TEAMS
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The Most Amazing Molecule - Teacher Notes

INTRODUCTION

If you ask your students what they think is the most amazing molecule on Earth, they're unlikely to say "water". But this simple molecule has a host of properties that make it vital for living things and for supporting the natural systems that provide conditions on our planet that are conducive to life. In this exercise, students will examine the physical and chemical properties of water with a hands-on activity for students and a teacher-led demonstration that introduces students to this "most amazing molecule".

OBJECTIVES

The students will investigate and explain why water is such a vital and versatile molecule that supports living things.

The students will explain the how the unique properties of water are related to the attractive forces between water molecules.

SCIENCE STANDARDS

National Science Standard:
Students will know, understand, and use the properties of common objects and materials

Georgia Performance Standards:
S2P1 Students will investigate the properties of matter and the changes that occur in objects.
S4E3 Students will differentiate between the states of water and how they relate to the water cycle and weather.

SCIENCE REFRESHER

Let's take a look at water, that most common of molecules, to see how this simple pairing of oxygen and hydrogen is the single most important molecule to life on our planet.

The molecular structure of water

Water is comprised of two hydrogen atoms bonded to a single oxygen atom, represented by the molecular formula "H_2O". The hydrogen atoms and oxygen atoms "share" electrons, resulting in covalent bond that holds the atoms together to form a water molecule. The sharing of electrons is not equal, however, as the oxygen atom exerts a stronger "pull" on the shared electrons than does the hydrogen atom. The electrons therefore spend more time near the oxygen atom than the hydrogen atom. This causes a water molecule to have a slight negative charge on the part of the molecule near the oxygen atom (where the negatively charged electrons spends more time), and a slight positive charge on the portions near each hydrogen atom (where the negatively charged electron spends less time). Water is therefore described as a **polar molecule** because it attains different charges on different parts of the molecule (Figure 1).

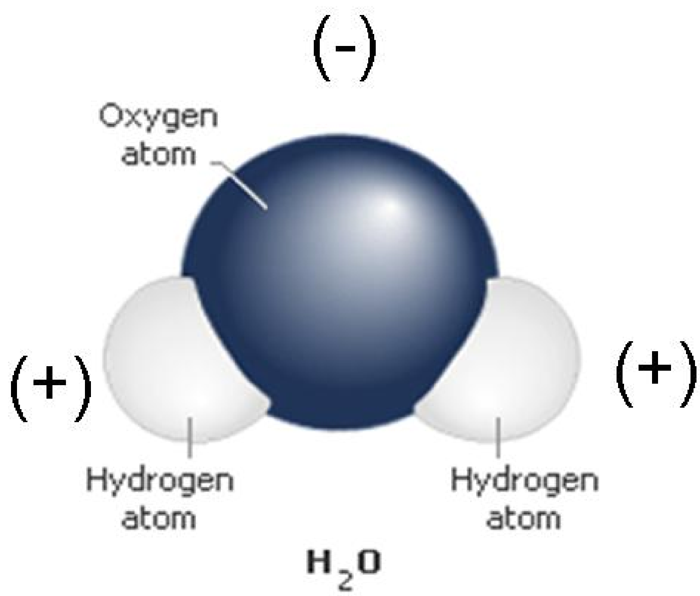


Figure 1. A water molecule's orientation gives one portion of the molecule a slightly negative charge and other portions a slightly positive charge.
[http://encarta.msn.com/media_461517886_761573158_-1_1/Water_Molecule.html]

Water's chemical structure enables it to bond with many molecules
The positive portion of one water molecule and the negative portion of another water molecule can come together to form a **hydrogen bond** between the two molecules due to the attraction of the slight negative charge by the oxygen atom and the slight positive charge by the hydrogen atoms (Figure 2). Numerous water molecules can bond to one another with hydrogen bonds and form a lattice of many interconnected molecules as unlike electrical charges attract one another and like electrical charges repulse one another. As we will see, most of water's properties derive from this manner of bonding.

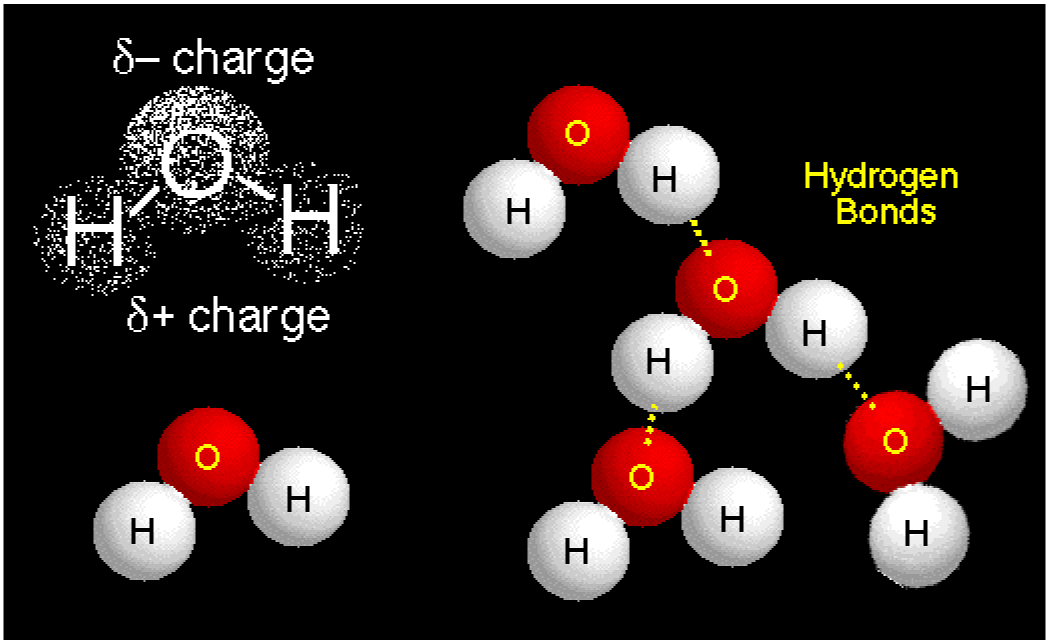


Figure 2. Water molecules bind with one another and other molecules due to the electrostatic attraction between areas of opposite charge.
[http://www.sp.uconn.edu/~terry/images/mols/atomfig5.html]

Water has high surface tension due to hydrogen bonding

When water molecules bind with one another with hydrogen bonds, it creates a lattice of interconnected molecules of surprising strength and flexibility. This gives water a high **surface tension**, and enables water striders and other insects to walk across the surface of a puddle or pond and support themselves on the strength of the water's surface tension (Figure 3).

Water's high surface tension also allows water to go from the roots of a tree to its highest branches, sometimes hundreds of feet. As the water is drawn up through narrow, specialized "tubes" within the tree, the attractive forces bind the water molecules to each other and to walls of the tube, allowing it to overcome the downward pull of gravity.

Your students will investigate water's surface tension in this activity's hands-on exercise. Students will fill a glass to rim with water and then add pennies to the cup in an attempt to make it overflow. Doing so will require a surprising number of pennies, however, as water's strong surface tension enables to water to rise *above* the rim of the glass and yet not immediately overflow.

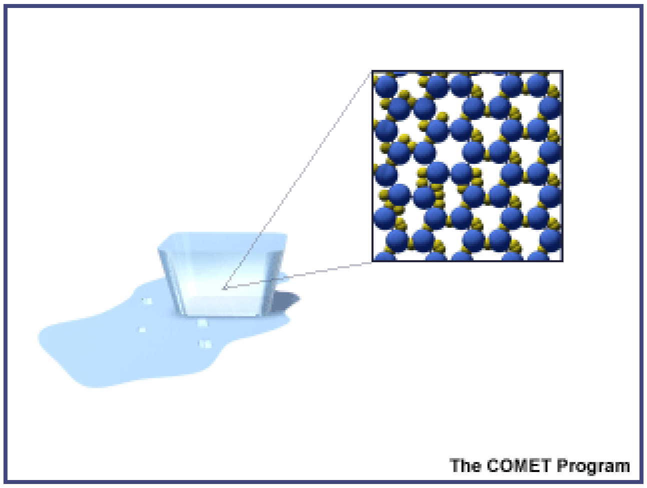
Figure 3. The strong surface tension of water enables water striders to walk on the surface of puddles and ponds.
[http://www.worsleyschool.net/science/files/waterstrider/pic03.jpg]

Water's phases are related to hydrogen bonding

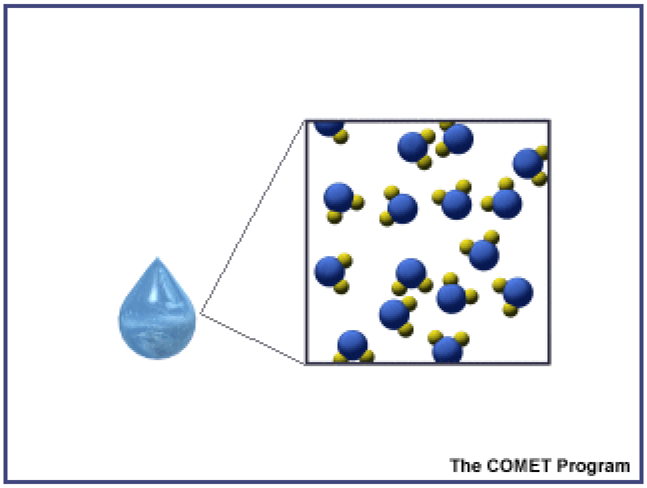
Water exists as a solid, liquid, and gas depending on temperature, which affects how water molecules bind together. When temperatures are low, water molecules have little energy and form a structured lattice of bonded molecules – ice. As this solid form of water has air spaces between molecules, it is less dense than liquid water and floats on the surface of liquid water (Figure 4a).

As water warms, the molecules attain more energy and move around. They rapidly form and break bonds with other molecules, resulting in the fluid properties of liquid water (Figure 4b).

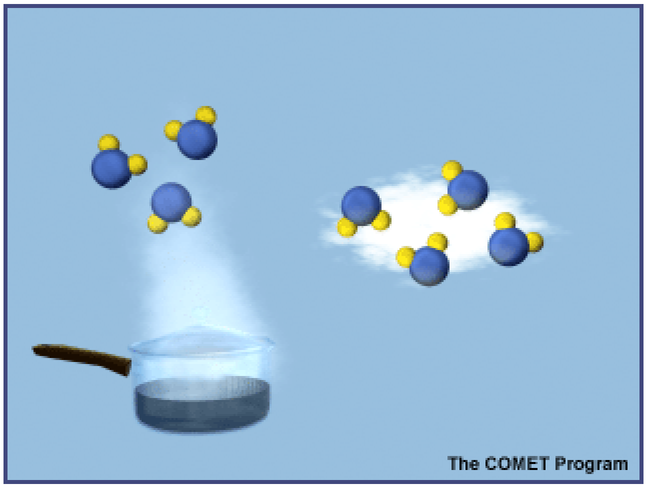
Water molecules have much higher energy at higher temperatures and escape into the atmosphere as a gas – water vapor. This vapor is invisible, but can be seen in clouds when gaseous water and small particles scatter light (Figure 4c).



(a.) Water molecules in ice form a rigid lattice.



(b.) Water molecules bind less rigidly in liquid water.



(c.) Water molecules can escape into the air as water vapor.

Figure 4. The phases of water are related to hydrogen-bonding patterns.
[http://www.ucar.edu/learn/1_1_2_3t.htm]

	**Additional Resources – Activity: The Phases of Water** http://www.ucar.edu/learn/1_1_2_3t.htm A class activity on the phases of water from the University Corporation for Atmospheric Research. Designed for grades 6-9 but easily adaptable to younger age groups. The site also contains a number of class activities on other science topics related to atmosphere.

Water as the "universal solvent"
Water's polar properties enable it to dissolve a wide range of substances. Water can bind to positively and negatively charged particles (called **ions**), or portions of molecules that contain a charge. Table salt (NaCl), for example, dissolves in water when the positively-charged sodium (Na) ions are surrounded by water molecules oriented towards the negatively-charged oxygen atom (Figure 5). The negatively-charged chloride (Cl) ion dissolves when it is surrounded by water molecules, oriented towards the positively-charged hydrogen atoms.

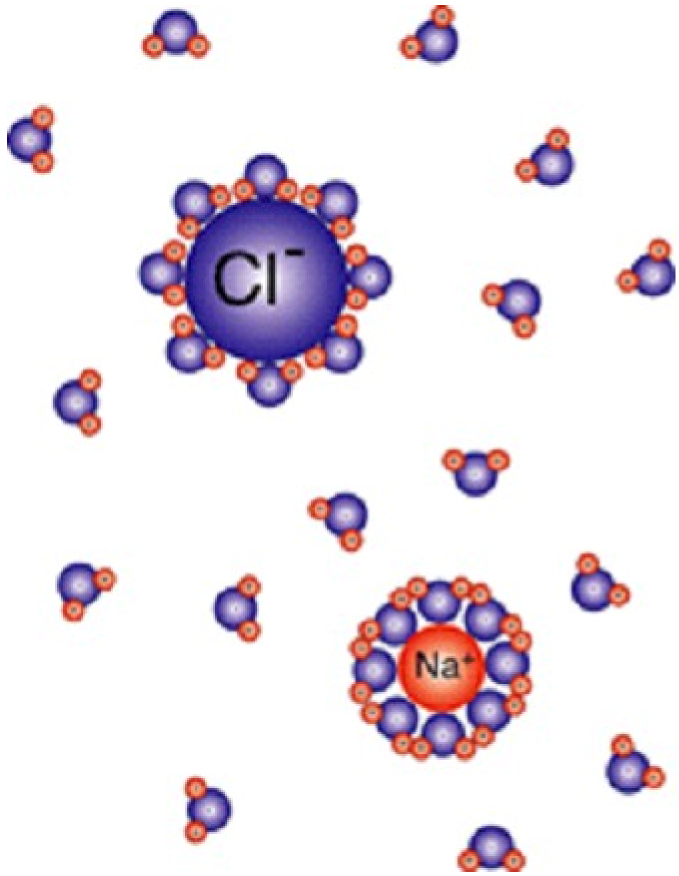


Figure 5. Water molecules dissolve substances, such as the ions in table salt (sodium chloride), by forming hydrogen bonds with the substance. Note that the water molecules orient differently depending on the charge of the substance.
[http://alford.bios.uic.edu/teaching%20pages/membrane%20potential.html]

This property makes water an excellent conveyor of substances - in oceans, in rivers, and in the tissues of organisms. Take the human body, for example. The water in your blood dissolves and transports many different compounds throughout your body. Oxygen is carried from your lungs to cells throughout your body, nutrients are carried from the intestines to cells, carbon dioxide is transported from cells to your lungs, and waste products are moved to the kidneys where they are excreted. If these substances were not able to dissolve in water, they could not be transported within the circulatory system, and our bodies would have a difficult time moving materials throughout our bodies. Similarly, the water in rivers and the ocean acts to dissolve, dilute, and transport nutrients and pollutants.

Gases, like solids, can also dissolve in water. The gases form very small bubbles and become trapped between bonded water molecules. Fish and other organisms are able to breathe oxygen dissolved in water using gills adapted for this purpose, but as we humans lack such a structure we asphyxiate in water, even though oxygen is dissolved in the water.

The bubbles of carbon dioxide in soda are similarly dissolved in liquid and are released quickly when the bottle is shaken or warms, both of which break bonds between water molecules and liberate trapped gas bubbles. In this activity's demonstration, Mentos candies are dropped into a 2-liter soda, resulting in a geyser of soda – by now, you've undoubtedly seen numerous videos on the web demonstrating this. This reaction occurs because chemicals in the candy rapidly break hydrogen bonds between water molecules in the soda and liberate huge numbers of carbon dioxide bubbles all at once – causing an eruption of soda many feet into the air.

Water is vital for life on Earth

Water is ubiquitous on Earth – it's in the oceans, rivers, lakes, below the ground, and in the atmosphere. Life depends on water, so it shouldn't be surprising that wet habitats, such as tropical rainforests, are simply teeming with life while arid habitats, such as deserts, support far less organisms. This shouldn't be surprising, given that water comprises anywhere from one-half to two-thirds of a typical organism's weight and plays key roles in a host of vital biochemical reactions. Water is the liquid in blood and allows compounds to circulate throughout an organism's body. It cools creatures when it evaporates from skin or other issues, and it forms the basis of the fluids inside the cells of every living thing – providing structural support and transporting materials within cells.

Water helps to minimize fluctuations in temperature

It takes a lot of energy to break apart bonded water molecules so water occurs as a liquid over a wide range of temperatures. The amount of energy needed to change the temperature of a substance is described by its **heat capacity**. If a substance requires large inputs of energy to change temperature, it will have a high heat capacity. If a substance changes temperature easily, its heat capacity will be low. Water has high heat capacity and is a useful buffer against rapid temperature changes. This is why we use water in a vehicle's radiator to prevent the engine from overheating. The large amount of water in living things serves a similar purpose and helps to maintain more constant internal body temperatures when air temperatures around the organism are extreme.

Water helps regulate Earth's climate and cools organisms through sweating

When water does change from a liquid to a vapor, it takes with it large amounts of heat that is later released when it becomes liquid again. This property helps to distribute heat throughout Earth, as water is warmed at the equator, evaporates, and releases heat at higher latitudes through precipitation. It also helps to cool organisms when they become overheated. When humans sweat, the water evaporating from the skin cools the tissues and helps to reduce elevated temperatures inside the body and return it to normal ranges of internal body temperatures.

Water keeps chemical conditions inside cells more stable

Additionally, water can serve as a chemical buffer to changes in pH. If the internal environments of cells become too acidic or too basic, biochemical reactions will become less efficient and the cell will suffer. The water inside cells helps prevent pH changes because it can dissociate to form hydrogen ions (H^+) which lower solution pH (make it more acidic) and hydroxide ions (OH^-) which raise solution pH (make it more basic).

MATERIALS – HANDS-ON ACTIVITY (Per student group)

1 16 oz. clear plastic cup	Must be clear to show students accumulating coins
Approximately 50-60 pennies	Added incrementally to cup until overflow occurs
20 oz. room temperature water	For filling plastic cup
Molecular models	For demonstrating molecular structure of water and bonding patterns. Models are commonly available at educational supply stores, including online vendors like those below (in each, enter "molecular models" in search box). Molecular models can also be easily created using inexpensive Styrofoam kits available at craft stores. Ward's Scientific http://www.wardsci.com/ Educational Innovations, Inc. http://www.teachersource.com/

CONSTRUCTION AND MATERIALS – AMAZING MENTOS

2-liter bottle of carbonated soda	Any variety is acceptable
3-4 Mentos candies	For insertion into 2 liter bottle
1 large paper clip	Holds Mentos prior to insertion into bottle
Soda cap with $^1/_4$ " hole in center	

Constructing the Mentos Delivery Apparatus

1. Drill a ¼" hole the center of a plastic cap for a 2 liter soda bottle.
2. Unwind a large paper clip as shown in Figure x.
3. Impale 3-4 Mentos candies onto the "hook" of the paper clip (Figure x).

EXPLORATION (Teacher-led):

Preparation

Begin the activity by asking your students which molecule they feel is the most amazing in the world today. You will likely get a multitude of responses, including molecules such as carbon dioxide, liquid nitrogen, and hydrochloric acid (to name but a few). Your students will then be surprised to hear your choice for the most amazing molecule – water. The activities described below will enable students to see water's amazing properties firsthand, and engage their interest in the molecular properties of water following these captivating exercises.

Procedure – Hands-on Activity (Pennies and Surface Tension)

Each student group is supplied with a clear plastic cup, room-temperature water to fill it, and around 50-60 pennies.

1. The students fill the cup with water until the water level is equal to the rim of the cup without overflowing.
2. Have the students view the water level from the side and ensure it is at or slightly above the rim.
3. Students predict the number of pennies they can add to the cup before causing it to overflow and record their prediction.
4. Pennies must be added carefully to the cup to minimize wave generation. Break the surface of the water with the penny and then release it, minimizing the vibrations to the cup.
5. Stop every 5 pennies and observe the water level from the side.
6. Stop adding pennies once the cup overflows and record results.

Guiding Questions:

1. How many pennies do you think are needed to cause the cup to overflow?
2. How accurate was your prediction? Were you surprised by your results?
3. Why do think you were able to add so many pennies?

Explanation (Concept Building)

After all groups have completed the activity, reconvene the class to share and discuss results. List the number of pennies for each group on the board to see the maximum and minimum values. Calculate statistics, such as the mean for all the groups, to integrate mathematical concepts into the activity and show the usefulness of such statistics.

Ask the students if they were surprised by their findings and solicit explanations for what they observed. Students often suggest that the water somehow "stuck" to the sides of the cup or to the water in the cup as it domed larger and larger with the addition of more pennies. Build on this observation and introduce students to the concept of surface tension. This surface tension was created by the bonding of water molecules in the cup with one another and was, up until a point, stronger than the force of gravity that was pulling the water downwards. Once that point was reached, however, the force of gravity exceeded the surface tension, causing the water to overflow. Use "ball and stick" molecular models to demonstrate interactions between water molecules, if you desire.

Once the core concepts have been presented, ask students to advance explanations for the variations in results between students groups. Variations in the number of pennies needed for overflow usually are related to (1.) slight but significant variations in the initial water level in the cup and (2.) the amount of disturbance when pennies are added. Overflow will occur with fewer pennies when the initial fill level is high and disturbances from penny addition are substantial.

Procedure – Mentos and Soda Demonstration

1. Show the students a 2 liter soda bottle and ask them to list the components of a typical soda. Students will give answers such as sugar (or artificial sweetener if a diet cola), water, artificial colors, and carbonation.
2. Focus the students on the carbonation and explain how very tiny bubbles of carbon dioxide are trapped in the soda between water molecules. Emphasize that gases, like solids, can be dissolved in water.
3. Show them the Mentos candies and inform them that Mentos contains a chemical that breaks apart the bonds that hold water molecules together – essentially breaking apart the surface tension examined in the previous exercise.
4. Have the students predict what will happen to the soda if the Mentos are added to the bottle. As many students have seen Internet video of Mentos and soda reactions, you are likely to quickly get an accurate prediction.
5. Test the prediction by taking the students outside to an open area.
6. Take the cap off the soda bottle, place it on the ground, and move the students back a safe distance (6-8 feet or so).
7. Thread the paper clip with attached Mentos candies up through the drilled hole in your modified bottle cap. The Mentos will now be hanging, like bait on a fishing hook, underneath the cap. Pull the paper clip upwards so the Mentos are snug against the bottom of the cap.
8. While holding firmly onto the paper clip at the top, screw the lid onto the bottle of soda, making sure the Mentos candies do not touch the soda in the bottle. Ensure that the cap is screwed on tight.
9. Ensure that all students are a safe distance back and then release then paper clip. The paper clip, weighted down with Mentos, will sink to the bottom of the bottle and instantaneously begin the reaction.
10. Move quickly away from the bottle. A geyser of soda will stream 10-20 feet into the air through the narrow opening in the bottle cap. As seen in the “Activity in Action” clip provided with this module, some children will wish to run into the stream of falling soda and can become somewhat messy – you have been warned.
11. Repeat the demonstration if you desire and then return to class with all materials.

Additional Resources – Extreme Mentos/Soda Online Videos
http://eepybird.com
The folks at Eepybird have created some magnificent shows utilizing with Mentos and soda. Check out their collection of videos of various experiments and share them with your students in class once they’ve seen the real thing in person.

Essential Questions

1. Explain why this reaction occurred based on your knowledge of water’s chemical properties.
2. Do you think that this reaction would work with a drink like Gatorade? Explain your thinking.
3. In your own words, write a paragraph to explain why you think water is really a most amazing molecule.

Safety and Disposal
There are no hazardous materials in this exercise. Teachers can emphasize safety, however, by wearing protective eyewear during the Mentos demonstration and only conducting it outside.

Explanation (Concept Building)
Here are the key concepts that should be emphasized in this lesson:

1) Water is comprised of two hydrogen atoms bonded to a single oxygen atom, represented by the molecular formula “H_2O”. Water is described as a **polar molecule** because parts of it have a positive charge and parts of it have a negative charge.

2) Water molecules attract to each other quite strongly. The attraction of these molecules to each other gives water a high **surface tension**. This tension allows water striders and other insects to walk across the surface of a puddle or pond and support themselves on the strength of the water’s surface tension.

3) Water’s polar properties enable it to dissolve a wide range of substances. This property makes water an excellent transporter of substances - in oceans, in rivers, and in the tissues of organisms. Take the human body, for example. The water in your blood dissolves and transports many different compounds throughout your body.

Extension Activities:

Compare # pennies needed to overflow in hands-on exercise with regular water and with water with addition of crushed Mentos (to weaken surface tension). Assign half of groups to one category, half to other. Calculate average for each treatment and graph to compare.

Compare Mentos/soda reactions with diet versus regular soda, colas versus clear sodas, differing brands of same soda, etc. Need to design method for measuring reaction (such as maximum geyser height), which could stimulate student creativity.