Insulation is measured in terms of its ***thermal resistance***, which is the resistance of a material to heat flow. You often hear it referred to as the ***R-value*** of the insulation. The higher the R-value, the better the insulation is. The recommended R-value of insulation depends on the location of the building, with buildings in colder regions needing higher R-value materials to retain heat in the cold months.

Insulation also works to keep a home cool when outside heat is excessive. This is because insulators don't transfer heat well—this means that heat that is inside stays inside (helpful when it is cold outside), and heat that is outside stays outside (helpful when it is hot outside).

Thermal Expansion and Contraction

The word *thermal* means related to heat. When objects are heated or cooled, they ***expand*** and ***contract***. When a solid, liquid, or gas is heated, its molecules move faster, bumping into each other as they move and causing the substance to spread out as it is heated. This is called ***expansion***. Different materials expand at different speeds and amounts. The amount of expansion depends on the composition of the material (what it is made of) and on how much the temperature increases.

Imagine you are standing in a group of tightly packed people. As long as everyone stands still, you can stand very close together. Imagine that music is played and everyone starts dancing—the movement will cause people to bump into one another and naturally spread out as they move. The dancing, moving group is less dense than the standing-still group because there is now more room in between people. This is how molecules act as they warm up: they start moving and bumping into one another, expanding outward.

You can't see expansion happening in a solid, but it is happening at the molecular level. Have you ever had difficulty opening a jar, and to make it easier you run the lid under hot water? This expands the lid, which loosens it. The glass jar doesn't expand as much because the metal lid is a better conductor of heat.

The expansion of a liquid is greater than the expansion of a solid. This is because molecules move differently depending on whether they are in a liquid, gas, or solid phase. Molecules in a solid cannot change position very easily while molecules in a liquid can change position and slide past each other, and molecules in a gas spread out evenly to fill the container they are in. The molecules in a solid are bound by the shape of the object, but the molecules in a liquid are free to move and take up all the space in the container they are in, and even spill over into the surrounding space. You can see this happening when a cooking pot boils over on the stove. A gas expands even more than a liquid when it is heated, completely filling its container, no matter how big it is.

Bridge expansion joints, like this one on the Harry Blaney Bridge in County Donegal, Ireland, allow for expansion and contraction of the asphalt and steel without damage to the bridge. (Image credit: Willie Duffin)

When matter cools, it contracts as the molecules slow down and move closer together.

As the molecules move closer together, the matter gets smaller and more dense. Materials contract at different speeds and different amounts and often this ***contraction*** is too small to see. Just like expansion, the amount of contraction depends on the composition of the material and on how much the temperature decreases.

Have you ever been told not to put a hot glass casserole dish or coffee pot into cold water because it might break? Or have you ever been told not to fill an ice-cold glass with boiling water because it might break? The glass would break because of thermal expansion and contraction. If one part of a piece of glass is heated or cooled more rapidly than the rest, the glass can crack or shatter. Special heat-resistant glass (such as "Pyrex") has been developed that contracts and expands very little with changes in temperature and this is what most cooking dishes are made of.

When you are walking down a sidewalk, you might notice places where it is cracked and uneven. This is often due to contraction in cold weather and expansion in hot weather. The concrete expands and stretches as it heats up, and small cracks form; when it cools down and contracts, these cracks get larger, forming bumps and uneven spots.

Special Properties of Water

Water is a unique substance that has specific and unusual properties. Just like all substances, water takes up the most space as a gas, and as it cools, it contracts. It becomes a liquid, and continues contracting as it cools, becoming more and more dense. But then a strange thing happens! At 4°C (39°F), it is at its densest point. As you continue cooling it from there, it starts expanding again! And when you get to the freezing point of 0°C (32°F), if it is still cooling, it freezes. In fact, when water freezes, it expands greatly. Ice is much less dense than water, which is why ice cubes float.

So why does this matter? This has huge significance! It is why road builders, especially in the north, are careful to build a gravel roadbed with good drainage under the road. If water is in or right under the pavement when it freezes, it causes cracks and "frost heaves" in the road. Those of you who live in northern climates are familiar with these huge uneven cracks in the pavement. The expansion of freezing water is a major force in weathering. A small amount of water in a crack in a rock can freeze and cause the whole rock to split open. If you have water pipes that freeze during a very cold winter, you have to worry about them breaking because of the expansion of the freezing water.

Temperature as a Measurement of Thermal Energy

Heat or thermal energy is an indication of how fast the molecules are moving in a substance. Temperature is a measure of how hot or cold a material is, but it is really a measure of the movement of molecules in matter.

As heat energy is added to a material, the material's temperature rises. As heat energy escapes from the material, the temperature of the material drops. The higher the temperature, the more rapid is the movement of the molecules in the matter, so the greater the space the molecules will occupy. Nearly all materials expand when their temperature is raised and contract when their temperature is lowered.

Temperature tells us what degree of heat is present in something (how much the molecules are moving), but it does not tell how much heat energy something contains. For instance, a cup of boiling water has a higher temperature than a tub of warm water, but a tub would contain more heat energy since it contains much more water. Heat energy is related to the quantity of the matter as well as the temperature.

Have you even wondered how thermometers measure temperature? When you put a thermometer into some material to measure its temperature, heat transfer occurs until the temperature of the tip of the thermometer is the same temperature as the material that is being measured. In a mercury thermometer, mercury is the element that is used to measure temperature because it expands as it heats and shrinks as it cools. Digital thermometers use electric current instead of mercury to measure temperature because the flow of electric current changes depending on the temperature. Once the thermometer and what it is touching are the same temperature, no more heat will flow between the two objects, and the temperature can be read.

The unit of measure for measuring temperature is ***degrees*** (°). Fahrenheit (F) and Celsius or centigrade (C) are the two systems most commonly used for measuring temperature. Whenever you read or write a temperature, it must always have a C or an F to show what scale is being used. Celsius is the metric scale and is used by most scientists.

Of course, water boils and freezes at the same temperature regardless of what scale is used to measure and describe the temperature. The freezing point of water is 0° Celsius (0°C) or 32° Fahrenheit (32°F); both of these numbers are describing the same actual temperature. The boiling point of water at sea level is 212°F or 100°C—both units indicate the same temperature.

Here are the simple formulas for converting units between Fahrenheit and Celsius.

To convert from Fahrenheit to Celsius, subtract 32 and divide by 1.8:

$$°C = (°F - 32) \div 1.8$$

To convert from Celsius to Fahrenheit, multiply by 1.8 and add 32:

$$°F = (°C \times 1.8) + 32$$

Increasing and Decreasing Pressure

Pressure is force exerted on an object. When you stand on one foot, you exert more pressure on the ground underneath than when you stand with two feet. This is because when you stand on one foot, your entire body weight is pushed into the ground through the area of one foot; when you stand on two feet, the same weight is pushed into the ground through an area twice as large (two feet). Pressure is a force that depends on the area of contact.

The pressure of a liquid does not depend on the volume (amount) of the liquid, but rather on the depth of the liquid. For example, the water pressure at one meter beneath the surface of a swimming pool is the same as the pressure at one meter beneath the surface of the Pacific Ocean. The size of the "container" doesn't matter—swimming pool or ocean—the depth is the influential factor. The greater the depth of the liquid, the greater the pressure. As you dive deeper in a pool or lake, you can feel the pressure of the water around you increasing. Engineers who build dams need to take this carefully into account. The deeper the water is behind the dam, the more pressure there will be on the dam.

A gas exerts pressure in all directions on its container. In a gas, the molecules are far apart and in constant motion. A gas always fills up the container it is in because the molecules will get farther and farther apart from each other in order to fill the available space. However, the number of molecules in a gas does not change as it fills up the container it is in. The amount of pressure that the gas exerts is related to how many molecules of gas are in the container. The more molecules, the higher the pressure.

Imagine you are filling a bicycle tire with air (a gas). If you double the amount of air inside, you are doubling the number of molecules while the available volume (the size of the inner tube) remains the same. The tire will feel harder as you increase the pressure because the gas is pushing on it from the inside. This is one way to change pressure; you are increasing the pressure of the gas by adding more gas to the container.

Another way to increase the pressure of a gas is to decrease the size of the container and keep the same amount of gas molecules inside. If we reduce the size of the container by half and the amount of gas (the number of molecules) inside is unchanged, the amount of pressure exerted on the walls of the container will double.

If you have a certain amount of gas (a certain number of molecules) and you keep the temperature consistent, increasing the volume of the container size will decrease the pressure, and decreasing the volume of the container will increase the pressure. This is because the pressure and volume of gas at a stable temperature are ***inversely proportional***. This means that when you increase the volume of a gas, the pressure will decrease a corresponding amount. An inverse relationship between two things means that if one gets bigger, the other gets smaller. When you decrease the volume of the gas, the pressure will increase a corresponding amount. Any change in one will cause an inverse or opposite change in the other.

The amount of pressure impacts the solubility of gas. When a gas solute dissolves into a liquid solvent, it creates a solution. Generally, as pressure increases, the amount of a gas that is soluble in a liquid will also increase. Pressure affects the solubility of gases because if pressure on a gas is increased, more molecules of the gas will enter or dissolve in the liquid.

For example, examine a bottle of soda from the outside. Look at the liquid before you open the bottle. You will not see very many bubbles, if any. The closed bottle is keeping the solution of soda and gas at a high pressure. This high pressure makes the gas soluble in the soda solution. But as soon as you open the bottle and release the pressure, the gas molecules start to come out of the solution. Bubbles form, rise to the surface of the liquid, and leave the solution, escaping into the air. The solubility decreases as the gas pressure goes down, making the soda "flat."

We all have pressure on our bodies at all times. This is known as ***atmospheric pressure***, and it is about 14.7 pounds per square inch. This seems like a lot but compare it to the pressure at 10,000 feet below sea level, where it is 4,400 pounds per square inch! Atmospheric pressure is caused by the weight of the atmosphere, so as you go up in elevation, it decreases. The air is less dense and the molecules are farther apart the higher you go. This is why airplanes need to have pressurized cabins, and it is also why there is less oxygen at high altitudes, such as at the top of high mountains.

Gabriel Daniel Fahrenheit (1686–1736)
German Physicist

Gabriel Daniel Fahrenheit devoted himself to studying physics and manufacturing precision meteorological instruments. Fahrenheit discovered that water can remain liquid below its freezing point and that the boiling temperature of liquids varies with atmospheric pressure. His invention of the alcohol thermometer emerged from these discoveries, for which he developed the Fahrenheit thermometric scale. He is also credited with inventing the first mercury thermometer.

Anders Celsius (1701–1744)
Swedish Astronomer

Known for his invention of the Celsius thermometer (also called centigrade), Anders Celsius was actually an astronomer. His development of the Celsius temperature scale took 0° as the freezing point of water and 100° for the boiling point. The scale is also called *centigrade* because of the 100-degree interval used between the two points (*centi-* = hundred).

Robert Boyle (1627–1691)
British Chemist, Natural Philosopher

Boyle was a pioneer in experiments on the properties of gases and the "corpuscular" view of matter, which was the forerunner of the modern theory of chemical elements. Boyle collaborated with Robert Hooke in constructing an air pump he used to perform experiments that led to Boyle's Law, which states that "at constant temperature, the volume of a gas is inversely proportional to its pressure." Boyle continued his experiments with air, vacuums, metals, combustion, and sound. His experimental approach did much to advance the practice of the modern scientific method.