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IN THE COLLEGE PREP CHEMISTRY CLASSROOM

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THE EDUCATIONAL VALUE OF CHEMICAL DEMONSTRATIONS IN THE COLLEGE PREP CHEMISTRY CLASSROOM

By

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ABSTRACT

THE EDUCATIONAL VALUE OF CHEMICAL DEMONSTRATIONS
IN THE COLLEGE PREP CHEMISTRY CLASSROOM

By

Katherine E. Hagerman

The educational value of chemical demonstrations in a college prep chemistry classroom was tested to determine whether or not demonstrations merit the required time and resources. Students were divided into three test groups, each of which used a different engagement method for the presentation of the demonstrations. One group was given materials specific to the demonstration to help guide them through the process of prediction, discussion and application of observations. The second group was given the same generic worksheet for each demonstration. The third group was not given any supplemental materials. Assessment data for the three groups was collected from pretest, posttest and survey questions. The data set was analyzed and compared to a control group of students who did not see demonstrations. Students who had a higher level of engagement during the demonstration process performed better than the control group.

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INTRODUCTION

Statement of Problem and Rationale

A typical high school chemistry teacher uses a variety of techniques to introduce students to the world of chemistry. Laboratory activities, lecture, discussions and demonstrations are all typically employed to help students learn chemical concepts. Chemistry is a unique subject in that it covers phenomena that can be colorful, flashy and occasionally explosive. Students are expected to test and observe many chemical relationships in the lab, but not all reactions are appropriate for a laboratory setting. Safety concerns, cost and limited resources are common reasons a teacher may elect to present material as a class demonstration rather than as a student laboratory activity. The goal of this study is to determine if demonstrations are an educationally valuable instructional tool in a chemistry classroom.

At the end of each school year I have given the students in my college prep chemistry classes the opportunity to complete an opinion survey after the final exam. The purpose of the survey was to provide perspective about students' experiences in the class over the previous year. The students used any time remaining after the final exam to complete the survey and were told that the surveys would not be read until after grades had been finalized. The survey contained questions that asked for opinions on topics such as teaching style, lab activities, general likes and dislikes and any improvements or suggestions for future years. Most students gave reasonable, well thought-out responses that helped me reflect on my teaching that year and consider new ideas for the future. One question was "In this class we should do more…" and students completed the statement indicating which type of activity they would have liked more of. Students most commonly indicated that they would have liked to have seen more chemical demonstrations presented to the class.

The number of demonstrations presented in this college prep chemistry has varied from year to year. Demonstrations were valuable for students to see and experience, but were not my first priority in planning lessons and activities. I treated them as something extra when time and resources allowed.

Increasing the number of chemical demonstrations presented to my classes was not a simple task and there were many factors to consider. Most of the chemical demonstrations I had been using required some preparation time. Many included chemical reactions that necessitated making solutions, weighting reagents and preparing the necessary equipment for multiple presentations. Demonstrations often required the use of consumable chemical resources and therefore added extra expense. Demonstrations also had many safety considerations. They could only be performed after having been practiced and while following all of the necessary safety precautions.

The 2006 revisions to the Michigan High School Content Expectation increased the amount of required content and therefore decreased the available class time for demonstrations and other similar activities. After considering the survey responses, increasing the number of demonstrations presented to my classes was warranted, but the time and money constraints of doing so needed to be taken into account.

This led to a desire to evaluate the educational value of chemical demonstrations. I suspected that students wanted to see more demonstrations because they liked to be entertained. They wanted to see something on fire or change color in an unexpected way. They were drawn to the entertainment aspect of demonstrations, but were not really focused on the relevant chemical content to which it was related. I needed to determine if there was a way to incorporate chemical demonstrations into my curriculum that did not require additional class time and remain content oriented. Could demonstrations be used as effectively and efficiently for teaching students the required content as lecture and practice?

In the summer of 2009, I began developing demonstrations, assessments and surveys that could be used to measure the educational value of demonstrations in the college prep chemistry classroom. I developed lessons and worksheets to accompany the demonstrations to try to make them more of an educational tool rather than just a source of entertainment for students. I hypothesized that if students were required to make predictions, discuss, think critically and perform data analysis as part of the demonstration process, then demonstrations could be a better, educationally useful tool. If the data collected showed that chemical demonstrations impact student learning in chemistry and provide more than just entertainment value, than the extra time and expense they require would be justified.

CLASSROOM DEMOGRAPHICS

This research project was implemented at Hartland high school during the 2009-2010 school year. Hartland High School is located in rural/suburban Livingston County, Michigan near the intersection of US-23 and M59. The school contains approximately 2000 students in grades 9-12.

College Prep Chemistry is the third year science course for most students, following completion of earth science and biology. Completion of a chemistry or physics course is required for Michigan Merit Credit and for graduation. College Prep is the higher level of the two first-year chemistry courses available at Hartland High School. The majority of students enrolled in College Prep Chemistry are juniors, with a few sophomores who tested out of a previous science course or doubled-up on science classes. A small number of seniors take College Prep Chemistry after having taken physics or anatomy as a junior.

During the 2009-2010 school year, ten sections of college prep chemistry were taught, three of which were included in this study. Hartland High School uses a traditional six hour per day schedule. Each section met once per day for approximately 55 minutes. Each section had a total of thirty-one students. Of the 93 college prep students enrolled in the 4th -6th hour sections used in the study, 56 consented to participate. 25 students were from 4th hour, 13 were from 5th hour and 18 were from 6th hour. Of the 56 participating students, 13 were sophomores, 39 were juniors and 4 were seniors. Thirty-eight of the participating students were female and 17 were male.

LITERATURE REVIEW

Presenting chemical demonstrations is a standard activity for many chemistry teachers. Each year at the Michigan Science Teachers' Association annual conference numerous sessions are devoted to chemical demonstrations new and old. When asking former chemistry students what they remember from their time in chemistry class, many will recount a favorite demonstration they saw that has remained in their memory for years afterward, but not the related chemical explanation. Television programs such as *The Late Show with David Letterman* will often include a segment of chemical demonstrations presented by high school chemistry teachers. Chemical demonstrations have the power to show people the flashy, colorful, explosive and unexpected nature of chemical reactions not normally seen.

The state of secondary education in Michigan has changed significantly in the past few years, possibly affecting the role of classroom demonstrations. The 2006 High School Content Expectations for chemistry were expanded to cover substantially more material than in previous years in the same or less amount of time. In addition, Michigan's poor economy has led to a decrease in funding provided to most schools. These conditions have caused chemistry teachers to re-evaluate and prioritize the content of their classes, including demonstrations. Do demonstrations in chemistry classes have enough educational value to be considered worth the extra preparation time and cost, compared to other teacher-led activities?

In '*Demonstrations as a Teaching Tool in Chemistry: Pros and Cons*', Beall (1996) summarized the comments of educators who felt that chemical demonstrations were not worth the time they required and provided only entertainment rather than education. This position was confirmed in the research of Pohl (2005) who found that demonstrations were the least helpful instructional method used in his classroom. He stated "much of the class put away their learning for "the show" and were not actually thinking about what they were learning."

Others see chemical demonstrations as a means of generating excitement for chemistry. Comancho-Zapata (1997) found that students reported being more interested in science after a series of demonstrations was added to the science curriculum. In his explanation of lecture demonstrations as "exocharmic" or charm generating, Bodner (2001) wrote that the curiosity stimulated by seeing demonstrations can lead students to investigate the science behind them.

Although demonstrations can stimulate curiosity, the role of a chemistry teacher is to educate students, not just to entertain them. Bodner (2001) added that even though students may be charmed by a demonstration, that does not guarantee they have learned anything from it. In his master's thesis research, Pohl (2005) found students indicating in surveys that they felt demonstrations were the best learning activity, but his assessment data showed that it was the least helpful. Although his students enjoyed the entertainment, or charm of a demonstration, that was not enough to generate long-term understanding or retention of the concepts. Crouch, et.al (2004) found that traditionally presented demonstrations, where students sit as passive observers and hear the instructor's explanation, are ineffective at teaching students the scientific concepts.

To be effective, a demonstration should not be a stand-alone, passive activity. In an explanation of why he presented demonstrations, Shakhashiri (1984) wrote, "To approach demonstrations simply as chances to show off dramatic chemical changes or only to impress students with the "magic" of chemistry is to fail to appreciate the opportunity they provide to teach scientific concepts and descriptive properties of chemical systems."

Tanis (1984) agreed with the idea that demonstrations are best used as a starting point for discussion and inquiry. Roadtruck (1993) cautioned teachers that demonstrations must include student interaction to be considered educationally relevant. He classified demonstrations as only a stepping off point for effective instruction.

Many chemical educators agree that the methods used for presenting demonstrations are as important as the demonstrations themselves. Roadtruck stated that the demonstrator must require students to question, predict, explain and test as part of the demonstration process. O'Brien (1991) wrote that "Teacher instruction without student construction has been characterized as words transferred from the lecturer's notes to the students' notebooks without passing through the minds of either."

In a collection of thoughts about chemical education, Bent (1980) reminded teachers that it is important to begin a demonstration not by saying "Now I will show you…" but rather "Let's see what happens when…" in order to stimulate learning. In research survey data from six thousand physics students, Hake (1998) found that students performed best when actively engaged in the discovery of the concepts through a demonstration as opposed to more passive instructional methods.

Demonstrations can be a useful tool for confronting students' misconceptions if the students are an interactive part of the process. Zimrot and Ashkenazai (2007) developed an instructional model to measure the effectiveness of lecture demonstrations at targeting specific student misconceptions in chemistry. The model they employed required students to make predictions about the results of a demonstration before seeing it. After recording observations, students discussed the outcome with a classmate and made predictions about a second, similar demonstration. The data showed that students were better able to confront and replace misconceptions with the correct chemical explanations after engaging in this process of prediction and discussion. Students who were not actively engaged performed about as well on assessments as those who did not see the demonstrations at all. Similar results were obtained by Ashkenazi and Weaver (2007) when studying lecture demonstrations used to teach the concept of solvent miscibility. Demonstrations were developed to help students differentiate seemingly similar but fundamentally different chemical concepts. The authors concluded that an interactive discussion method is necessary in order for students to refine their scientific knowledge enough to disregard misconceptions and apply the correct explanations.

Crouch et al. (2004) also assert that the method by which a demonstration is presented determines its effectiveness. For their research, they presented lecture demonstrations in two modes; 1) observe and 2) predict and discuss. The results were compared to a control group of students who didn't see the demonstrations. Students who were required to predict and discuss events performed better on assessments and had better long-term retention of knowledge than those who passively observed the demonstrations.

This literature review shows that demonstrations have more than just entertainment value for students. Demonstrations can increase learning if students are an interactive, rather than just passive, part of the demonstration process. Students who are required to observe, predict and discuss their observations will have a better understanding of the concepts than student who just watch passively. To provide the best instruction, demonstrators must develop materials to include interaction as a part of the demonstration process.

SCIENTIFIC BACKGROUND

This research project was conducted over the course of two units of study during the second semester of college prep chemistry. The units covered the properties of gases and the gas laws, intermolecular forces and phase changes. Each of these topics has a variety of well known demonstrations and the underlying chemical concepts of each can easily be qualitatively and quantitatively observed.

The properties of the particles in a sample of gas are described by the assumptions of Kinetic Molecular Theory (KMT). KMT makes the assumption that gas particles are in constant, random motion. This means that, except at very low temperatures or very high pressures, gas particles in a sample will move apart to fill their entire container equally. This causes gas particles to have a much lower density and a higher compressibility than a liquid or solid form of the same material.

KMT also assumes that the average motion (kinetic energy) of the particles depends on the temperature of the gas. As the temperature of a gas sample is increased, the particles will move faster and the average kinetic energy will increase. In addition, KMT assumes that kinetic energy is not lost when particles of a gas collide. Energy can be transferred between particles but there is no net gain or loss.

Gas particles are also assumed to have no forces of attraction between them. This means that they will easily glide past one another with a fluid motion similar to those in a liquid.

The Gas Laws are a compilation of the mathematical relationships between the variables of temperature, pressure, volume and number of particles in a sample of a gas.

The Gas Laws are used to predict and calculate the way one variable will change in response to the change of another. The Gas Laws can be used to describe many real-world observations of gas samples.

Boyle's Law compares the relationship between the pressure and volume of a gas sample at constant temperature. The law states that as pressure is increased volume is decreased and mathematically there is an inverse relationship between the two variables. Boyle's Law is often experienced during a change in altitude in an airplane. As the altitude of the plane increases the atmospheric pressure will decreases. As a result, the gas particles in the ear spaces move apart and create a sensation of discomfort until the inner and outer pressure is again equalized.

Charles' Law describes the direct relationship between volume and temperature of a gas sample at a constant pressure. If temperature is increased, volume will increase. This can be observed by studying a hot air balloon. As the air particles inside the balloon are heated, their total volume increases, according to Charles' Law. An increase in volume causes a decrease in density and the warmer particles inside the balloon become less dense than the cooler particles outside and the balloon rises.

Gay-Lussac's Law explains that a direct relationship exists between pressure and temperature when the volume of a gas is held constant. As temperature increases, so will pressure. This explains why sealed aerosol cans have strict temperature requirements and become very dangerous at high temperatures.

Graham's Law of Effusion describes the behavior of gas particles as they move through small holes or pores. In general, the rate of gas effusion depends on particle mass. Heavier particles will effuse more slowly. Graham's Law explains why a balloon filled with helium will deflate faster than one filled with air. Helium particles are less massive and therefore effuse from the balloon at a faster rate.

One way to produce gas particles is by generating them in a chemical reaction. The Law of Conservation of Mass explains that the amount of reactants converted in the reaction will dictate the amount of products produced in the reaction. A balanced chemical equation is used to show the mathematical relationship between the amount of particles (in moles) of reactants and the amount of particles of products. If the amounts of reactants present do not correspond to the ratio given in the balanced equation, the reaction will only continue until one of the reactants is fully converted. The reactant that is consumed first is known as the limiting reactant and it can be used to calculate the amount of gas produced.

The conditions at which a substance becomes a gas are dependent on its intermolecular forces (IMFs). IMFs are the attractions that are present between the molecules within a substance and are a result of the arrangement of electrons within each molecule. Molecules that have a symmetrical electron arrangement have no polarity because the electron charge is spread evenly around the molecule. Because of the even charge distribution there is very little attraction from one nonpolar molecule to another.

Molecules with an uneven electron arrangement are considered polar, having regions of overall negative charge and regions of overall positive charge. The positive region of one molecule attracts the negative region of another molecule, producing an intermolecular force of attraction. A greater force of attraction between molecules is indicative of a greater molecular polarity.

IMFs are classified into three main types. The weakest type of IMF is known as London Dispersion Forces. When two molecules move close to each other, they can cause a change in electron arrangement. The electrons in one molecule repel the electrons in the other, inducing a temporary polarity. The slight increase in polarity is enough to cause an attraction between molecules. The more electrons within the molecule, the greater the increase in polarity and the stronger London Dispersion Forces.

Molecules that are polar have a stronger IMF known as dipole-dipole attractions. Dipole-dipole forces are the permanent attraction between molecules that have an asymmetrical electron arrangement. When the molecules contain a hydrogen atom bonded to an oxygen, nitrogen or fluorine atom the polarity of the electrons in the molecule increases and so does the strength of the IMFs. This strongest type of IMF is known as hydrogen bonding.

The strength of intermolecular forces is responsible for the amount of energy required for a phase change. The greater the forces of attraction between molecules, the more energy that is required to separate them. Molecules that contain hydrogen bonding, such as water (H_2O), will have a higher boiling point than a molecule with only London Dispersion forces such as methane (CH_4). Water will also have a higher freezing point and a slower rate of evaporation. By comparing the size and shape of molecules, predictions can be made about the relative strengths of the intermolecular forces between them and thus the amount of energy required for a phase change.

In addition to IMFs and temperature, phase changes can also be affected by changes in pressure. A phase diagram shows the relationship between temperature, pressure and phase for a substance. For a given substance, the state of matter is dependent on both temperature and pressure. For example, at 25°C and 1 atm (room conditions) water is a liquid. Water can be converted a vapor by an increase in temperature, a decrease in pressure, or a combination of the two. Any point on the line between liquid and vapor on a phase diagram is considered a boiling point. The point on the line at 1 atm is considered the normal boiling point because it corresponds to the atmospheric pressure present at sea level.

The Michigan High School Content Expectation P4p1 requires that students be able to state the properties and arrangement of gas particles and how they differ from the particles in a liquid or a solid. Students are also required to understand the mathematical relationship between variables of pressure, temperature, volume and number of particles for a sample of a gas for standard C4.5x. Expectation C4.3 and C4.5 require that chemistry students learn intermolecular forces and how they relate to phase changes. In addition, students should use molecule size and polarity to predict the relative boiling points for a given set of molecules.

IMPLEMENTATION OF PROJECT

The purpose of this study was to test the educational value of chemical demonstrations in a college prep chemistry classroom. I chose this project to see whether or not demonstrations impact student understanding of the chemical concepts or rather, if they simply provide excitement or entertainment for the students. My initial prediction was that students must be engaged in the demonstration process by making predictions, recording observations and discussing results in order to learn chemical concepts from the demonstrations. My previous experience with presenting chemistry demonstrations was that students would sit back and watch the show, not realizing that I expected demonstrations to be another method of teaching the concepts. I also found that students would perform poorly on assessment questions related to the specific demonstrations, which illustrated to me that the demonstration process was not really an educational one.

To test my hypothesis, I began the project by surveying students to discover their perceptions about chemical demonstrations in the classroom. The survey questions (Appendix B) asked students whether they felt demonstrations were important in a chemistry classroom and what purpose they served. I also asked students how helpful they thought demonstrations were for learning as compared to lecture, labs, homework and textbook reading. Finally, I gave students different examples of types of demonstrations that can be done and asked their opinions about when each type should be used.

A set of demonstrations was developed to be presented to students over the course of two units of study. The demonstrations related to the topics of the gas laws, intermolecular forces and phase changes. I chose demonstrations that I knew to be reliable for classroom presentations as well as new ones that related to the relevant chemical concepts. I organized a set of about twelve demonstrations, nine of which (Table 1) were included in the final project data (Appendix D).

Table 1. Research Project Demonstrations and Related Chemical Principles

Demonstration	Objectives and Chemical Principles
1) Limiting Reactant & Carbon Dioxide Production	The limiting reactant will determine the amount of product formed in a reaction. Gas volume can be used as a measurement of the amount of product formed.
2) Properties of Gases	Gases exhibit the physical properties of mass, fluidity and compressibility. The force of atmospheric pressure is equivalent to 14.7 psi at sea level.
3) PVT Relationships	A sample of gas particles exhibits a mathematical relationship between the variables of pressure, temperature and volume. The PVT relationships can be related to many real world situations involving gases.
4) Graham's Law of Effusion	The rate of effusion is dependent on the molecular mass of the gas.
5) Hot Air Balloons	A temperature increase results in a density decrease for a gas sample.
6) Gas Density	Gas density is dependent on molar mass.
7) Gas Stoichiometry	The volume, temperature and pressure of a gas produced in a chemical reaction can be used to calculate the amount of the limiting reactant used in the reaction.
8) Rate of Evaporation	The rate of evaporation for a sample of gas particles is dependent on the strength of the intermolecular forces.
9) Phase Diagrams	Phase changes can occur as a result of both changes in temperature and pressure.

I developed and administered a pretest (Appendix C) over the chemical principles I planned to demonstrate in class. The pretest questions were designed to test student understanding of the concepts, rather than the specific procedural details of the demonstrations themselves. Most of the questions were multiple choice format, but also included were some short answer questions, calculation based questions and questions where students were expected to draw molecular diagrams to illustrate concepts.

To test the project hypothesis, I set up three methods for presenting demonstrations in class. The first method required students to complete a specific, guided worksheet for their data and observations as the demonstrations were presented. A specific worksheet was developed for each demonstration that required students to make predictions, record observations, draw diagrams and summarize the demonstrations and its related chemical concepts. This group is referred to as the SW group for the project.

In the second method, students were given a generic demonstration sheet (Appendix D) that asked them to record observations and summarize the demonstration and its concepts. The same generic worksheet was used for each demonstration. This group is referred to as the GW group for the project.

For the third method, students were not given any additional materials or guidance during the demonstrations. At the end of each hour, students were required to complete a short summary (Appendix D) of the demo and its concepts. The purpose of the summary was to have some data for day to day comparisons between the three different methods of engaging students in demonstrations. Students in this group are referred to as the NW group for the project.

The demonstrations were presented to my 4^{th}, 5^{th} and 6^{th} hours. In order to try to eliminate the normal variations in performance between classes, a plan was established so that each class would use each of the three methods in rotation. For example, 4^{th} hour got the specific work sheet for the first demonstration, the generic sheet for the second and no worksheet for the third. Therefore, all students participated in each demonstration method for the project. All students were told at the beginning of the project that they could take extra notes if they desired and that any of the demonstration results and concepts were subject to appear on tests and quizzes.

THE DEMONSTRATIONS: Gas Laws

The first seven demonstrations for this project related to the content studied during the Gas Laws Unit. The demonstrations were chosen to help students understand the relationship between the variables of temperature, pressure, volume and number of particles in a sample of gas particles.

1) The first demonstration for the project was related to carbon dioxide production and the concept of a limiting reactant. Students were presented with four flasks, each filled with an equal amount of vinegar. For the demonstration, the baking soda was emptied from the first balloon and students observed the carbon dioxide production and the resulting diameter of the balloon. Students in the SW method group were asked to record predictions about the size of the balloons for the next three flasks. The second balloon had double the diameter of the first and the third balloon had double the diameter of the second as expected. Many students predicted the fourth balloon would double in volume again because the baking soda was again doubled, but the diameter was the same as the third balloon.

At first, students were disappointed, expecting a giant balloon for the fourth flask; then, not getting one led them to believe something had gone wrong. They were instructed to look more closely at the flask for any evidence that could explain what had happened. They noticed that the fourth flask contained excess baking soda and the other three did not. At this point students were instructed to write a balanced equation for the reaction and generate a chart of the mole values to look for any patterns. After completing the chart students were able to see that the fourth balloon did not contain any more carbon dioxide that the third balloon because vinegar had become the limiting reactant.

This demonstration served as both a review of stoichiometry and an introduction to the study of gases. Students were to realize that gases are still subject to the mathematical relationships in stoichiometry and that the amount of gas particles produced is related to the amount of reactants, just like a solid precipitate would be.

2) The second set of demonstrations covered Kinetic Molecular Theory and properties of gases. A series of six short demonstrations was adapted to illustrate mass, density, fluidity, compressibility and the force of air pressure. Gas particle mass was demonstrated by using a microgram balance to find the mass of an empty syringe, a syringe filled with air and a syringe filled with an equal volume of water. Students then used the data to calculate the densities and the number of molecules (assuming air is mostly nitrogen gas) of both the air and water samples.

To test compressibility, pressure was applied to the water and air filled syringes and the volume changes were noted for each. The syringes were passed around the classroom for students to observe for themselves.

To illustrate fluidity, a burning candle was placed on the demonstration table and quickly extinguished with a puff of air from a two liter plastic bottle. The candle was relit and moved about two meters away. It was easily extinguished again at the greater distance. The purpose of this demonstration was to show that air particles are fluid and will move past one another easily, similar to the way liquid particles do.

A set of three demonstrations was presented to show the force of atmospheric pressure. The goal was to illustrate for students the relative force of atmospheric pressure at sea level (1 atm or 14.7 psi). Given a choice of a ping pong ball, basketball, beach ball or bowling ball sitting on a table, students in the specific worksheet group were asked to predict which most closely presses on the table with a force equivalent to that of the force of atmospheric pressure. Next, a meter stick was placed on a lab table with 50 cm on the lab and 50 cm sticking off the side. A piece of poster board was placed over the half of the meter stick on the bench. A volunteer student hit the uncovered end of the ruler, easily breaking it in half. Students expected that hitting the ruler would cause the poster board to catapult into the air, but rather, the air pressing on the surface of the poster board was enough to hold it down and break the ruler instead. We then measure the surface area of the poster board and calculated the air pressure that was pushing down on it.

For the second part of the air pressure demonstration an aluminum pop can was filled with a few milliliters of water and put it on a hotplate. When the water was boiling and the can was sufficiently filled with vapor it was inverted it into a container of ice water. The change in temperature caused the vapor in the can to condense. With few gas particles remaining inside the can the force of atmospheric pressure easily crushed it in less than 1 second.

The final demonstration of the day used the force of atmospheric pressure to inflate a balloon inside a flask. Similar to the pop can, a small amount of water was placed in an Erlenmeyer flask and heated to boiling. When the flask was sufficiently filled with vapor an empty balloon was placed over the opening. As expected, the balloon started to inflate with water vapor. Next, it was removed from the heat. As the water cooled and condensed the balloon deflated and then reinflated inside-out on the inside of the flask.

Students in the SW group were required to draw diagrams illustrating the gas particles in both the pop can and the balloon demonstrations. Most students expected the can to crush but did not understand why. Also, students expected the balloon to deflate, but were surprised to see it reinflate inside the flask. By having students draw the water molecules in each stage of the demonstrations I expected them think through each process and realize that the force of gas particles in the atmosphere is quite significant.

3) The third day of demonstrations illustrated pressure, volume and temperature relationships as described in Boyle's, Charles' and Gay-Lussac's Gas Laws. Relatively simple demonstrations were chosen so that students would not get confused with more complex procedural details. To illustrate the relationship between pressure and volume, a marshmallow Peep was placed in a flask which was connected to a vacuum pump. As the flask was evacuated, the volume of the Peep increased.

As a second pressure/volume demonstration a Cartesian diver was set up in a sealed two Liter bottle of water. The diver started out at the top of the water and as the bottle was squeezed the diver sank to the bottom. When the pressure was released the diver rose back to the top.

To demonstrate the relationship between temperature and volume, three balloons were inflated to equal volume. One was placed one in hot water and one in liquid nitrogen, leaving the third as a control. The warmer balloon expanded and the liquid nitrogen balloon decreased in volume significantly.

The relationship between pressure and temperature was demonstrated by placing a LCD temperature strip inside a plastic bottle. The bottle cap was altered so that it had a tire valve stem inserted through a hole drilled in the center. A tire pump with a pressure gage was used to add air to the bottle. Students monitored the pressure and temperature changes as air was added to the bottle over the course of two to three minutes. As the pressure in the bottle increased, so did the temperature reading on the LCD strip.

Students assigned to the SW method group were asked to make predictions before each demonstration. Some were easy, such as knowing that a balloon in hot water will expand, but few predicted that the Cartesian diver would sink when the bottle was squeezed. The SW students were also asked to relate each demonstration to a real-world example, such as SCUBA diving or changes in car tire pressures.

4) Demonstrations on the fourth day related to Graham's Law and effusion. To demonstrate the general concept of effusion, balloons containing vanilla, strawberry and peppermint extracts were passed around the classroom. Students noticed that each of the balloons had an odor and after more careful observations were able to detect the separate scents. They were told that extracts had been placed inside each balloon and asked how they were able to detect them outside the balloon.

To illustrate Graham's Law and rate of effusion, one balloon was filled with air and another with an equal volume of helium. For the next two days students observed the relative diameters of the balloon to compare the rates of effusion of the two gases. The helium balloon decreased in volume much faster than the air filled balloon.

Students in the SW group were required to describe effusion based on their balloon observations. Students also had to predict rates of effusion and then perform the Graham's law calculations to support their observations.

5) The fifth day of demonstrations related to gas density. A mylar balloon partially filled with helium was heated with a hair dryer. As the temperature increased the volume of the gas also increased, as explained by Charles' Law. As the volume increased, the density decreased and the hot helium balloon floated to the ceiling. As it cooled, it sank back down and the process was repeated. It was also explained to students that although the principles are the same, the demonstration set-up was not an exact replica of a hot air balloon, but sometimes alterations are necessary to make thing work easily at a different scale.

6) The concept that different types of gases have different densities was the basis for the next demonstration. Of course, students know that a helium balloon will float and an air-filled balloon will not; however, they are not able to explain why or predict what other gases will do. Soap bubbles filled with methane were compared to soap bubbles filled with carbon dioxide. The methane bubbles rose to the ceiling and the carbon dioxide bubbles sank to the floor.

Students in the SW group were required to make predictions about whether the gases would sink or float. After recording their observations they performed Charles' Law and density calculations to support their data.

7) The last of the gas law demonstrations related back to chemical reactions and stoichiometry. A piece of magnesium ribbon was reacted with hydrochloric acid to produce hydrogen gas. The gas was collected in a graduated cylinder via water displacement and the volume of hydrogen gas formed was measured. Students used the data to calculate the original mass of the magnesium metal used in the reaction.

SW students were asked to predict what would happen in the demonstration and what the data could be used to find. They also discussed other variables that could be solved for, such as gas density. In addition, students had to predict how an error in the temperature or pressure data would affect the mass result and prove their prediction with more calculations.

At this point in the project, the study of gases was finished. Students completed the unit assessment which included the same questions that were given on the pretest. In order to expose each class to the different research methods an equal number of times, two more demonstrations were presented during the next unit, for a total of nine demonstrations.

THE DEMONSTRATIONS: Intermolecular Forces and Phase Changes

The second unit of study included in the project related to the concepts of intermolecular forces and phase changes. A pretest with questions about concepts I expected to demonstrate in class was developed and administered.

8) The first demonstration for the second unit showed the relationship between rate of evaporation and intermolecular forces. As the demonstration took place, I explained to the class that evaporation is an endothermic process and that a greater temperature decrease indicates a faster rate of evaporation. The process was repeated and data were collected for six different organic compounds. Students were then able to make correlations between the properties of the molecule, the types of intermolecular forces and the rate of evaporation.

Students in the SW group for this demonstration had to make predictions about the relative temperature changes for the molecules before each was tested. They had to support their predictions with reasoning that included structural characteristics and intermolecular forces. At first students simply relied on IMF type as a predictor of evaporation rate, but the final trial compared methanol (CH_3OH) with hexane (C_6H_{14}). Methanol molecules form the stronger hydrogen bonds between them whereas hexane molecules have only London Dispersion forces of attraction. Most students predicted hexane would evaporate faster but in fact it was the slowest of all the molecules used. This lead students to go back and reexamine their data to see what other variables could be considered. They discovered that the strength of IMFs is also dependant on the total number of electrons. Although London forces are overall a weaker attraction than hydrogen bonds, hexane has many more electrons and thus can form attractions stronger than the single hydrogen bond in methanol. Students also had to graph their data and make predictions about evaporation rates for other similar molecules.

9) The final demonstration for this project illustrated phase diagrams and how phase is dependent on both temperature and pressure conditions. This topic was chosen for a demonstration because students' everyday experience with phase changes are mostly with water at roughly 1 atm of pressure. Students often use water as a frame of reference that can lead to many misconceptions, for example assuming that for something to be frozen it must be colder than 0°C.

For the first part of the demonstration a five gallon glass bottle was filled with water. Students were asked to predict how long it would take for the water to boil. The bottle was connected to the vacuum pump and the air was evacuated from the container. With the decrease in vapor pressure the water began to boil in less than one minute. Based on the observations, the class examined phase diagrams and plotted the initial and final pressure and temperature values for the water and its corresponding phase change.

For the second part of the demonstration students compressed butane filled syringes until condensation occurred. Students also examined a phase diagram for butane and examined the related points from the demonstration.

The final demonstration for phase diagrams started with solid iodine added to a beaker, covered with a watch glass and gently warmed on a hot plate. SW students made predictions about what would happen to the iodine, most predicting it would melt. However, at atmospheric pressure iodine will undergo sublimation, changing directly from a solid to a purple vapor. This led students to want to examine the phase diagram to see that in fact pure iodine does not exist as a liquid at 1 atm.

Students in the GW and NW study groups were shown all the same demonstrations as the SW group, but were not asked to make predictions or discuss results. They viewed the game graphs and calculations but were not required to do them on their own. Some students took notes for themselves and others chose to only watch the demonstrations instead. All groups were required to summarize the demonstrations and the related concepts at the end of each hour. For each demonstration all of the worksheets were collected and copied for research purposes. The originals were returned to the students to be used for test preparation. At the end of the study, another unit assessment was administered for IMFs and phase changes and included the items given on the pretest. Students were also asked to write a summary of how beneficial the demonstrations were for helping them learn and remember the chemical concepts.

RESULTS

The goal of this project was to test the educational value of demonstrations in the chemistry classroom. Further, I wanted to investigate whether students who were more involved in the demonstration process performed better on assessments than those who were more passive observers. To test these hypotheses, I collected and compared pretest and posttest data from questions relating to concepts presented in the demonstrations. Students were also surveyed on their opinions about the role of demonstrations in the classroom. Daily summaries were collected from all students as a day to day comparison of the effect of demonstrations on student learning.

For each demonstration, students were initially divided into three groups, SW GW and NW as described in the Implementation of Project section. After the data were collected a fourth analysis group was added to serve as an ad hoc control.

During the six weeks of data collection, a significant number of students were absent for one or more of the nine demonstrations used in the project. Most were absent for school related reasons and a different set of students were absent for each demonstration. The number absent ranged from four to fifteen.

Absent students still learned the related material but did not actually see the demonstrations in class and were not given a make-up opportunity. Pretest and posttest data scores for absent students were separated into a fourth group for comparison with the other three demonstration methods.

Before seeing any of the project demonstrations students were surveyed about the role of demonstrations in chemistry and how they should be included (Appendix B).

97.7% of students responded that it is important for demonstrations to be included in chemistry class. When questioned about the purpose of demonstrations, 77.9% felt the purpose should be to learn about concepts, 20.9% felt the purpose of demonstrations is to generate excitement about chemistry and the remaining 2.2% felt demonstrations should be for entertainment only.

The final survey question described four different types of demonstrations that are typically done in chemistry: demonstrations to provide entertainment only, demonstrations to illustrate a chemical concept, demonstrations to provide data and observations for analysis, or demonstrations to introduce a lab or activity. 50% of students indicated that they most preferred demonstrations that illustrate a concept in class. 29.1% of students preferred demonstrations for entertainment and the remaining 20% of students were divided between demonstrations with a worksheet and demonstrations to introduce an activity.

A majority of students viewed demonstrations with a worksheet or those related to the concepts as being the best for learning the material and the most helpful for answering test questions. When responding about entertainment demonstrations, no students considered them most helpful for learning or answering test questions but 62.8% of students classified them as the most memorable.

Overall, the survey data showed that students like demonstrations and feel they are important to learning chemistry. They also showed that students would prefer to learn from demonstrations that are flashy and entertaining as well as educational. Although students indicated they would like the learning process to be entertaining, the survey results show that they also realize that activities done in class should be ones that address the concepts and prepare them to be successful on assessments.

Data from the pretest and posttest scores were analyzed for evidence of the effectiveness of demonstrations on learning in general and also for improvements between the SW, GW, NW and Control groups. Each of the nine demonstrations used in the project had one or more questions about its content on the pretest. The same questions were used again on the posttest. The data were evaluated for improvement in the percentage of total points earned from the pretest to the posttest for each of the four analysis groups. A t-test was then used to evaluate the percentage increase data between each pair of analysis groups for statistical significance.

Overall, students who saw demonstrations in class had a larger improvement on posttest scores than students who were absent for the demonstrations (Fig.1). Over the course of the study the average improvement from pre to posttest for the control group was 17.96%. The average improvement for students who saw demonstrations of any method was 32.14%. This shows that students who saw the demonstrations performed much better than students who were absent. Student comments at the end of the project also supported this finding. Many students commented that while taking the unit assessment they felt they were able to remember what they saw in the demonstrations and use that to help them answer the questions.

To test the effectiveness of the three demonstration methods employed for the project, the student pretest and posttest scores were separated by method. The total percentage of points earned on the pretest and posttest were calculated as well as an improvement (Fig. 1). The specific worksheet method group earned 36.6% of points possible on the pretest and 66.3% of points possible on the post test for an overall improvement of 30.0%. The generic worksheet method group earned 33.3% of possible points on the pretest and 66.8% of possible points on the post test for an improvement of 33.5%. The No Worksheet method earned 34.6 % of the points on the pretest and 67.5% of possible points on the posttest for an improvement of 32.9%

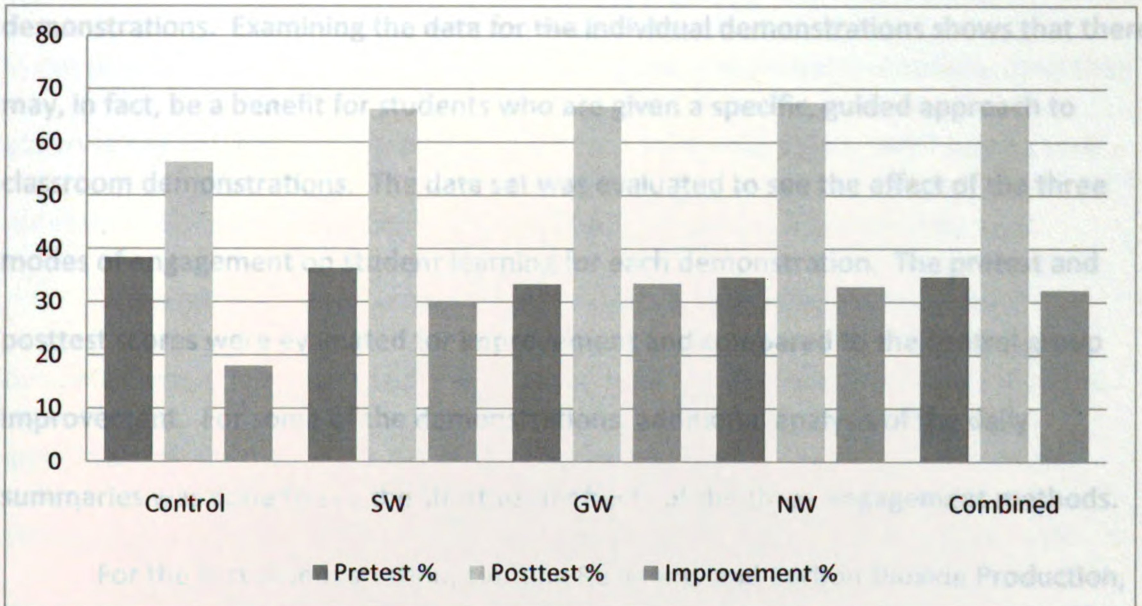


Figure 1. Graphical comparison of pretest and posttest scores by type of worksheet as compared to the control group. Combined data is for all students that saw demonstrations.

A comparison of just the pretest and posttest showed that there is not a real difference between demonstration methodologies. All three groups had about the same pretest and posttest scores. Although the overall data indicated that demonstrations are beneficial to student understanding, they do not support my hypothesis that the engagement method by which demonstrations were presented affected student performance.

In order to determine if there were differences between the methodologies of student engagement, the data set for the individual demonstrations and questions was examined. For the nine demonstrations used in the study, the specific improvement method group showed the greatest improvement for five of the demonstrations and the generic and no worksheet groups each had the greatest improvement for two of the demonstrations. Examining the data for the individual demonstrations shows that there may, in fact, be a benefit for students who are given a specific, guided approach to classroom demonstrations. The data set was evaluated to see the effect of the three modes of engagement on student learning for each demonstration. The pretest and posttest scores were evaluated for improvement and compared to the control group improvement. For some of the demonstrations, additional analysis of the daily summaries was done to see the short term effects of the three engagement methods.

For the first demonstration, Limiting Reactants and Carbon Dioxide Production, students were required to turn in a summary of the demonstration and its related chemical concepts. The summaries were scored according to a three point rubric. Three points were awarded for students who correctly explained the limiting reactant and how it related to the amount of gas in each balloon. Two points were earned for mentioning the limiting reactant concept but not applying it to the specific results. Students who simply summarized the procedure earned one point.

Table 2. Demonstration 1: Limiting Reactants and Carbon Dioxide Production pretest and posttest assessment data by engagement method

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
45	45	0	57	69	12	58	72	14	72	79	8

Table 3. Demonstration 1: Average scores on daily summary out of three possible points.

	SW	GW	NW
Daily Summary Average Score	2.5	2.2	1.9

The results show that there is a short term benefit for students who are more active participants in the demonstration process (Table 3). The most notable difference in the summaries was that students who were given a worksheet commonly cited their observations and data in their explanations. Students who simply watched and took notes on their own did not include details about the specific reaction they saw.

Although the type of presentation made a difference on the short term formative assessment, the results were more equal for the posttest at the end of the unit (Table 2). Students who did not see the demonstration had 0% improvement. Students in the specific group had a 12% improvement, the generic group has 14% improvement and students without a worksheet had 8% improvement. Students who were given supplemental materials performed better that those who were not and much better than students who did not see the demonstration at all.

Table 4. Demonstration 2, Properties of Gases: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
60	55	-5	50	85	35	54	84	30	52	86	34

For the second demonstration, Properties of Gases, students in the specific group had an improvement of 35% from the pretest to the posttest (Table 4). Students in the generic group improved 30%, students without a worksheet improved 34% and the control group actually had a decrease in their scores by 5%. The fact that the control group scored lower on the posttest than on the pretest illustrates the important visual aspect of chemical demonstrations. At the end of the unit students commented that remembering the gas properties they saw demonstrated in class helped them to answer questions on their test. Clearly, students who did not see the demonstrations were at a disadvantage.

Table 5. Demonstration 3, Pressure, Volume & Temperature Relationships: Pretest and posttest assessment data by engagement method

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
40	80	40	35	77	42	23	64	41	32	72	40

Table 6. Demonstration 3: Average scores on daily summary out of three possible points.

	SW	GW	NW
Daily Summary Average Score	2.5	2.1	2.0

The third demonstration illustrated the relationships between pressure, volume, temperature and the gas laws. The specific group improved by 42%, the generic group improved by 41%, the no worksheet group and the control group both improved by 40% (Table 5). The improvement was almost the same for all three demonstration methods and students who did not even see them. This was most likely because the gas laws were a central theme of the unit and the demonstrations were just one of many techniques used to teach the concepts. Although different techniques were used for the demonstration, all students completed the lecture, labs and homework assigned for the topic.

To try to determine the effectiveness of the three teaching methods for this demonstration, the daily summaries were graded using a three point rubric (Table 6). One point was earned for summarizing the procedural details of the demonstration. Two points were earned for relating the demonstrations to the individual gas laws. Three points were earned for describing the mathematical relationship between the variables. Again, the daily formative data shows that students benefit when they are more actively engaged in the demonstration process.

Table 7. Demonstration 4, Graham's Law and Effusion: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
43	85	42	14	86	72	23	92	69	21	57	36

The fourth demonstration illustrated Graham's Law and compared rates of effusion for helium and nitrogen gases. The pretest and posttest data for this activity showed a large difference between students who participated in the process and those who did not (Table 7). The data show a definite increase for the two groups who were given supplemental materials and the no worksheet group actually had less improvement that students who did not see the demonstration at all.

The difference between the pretest and posttest data shows that not only is it important for students to have a visual component to the demonstration but that calculations and applications are important. All of the students in each method group saw the same demonstrations, but only students in the specific and generic groups were required to apply the data to other situations.

Table 8. Demonstration 5, Hot Air Balloons: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
42	58	16	44	67	23	37	81	44	18	82	64

The data for the hot air balloon demonstration are anomalous as compared to the other demonstration data. For this demonstration the group that did not participate had the greatest increase, but it was partly due to having significantly lower scores on the pretest (Table 8).

A comparison of the posttest scores for the hot air balloon demonstration still shows that the no worksheet group performed the best on the posttest assessment. Overall, the data for this activity show that the specific worksheet was least helpful for students. This could be due to the design of the worksheet itself, which was not very detailed for this activity. Perhaps it did not lead students to draw any additional conclusions that they would not have developed on their own.

Table 9. Demonstration 6, Gas Density: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
81	81	0	43	77	34	53	72	19	58	77	19

The Gas Density data (Table 9) are quite different from the Hot Air Balloon demonstration data, though they were done the same day. The gas density data support my hypothesis that students in the SW group will have the greatest increase in assessment scores. Students were very engaged in this demonstration, as the falling carbon dioxide filled soap bubbles can be quite dramatic.

Table 10. Demonstration 7, Magnesium and Hydrochloric Acid: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
10	55	45	34	49	15	31	64	33	27	63	36

Results from the Magnesium and Hydrochloric Acid demonstration were unexpected (Table 10), in that students who saw the demonstration and participated with the specific worksheet only improved by 15%. The fact the control group had the best improvement leads me believe that there were other factors that determined student success on this topic. This demonstration addressed the relationship between stoichiometry and gases, a central concept in the unit. I suspect that the posttest question really measured the students' proficiency with stoichiometry, rather than the effect of the demonstration had on helping students learn the material as compared to other instructional methods. In addition, the control group had the lowest pretest scores which also contributed to a larger improvement.

Table 11. Demonstration 8, Rate of Evaporation: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
0	13	13	8	35	27	13	57	44	4	33	29

Results for the Rate of Evaporation demonstration were inconsistent (Table 11). In this case, seeing the demonstration improved the scores, but the improvement between the three test methods was inconsistent. The generic worksheet group had the greatest improvement, and the specific group had about the same as those without a worksheet. It appears that the specific worksheet did not help students but the generic worksheet did.

The day this demonstration was presented a fire drill occurred during the presentation to the generic group. This required the demonstration to be done over two days, which gave this group more time to work with the data. Perhaps introducing the material one day and coming back to it again a second day helped the students in this group gain a better understanding of the concepts and perform better on the posttest.

Table 12. Demonstration 9, Phase Diagrams: Pretest and posttest assessment data by engagement method.

Control %			SW %			GW %			NW %		
Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase	Pre	Post	Increase
28	50	22	29	67	38	21	53	32	31	57	26

The Phase Diagram demonstration was the final demonstration of the project (Table 12). Students saw a series of three phase changes related to pressure and temperature and the corresponding phase diagrams. Students in the specific group had the greatest improvement at 38% increase from the pretest to the posttest. All three methods had a greater improvement that the control group which increased by 22%.

The data for this demonstration show that students who saw the demonstration had a better understanding of the chemical concepts than students who were absent. They also support the hypothesis that students who are given materials will perform better than students who are not and that if the materials require students to make predictions and apply the concepts to other situations they will have a better understanding of the material.

According to this analysis, students in the specific worksheet group had the greatest improvement 5 times, the generic group had the greatest improvement twice, the no worksheet group improved the most for one demonstration and the control group also had the greatest improvement for one demonstration. This indicates that there is some rationale for instructors to hold students more accountable during the demonstration process. Students who were required to make predictions, record data and observation, support conclusions with calculations and apply their results to new situations performed better on assessments a majority of the time.

For some instances where the pretest and posttest data did not support the hypothesis, evaluation of the daily summative assessment data (Tables 3 and 6) showed that at the end of the demonstration, students who used the specific worksheets were better able to articulate the results of the demonstration and its related chemical concepts. This also points to a benefit of student interaction during demonstrations.

The summative data from student surveys support the hypothesis that students will perform better if they have more involvement in the demonstrations process. Students commented that they found the visual aspect of demonstrations useful for remembering the relationships between variables for the gas laws. Students also liked that the demonstration guide had been prepared for them so they knew what information was considered the most important.

Survey comments also indicated that some students were disappointed that they were expected to record data and observations during the demonstrations. They frequently asked why they were expected to do anything and could not just watch. This attitude reflects my earlier experiences where students viewed demonstration time as more for entertainment and less for learning. Although I explained to students that the material covered in the demonstrations was likely to appear on tests, some students said they would not have recorded information if they were not required to. Even students in a college prep level class need to be held accountable for all of the class activities to be successful.

In summary, the primary data analysis for this project consisted of comparing pretest and posttest scores for questions related to the chemical concepts presented to students over nine days of classroom demonstrations. The majority of the data supports the project hypothesis that students will understand the concepts better when they are required to participate in the demonstration process.

STATISTICAL ANALYSIS

Data were also statistically analyzed for the project by using a t-test to compare the improvement data between the three research method groups and the control group for the study. Generally, t-test analyses with a p value less than 0.05 are considered statistically significant. The first t-test analysis was a comparison of improvement for the nine demonstrations by students in the control group compared to improvement of all other students who saw the demonstrations. The results show a value of $p = 0.038$, indicating that the data used in the project analysis is statistically different.

A t-test was also done to compare the performance of each of the three research methods to the control group. The t-test for the SW and control group comparison showed a value of $p = 0.040$. The t-test for the GW and control group comparison showed a value of $p = 0.005$. The t-test for the NW and control group comparison showed a value of $p = 0.039$. All of the improvement scores used for this study fall within that range when compared to the control group improvement data.

CONCLUSION

The idea for this project developed from the request by students to see more demonstrations in their college prep chemistry class. Though often exciting, chemical demonstrations consume resources and both instructional and teacher preparation time. The goal of this project was to determine whether chemical demonstrations have enough educational value to justify the cost and time required to implement them in the classroom. The hypothesis of this project predicted that demonstrations which involve students by means of making predictions, analyzing data and applying results to new situations are more effective educational tools than demonstrations where students are passive observers.

To test the hypothesis students were divided into three groups: 1) SW, 2) GW, and 3) NW. In the SW group students were given materials to help them participate in the data collection and analysis part of the demonstrations. A specific worksheet was developed for each of the nine days of demonstrations included in the study. Students in the GW group were given a generic worksheet for recording observations and summarizing the concepts. The same sheet was used for each demonstration. The NW group was not given any supplemental materials.

Data were collected for nine different classroom demonstrations. Scores on pretest and posttest questions were analyzed for improvement on each of the three groups. The improvement for each research method was compared to a control group of students who were absent for the demonstrations. Daily summaries were also collected for all students at the end of each demonstration. The summaries were analyzed on a three point scale for understanding of the chemical concepts presented in the demonstrations. In addition, students responded to survey questions by indicating their preferences about including demonstrations as part of regular classroom instruction.

The data analysis provided a variety of results. The general analysis showed that students who saw demonstrations performed better on the final assessment than those who did not. It also showed that students in the generic group had the most improvement from pretest to posttest (Figure 1). These results supported the hypothesis that demonstrations can improve student performance, but not that the SW group would have the most improvement (Figure 1).

Pohl (2005) found that seeing demonstrations did not increase student performance on assessments. His data analysis showed that students who saw demonstrations had no greater improvement that those who did not. Beall (1996) also confirmed that demonstrations were not worth the necessary preparation time and expense. Their findings contrast the analysis for this project, which showed that there is an educational benefit for students who see chemical demonstrations over those who do not.

More specific analysis of the pretest and posttest scores evaluated the improvement by each test group for each of the nine demonstrations. This analysis showed that the specific group did have the most improvement for five of the nine demonstrations. The NW group had the least improvement the majority of the time. These results agree with those of Crouch (2004) who found that demonstrations where students are passive observers are ineffective at teaching students the scientific concepts.

Although the data analysis for each of the individual demonstrations supported my hypothesis, I was a bit disappointed that the overall average improvement for all demonstrations combined (Figure 1) did not. There were two demonstrations in particular, The Magnesium and Hydrochloric Acid demo and The Rate of Evaporation demo, that seem to be outliers. Considering possible reasons for this led me to evaluate the demonstrations themselves more carefully. Both covered concepts that were "big ideas" in their respective units. The Magnesium and hydrochloric Acid demonstration, for example, addressed the concepts of gas stoichiometry and the ideal gas law. These concepts were also extensively covered in the lecture notes, the homework and in the laboratory.

In reflection, it may be difficult to tell the role the demonstration itself actually played in students' overall understanding of the material. I suspect that most likely the posttest questions were really testing their overall understanding of gas stoichiometry from the gas laws unit in general. A better analysis of the effect of the demonstrations themselves may have been obtained by giving students an assessment shortly after the demonstrations, rather than at the end of the unit.

The other outlier demonstration, Rate of Evaporation, required students to watch as the Vernier technology produced a graph of temperature change vs time for six volatile organic compounds. Students had to analyze molecular structure and make predictions about which compounds would have the greatest temperature change and thus the greatest rate of evaporation.

The specific materials for this demonstration were perhaps the most complete that I used for the entire project in terms of SW student prediction and discussion as part of the demonstration process. Students had to make and discuss predictions and use their observations to revise predictions for the next trial. They had to draw molecular structures and graph their data to look for overall trends. Although students couldn't actually see molecules evaporate, the demonstration did incorporate a visual element by displaying the real-time temperature graph for the class.

To see that the specific group did not have the greatest improvement from the pretest to the posttest (Table 12), led me to consider other factors that may have contributed to the posttest data. The Rate of Evaporation demo also addressed concepts that were covered extensively during the unit on intermolecular forces and phase changes. Students analyzed the same set of six organic compounds numerous times in lecture, homework and the lab, including a lab activity on rate of evaporation. To see the actual impact of the demonstration materials on the SW group, questions that related to the demonstration itself rather than just the overall concepts, should have been included as part of the posttest.

A demonstration that was a better representation of the project goals was the Graham's Law and Effusion demonstration. For these concepts, the demonstrations were the only method of instruction used to teach the concepts. It was a good reflection of the project goals because students were only able to rely on their experience with the demonstration to answer the posttest questions. The data analysis for this demonstration shows that students who were in the SW group had the greatest improvement, closely followed by students in the GW group. Improvement by students in the NW and control groups was significantly lower. The results of the more specific analysis for the Graham's Law demonstration agree with those of Hake (1998) who found that students performed best when actively engaged in the discovery of concepts as opposed to more passive instructional methods.

The data analysis for this project leads me to recommend that if further study of this hypothesis is done it should include concepts that can better be isolated as demonstrations. Demonstrations similar to those for effusion or gas density were more appropriate than those that related to the more central themes of the unit. Choosing to include demonstrations that related to main concepts made the overall analysis difficult to interpret. Although I felt the demonstrations were beneficial to students, it was difficult to extract the role of the three engagement methods themselves from the more general assessment question data.

Another surprising aspect of the project was the performance of students in the GW group. Classroom observations led me to subjectively conclude that this group would have the least improvement of the three research method groups. It seemed that students found the generic worksheet cumbersome because it only asked for a description of the demo, result and a brief summary. Students were not given specific questions or provided with supplemental materials to help them understand the concepts. Students seemed unsure as to where to record extra observations or other related information and were often seen going back and forth between the worksheet and their own notebook.

The other two research method groups did not seem to experience this issue. The SW group had the necessary resources and direction for each demonstration. The NW group did not, so students who chose to do so recorded everything in their own notebook without having to go back and forth to a separate sheet.

I expected that the discontinuity of the GW engagement method would cause confusion for students and thus lower their posttest scores. However, this group had the highest overall average improvement and the highest individual improvement for two of the nine demonstrations. The improvement for the GW group was also greater than the NW group for six of the nine demonstrations. In these cases students were not hindered by the confusion of the generic worksheet.

Overall, this project was a success. A majority of students submitted comments stating how much they enjoyed seeing the demonstrations that were included in the project. This suggests that demonstrations can, in fact, make teaching and learning chemistry "exocharmic," which Bodner (2001) felt could increase interest and possibly lead students to investigate the science behind the demonstrations.

My initial goal was to determine whether or not demonstrations have enough educational value to compensate for the additional time and resources they require. Working on this project forced me to continuously research and prepare a series of demonstrations and allot class time for their presentation. It also required the preparation of specific supplemental materials for each of the demonstrations used in this study. Although the monetary cost was not great, the amount of preparation time devoted to the demonstrations was substantial. The data analysis shows that students do benefit when demonstrations are included as part of the instructional process. Students benefit somewhat because they like to see demonstrations and find them entertaining. However, students can benefit greatly if they are held accountable for active learning as part of the demonstration process. Students who made predictions and evaluated their observations for further application benefitted more from the process from the demonstration process that those who sat as passive observers.

The use of chemical demonstrations is justified as being educationally valuable in the college prep chemistry classroom. I plan to use the materials I developed for this project, perhaps with some revisions to encourage students to think more deeply about their observations. Demonstrations can be a valuable instructional tool if presented in a way that incorporates them as part of the learning process, rather than just as entertainment.

APPENDIX A

The Educational Value of Chemical Demonstrations in a College Prep Chemistry Classroom
MASTER'S THESIS RESEARCH PROJECT CONSENT FORM
Mrs. Hagerman
Hartland High School

Dear Parent or Guardian,

As a student in my College Prep Chemistry class, your child is being asked to participate in the thesis research project for my master's degree from the Division of Science and Math Education at Michigan State University. The research will focus on how chemical demonstrations affect student comprehension of the chemical concepts presented in class. The project will use a variety of methods to incorporate chemical demonstrations into the class presentations. The research will attempt to determine the best method for performing demonstrations in a chemistry classroom.

The data used for the project will be in the form of routine class work such as student homework, surveys, pre-and post tests and quizzes. The data collected for the project will remain confidential and your child's privacy will be protected to the maximum extent allowable by law. Your child's identity will not be attached to any of the data analyzed in the research and will not be identified in any of the images used in the thesis presentation. The only risk to students in the study is that there is no educational value to observing chemical demonstrations as part of the normal classroom process. I may discover through the project that demonstrations serve only as entertainment and are not an educational use of class time. The amount of instructional time spent on demonstrations will be small compared to other activities, so overall risk is considered minimal. However, if demonstrations prove to be an effective teaching tool, student learning will increase as a result of the study.

Participation in this research project is voluntary. There will be no penalty for those not willing to participate, though they will still be required to complete all assignments. Consent forms will be sealed during the data collection and stored in the main office. I will not know until the end of the project the names of students who chose to participate. At any time during the research you may request that your child's data not be included. Requests to withdraw before grades are posted for assignments included on the study should be made to Mr. Lawrence Pumford, Dean of Students. Those wishing to withdraw from the study after grades are posed may inform me directly. Students will not be required to complete certain assessments, such as surveys, that are not part of normal classroom instruction. I will not know until after grades are completed the identities of students who answered survey questions.

If you are willing to have your student participate in the study, please complete the attached form and return it to me by October 1, 2009. If you have any questions about the project please contact me by email at katehagerman@hartlandschools.us or by phone at (810) 626-2323. You may also contact the program director, Dr. Merle Heidemann, at heidema2@msu.edu or (517) 432-2152 ext 107.

If you have any questions about the roles and rights of a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or email irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.
Thank you,
Kate Hagerman

I voluntarily agree to have ______________________________participate in Mrs. Hagerman's thesis research study. (Print student name)

Please check all that apply:
DATA:

_____I give Mrs. Hagerman permission to use data generated from my child's work in College Prep Chemistry. All data from my child will remain confidential.

_____I do not wish to have my child's work used in this thesis research project. I acknowledge that my student's work will be graded in the same manner regardless of participation.

IMAGE:

_____I give Mrs. Hagerman permission to use images of my child through video and photography during her work on this thesis project. My student will not be identified in these images.

_____I do not wish to have my student's image used at any time during this thesis project.

____
(Parent/Guardian signature) (Date)

I voluntarily agree to participate in this thesis project.

____
(Student signature) (Date)

APPENDIX B

College Chemistry 09/10 DEMO SURVEY

Do you think it is important to include chemical demonstrations in a chemistry class?
A. Yes
B. No
C. Unsure at this point.

What is the purpose of chemical demonstrations in chemistry class?
A. to get students excited about learning chemistry
B. for entertainment only
C. to help students learn concepts

Which activity is the best for helping students learn material?
A. class notes/lecture
B. labs
C. demonstrations
D. homework
E. reading the textbook

There are four ways of doing demonstrations that will generally be used in this class. They are:
1. demonstrations for entertainment only
2. demonstrations that show a concept currently covered in class
3. demonstrations with a worksheet to record and analyze observations
4. demonstrations that are an introduction to a lab or group activity

Of the four types, which do you feel:

A. is the style you most prefer
B. is the best for learning the material
C. is the most helpful for answering test questions
D. is the most memorable

APPENDIX C

Gas Laws Pretest/Posttest Questions & Rubric

Answer the following to the best of your ability.

1. Air pressure is caused by the force of air particles pushing against the surface of objects, such as a desk. If four types of balls were sitting on a desk and making contact with about one square in of the surface, which would push on the desk with a force closest to the force of the air pushing on a square inch of the desk surface?
    A. ping pong ball
    B. inflated beach ball holding 22.4 L of air
    C. basketball
    D. 15 lb bowling ball.

Answer: D
1 point

2. Which of the following can be done using the force of atmospheric pressure to accomplish the task? Circle all answers you believe to be correct.
    A. crush a pop can
    B. break a wooden ruler
    C. inflate a balloon
    D. crush a 55 gallon steel drum

All are correct.
3 points earned for selection of all four or any 3
2 points earned for selecting any 2
1 point earned for selecting any 1

3. For a demonstration, a chemistry teacher wants to fill balloons with increasing amounts of CO_2 gas using baking soda and vinegar according to the equation below. Describe some factors that should be considered to ensure each balloon is larger than the one before.

$$NaHCO_3 + H(C_2H_3O_2) \rightarrow Na(C_2H_3O_2) + H_2O + CO_2$$

3 points earned for explaining that the limiting reactant will determine the amount of gas
2 points earned for say that the amount of reactants will determine the gas production
1 point earned for variables of temperature or pressure

Four commonly used gas law equations are shown below. For items 4-8, choose the gas law that best describes each situation. Choices may be used more than once or not at all.

_____4. Car tire pressures have to be checked after a drive to Florida	A. Boyle's Law $P_1V_1 = P_2V_2$
_____5. A propane tank gets frost on the outside as it is used for a gas grill in the summer	B. Charles's Law $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
_____6. Air filled balloons stay inflated better than helium filled balloons	C. Gay-Lussac's Law $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
_____7. The most important rule in scuba diving is to never hold your breath	D. Graham's Law $\frac{r_1}{r_2} = \sqrt{\frac{M_1}{M_2}}$
_____8. Aerosol cans should never be exposed to fire	

4. C
5. C
6. D
7. A
8. C

1 point each

9. The teacher fills large size balloons with equal volumes of the following gases and wants the balloons to sit on the lab counter. Circle the ones that should have to be weighted down.

He $\qquad$ N_2 $\qquad$ CH_4 $\qquad$ CO_2

2 points earned for selecting only He and CH_4

1 point earned for selecting either He or CH_4

1 point earned for selecting all four

11. A teacher wants to produce hydrogen gas by adding magnesium metal to hydrochloric acid, according to the balanced equation below.

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

If the teacher wants to produce 8.0 Liters of gas at room conditions, what mass of magnesium is required?

5 points earned for using the ideal gas law with correct calculations and units
4 points earned for using the ideal gas law with an incorrect calculation or unit
3 points earned for using the ideal gas law with an incorrect calculation and unit

2 points earned for a calculation using 22.4 Liters/mol
1 points earned for an attempt at a calculation

12. How does a hot air balloon work? Explain in detail using chemical principles.

3 points earned for correctly explaining the temperature, volume and density relationships
2 points earned for describing the relationship for two of the three variables
1 point earned for a statement of hot air rises with no explanation

IMF and Phase Changes Pretest/Posttest Questions and Rubric
Answer the following to the best of your ability.

_____1. Which of the following liquids will have the greatest rate of evaporation?

A. H_2O B. C_5H_{12} C. C_6H_{12} D. CH_3OH

1 point earned for choice B.

_____2. Which of the following factors can be used to measure the evaporation rate of a liquid?

A. temperature change
B. boiling point elevation
C. viscosity
D. rate of effusion

1 point earned for choice A.

_____3. The physical properties of gases, liquids and solids are influenced the most by:

A. phase
B. crystal structure
C. specific heat
D. intermolecular forces

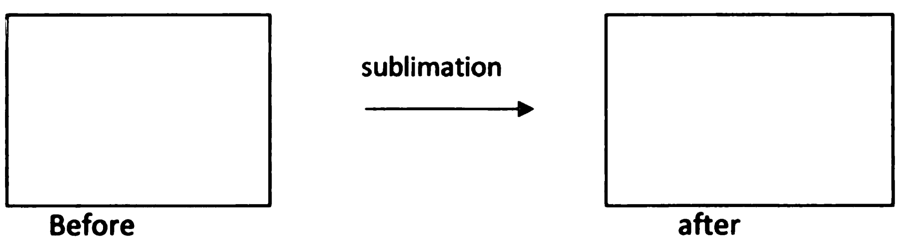
1 point earned for choice D.

4. Which of the following temperatures would be considered valid boiling points for water? Circle all that are correct.

32°C 100°C 373 K 25°C 0°C 298 K

3 points earned for choosing all or all except 0°C.
2 points earned for choosing any three
1 point earned for any 1 or two

6. Iodine forms iridescent purple crystals at room temperature. When heated slightly the iodine crystals will undergo the process of sublimation. Draw models of the iodine molecules before and after sublimation in the boxes below. Use "I" to represent an iodine atom.



5 points earned for showing correct representation for solid and gas phases and breaking only IMFs
4 points earned for showing correct representation for solid and gas phases and breaking only IMFs, but not using "I" to represent the atoms
3 points earned for breaking only IMF but showing the incorrect phase change
2 points earned for correct representation of phases
1 point earned for one correct phase representation

APPENDIX D

Limiting Reactant and Carbon Dioxide Production
Student Version

1. This demonstration involves the following chemical reaction. Is it balanced?

$$NaHCO_3 + H(C_2H_3O_2) \rightarrow Na(C_2H_3O_2) + H_2O + CO_2$$

2. Draw the four flasks set up on the demonstration counter. Label the contents of each.

3. Predict what will happen when the baking soda in the first balloon is emptied into the flask.

4. Record observations for the first flask.

5. Predict what will happen when the baking soda in the 2nd and 3rd balloons is emptied into each flask.

6. Record observations for the 2nd and 3rd flasks.

7. Predict what will happen when the baking soda in the 4th balloon is emptied into the flask.

8. Record observations for the 4th flask.

9. Complete the table for the amounts of moles of reactants and products in each trial.

$NaHCO_3 + H(C_2H_3O_2) \rightarrow Na(C_2H_3O_2) + H_2O + CO_2$

1					
2					
3					
4					

10. Summarize the demonstration and the chemical concepts involved.

Limiting Reactant and Carbon Dioxide Production
Teacher Version

Materials
4 250 mL Erlenmeyer Flasks
Baking soda
5% vinegar
4 large size balloons
1 plastic spoon for scooping

Set – Up
1. Fill four equal E-flasks with 200 mL of 5% vinegar.
2. Label four large-size balloons .25, .5, 1 and 2
3. Fill the balloons with .25 scoop, .5 scoop, 1 scoop and 2 scoops of baking soda, respectively.
4. Stretch the opening of each balloon over the mouth of one of the flasks.

Procedure
1. Empty the .25 balloon into the vinegar in the flask. The balloon will fill slightly with carbon dioxide gas.
2. Have students make a prediction about the volume of the next two balloons and react each.
3. Have students predict the volume of the fourth balloon and react the contents. When the reaction is complete excess baking soda should be present in the flask.
4. Complete the chart using the values on the balloons as moles.

Properties of Gases Demo Sheet
Student Version

Demo 1

a. Record mass of empty syringe______. Record mass of filled syringe_____.

b. What does this demonstration prove?

Demo 2

a. With a partner, list some examples of fluids.

b. Discuss whether air can be considered a fluid and explain why/why not.

c. Record observations:

b. What does this demonstration prove?

Demo 3

a. Record observations:

b. What does this demonstration prove?

Demo 4

a. Predict what happens when force is applied to the ruler?

b. Record observations

c. Explanation?

Demo 5 – Draw the contents of the can using dots for molecules and arrows to represent the force of air pressure.

Initial | During heating | After Cooling

Predict what will happen when the can is added to the ice water.

Use the diagrams to explain your observations.

Demo 6 –

a. Draw the molecules in the system before, during and after the balloon is added.

Summarize today's demonstrations and the chemical concepts involved.

Properties of Gases Demo Sheet
Teacher Version

Demo 1
Mass an empty syringe and an air-filled syringe on a microgram balance. A larger syringe will give a better difference.

Demo 2
Light a small candle and place it on the demonstration counter. Use an empty 2 Liter soda bottle to blow a puff of air and extinguish the candle. Relight the candle and repeat from a distance of 1-2 meters. This takes practice to get the bottle height just right to extinguish the candle.

Demo 3
Fill a syringe with a volume of water equal to the volume of air in the syringe from Demo 1. Cap each syringe. Pass the set around so students can compare the relative compressibility of each.

Demo 4
Place a wooden meter stick on the lab counter with the 50 cm mark at the edge of the counter. Place a piece of poster board over the half of the ruler on the counter so the all 50 cm are covered. Have a student hit the uncovered end to the ruler with their fist. The ruler will break under the force of the pressure from the fist at one end and the pressure of air on the poster board at the other. This can be done with newspaper, but is less reliable.

Demo 5
Place about 5-10 mL of water in an empty pop can and heat to boiling with a hot plate or Bunsen burner. When the can is filled with water vapor, use beaker tongs to invert it into a very cold ice water bath.

Demo 6
Add about 25 mL of water to a 500 mL Erlenmeyer flask and heat to boiling. When the flask is filled with water vapor, place a large size balloon over the opening and continue heating until the balloon inflates. Remove the flask from the heat. The balloon will deflate and reinflate inside the flask.

PVT GAS LAWS DEMOS
Student Version

DEMO 1: Marshmallow Madness (pressure vs volume)
Predict what happens to the marshmallow when the vacuum pump is turned on.

Observations:

1. What happens to pressure in the chamber as the vacuum pump runs?

2. How does this change affect the air pockets in the marshmallow?

3. Write a statement relating pressure and volume.

DEMO 2: The Cartesian Diver
Carefully squeeze the bottle and watch what happens to the dropper inside.

Observations:

1. What happens to the pressure inside to bottle as it is squeezed?

2. What happens to the volume of air inside the dropper as the bottle is squeezed?

3. How does this change affect the density of the diver? Use the equation for density to prove your answer.

4. Write a statement that summarizes all the processes/changes involved from beginning to end.

APPLICATION: Why is the #1 rule of scuba diving to never hold your breath? Discuss with a partner and write you answer below.

DEMO 3: Volume vs. Temperature

Predict what will happen to the balloons when exposed to warmer and cooler conditions.

Observations:

1. Write a statement relating temperature and volume.

DEMO 4: Temperature vs Pressure

Predict what happens to temperature in the container as the pressure is decreased.

Observations:

Predict what happens to temperature in the container as the pressure is increased.

Observations:

1. Write a statement relating temperature and pressure.

APPLICATION

Explain why a sealed aerosol should never be thrown into a fire.

SUMMARY: Write a summary of today's demonstrations and the chemical concepts involved.

PVT GAS LAWS DEMOS
Teacher Version

DEMO 1
Place a marshmallow in an E-flask and connect to a vacuum pump. Evacuate the flask until the marshmallow stops expanding. Equalize the pressure to flatten the marshmallow. This can also be done with a small marshmallow in a syringe.

DEMO 2
Set up a Cartesian diver in a 2 Liter bottle of water so the diver sinks when the bottle is squeezed. Pass around for student observation.

DEMO 3
Inflate three balloons to equal volume. Place one on a beaker of warm water, the other in a container of liquid nitrogen and keep the third as a control.

DEMO 4
Drill a hole in a 1 or2 L bottle cap so that a truck tire replacement valve stem will fit securely in the hole. Affix an LCD temperature strip to the inside of the bottle. Cap the bottle and attach a tire pump with a pressure gage to the valve stem. Note the temperature change as the tire pump is used to increase the pressure.

Repeat the procedure, but this time place the LCD strip in a E-flask and connect it to a vacuum pump. Note the temperature change as pressure is decreased.

Graham's Law and Effusion
Student Version

DEMO 1: Escaping Gases
Pick up and closely observe each balloon.

Observations :

Discuss with a partner possible reasons for your observations.

Predict how the observations would be different if a mylar balloon were used for the demonstration.

1. Identify and describe the property of gases particles that causes this occurrence.

DEMO 2

Predict what will happen to the volume of the two balloons over a period of 24 hours.

Record observations:

Use a Graham's Law calculation to support your observations.

Summarize today's demonstrations and the chemical concepts involved.

Graham's Law and Effusion

Teacher Version

DEMO 1

Add a few drops of cooking extract (vanilla, strawberry, mint, etc.) to a few balloons and inflate. Pass the balloons around the classroom for student observation. One set of balloons should last the entire day.

DEMO 2

Inflate one balloon with helium and another with an equal volume of air and plane them on the demonstration counter for student observation. After 24 hours the helium balloon will have a much smaller volume than the air-filled balloon. Students can use nitrogen gas for the air balloon and get good results for their calculation.

HOT AIR BALLOONS AND GAS DENSITIES Demo Sheet
Student Version

DEMO 1: Gas bubbles

Predict whether bubbles of methane will float, sink or be neutrally buoyant in air.

Observations:

Predict whether bubbles of CO_2 will sink or float in air.

Observations:

Discuss your observations with a partner. Try to find some differences between the two gases that could explain the observations.

Include a calculation to support your answer.

DEMO 2: Hot Air Balloon

Predict what will happen when a helium balloon is heated.

Observations:

Draw a diagram of the particles in the balloon before and after heating.

Discuss with a partner which gas law equations could be applied to this situation and why.

Explain your observations in terms of the gas laws, a calculation may be included.

Summarize today's demonstrations and the chemical concepts involved.

HOT AIR BALLOONS AND GAS DENSITIES Demo Sheet
Teacher Version

DEMO 1:
Methane Bubbles: Prepare a bubble mixture of about a 1:1 ratio of dish soap (Dawn and Joy work well) and water. Add about a tablespoon of glycerol and stir.

Connect a 2ft piece of rubber tubing to a funnel at one end and to the gas jet at the other end. Dip the funnel in the bubble mixture and gently turn on the gas. The methane will form bubbles in the soap mixture that will separate and rise to the ceiling. If desired, the bubbles can be igniteg using a burning splint or wax taper taped to the end of a meter stick.

Carbon dioxide bubbles: Add dry ice pieces to an empty 2 Liter bottle. Add water to the bottle and attach a piece of PVC pipe as a spout. Bubble the carbon dioxide through the same bubble solution used in DEMO 1. The Carbon dioxide bubbles should separate and fall to the floor.

DEMO 2:
Fill a mylar balloon about 2/3 full with helium. Add enough paperclips to the bottom of the balloon so that it just rests on the lab counter. Use a hairdryer to heat the helium gas in the balloon until it rises on its own. As it cools it will sink and the process can be repeated.

Mg + HCl Demo Sheet
Student Version

1. Predict what will happen when the Mg metal and HCl react together. Write a balanced equation to support your prediction.

2. Observations:

3. Use the volume of gas produced to calculate the original mass of magnesium.

Record the actual mass here:_____. Calculate the percent error.

Discuss with a partner possible sources of error.

4. Use the ideal gas law to find the mass of magnesium instead of 22.4 L/mol.

5. How does this affect the percent error?

6. Write a summary of the demonstration and the chemical concepts involved.

Mg + HCl Demo Sheet
Teacher Version

Materials:
1 -2 cm Mg ribbon, polished and massed
10 mL 6 M HCl
Thread
1 L beaker
25 mL graduated cylinder
Scrap of paper 10 cm x 10 cm

Procedure:
1. Tie one end of the thread around the Mg ribbon.
2. Fill the beaker with about 800 mL of tap water.
3. Add the HCl to the graduated cylinder. Carefully fill the cylinder the rest of the way with water. Try to keep the acid as a separate layer on the bottom of the cyinder.
4. Place the Mg on top of the water in the cylinder and cover the top of the cylinder with the scrap of paper. While holding the paper tightly, quickly invert the cylinder into the beaker of water.
5. The acid will sink and react with the magnesium. The thread will keep the ribbon from floating to the top of the water. As gas is produced it is collected in the cylinder.
6. At the end of the reaction the pressure in the cylinder can be equalized with the atmospheric pressure by moving the cylinder up or down so the water level is the same inside and out.

Evaporation and Intermolecular Forces
Student Version

Background Information: Complete the following table.

Name	Formula	Structure	Total electrons	IMF
Ethanol				
Propanol				
Butanol				
Pentane				
Methanol				
Hexane				

Data Table 1

Name	t1	t2	Δt
Ethanol			
Propanol			
Butanol			
Pentane			
Methanol			
Hexane			

Predicted Δt	Justification

1. **What factor is responsible for determining the rates of evaporation for butanol and pentane? Support your answer with examples from the data.**

2. **a. Which of the alcohols studied has the strongest IMFs?**

   b. the weakest?

   c. What factor is responsible for this? Support your answer with examples from the data.

3. **a. Which of the alkanes studied has the strongest IMFs?**

   b. the weakest?

   c. What factor is responsible for this? Support your answer with examples from the data.

4. **Explain why evaporation is an endothermic process.**

5. **Explain why molecules with weaker IMFs evaporate faster.**

6. **Plot a graph of Δt values for the four alcohols vs the number of electrons. Describe the trend.**

Write a summary of the demonstration and the chemical concepts involved.

Evaporation and Intermolecular Forces
Teacher Version

Materials
Samples of ethanol, 1-propanol, butanol, pentane, methanol and hexane.
Temperature probe
Chromatography paper
Small rubber bands (the rolled up end of a water balloon works well)
Data interface, computer and projector.

Procedure
1. Wrap a 5-10 cm strip of chromatography paper to the end of the temperature probe and place it in the first liquid. Record the initial temperature as t1.
2. Remove the temperature probe and note the temperature decrease that occurs with evaporation record the final temperature after 1-2 minutes.
3. Repeat with the five remaining liquids, having students make predictions about the Δt values.
4. If possible, connect the temperature probe to a computer interface and project a graph of temperature vs time for students. The liquids and also be used two at a time for faster data collection.

Phase Changes Demonstrations
Student Version

Draw a diagram representing the particles in a solid, liquid and gas below. Use dots to represent the particles. Use dashed lines to represent IMFs.

Discuss with your partner how a substance can be altered to cause a phase change. Record your ideas below.

Predict what will happen to the water when the vacuum pump is turned on.

Using the reference in your book, sketch a phase diagram for H_2O below.

Plot point R on the diagram to represent water at room conditions.

Draw a line to show the change that occurred with the vacuum pump.

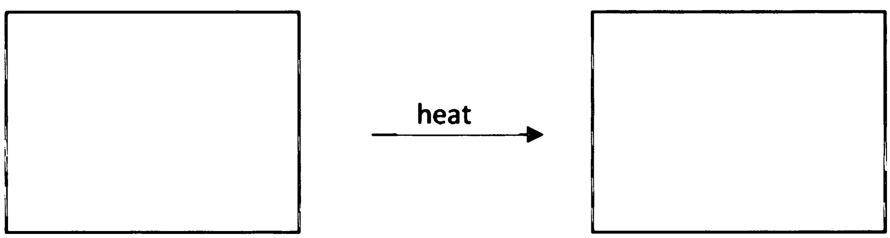
Copy the phase diagram for butane given on the board. Label point R on the graph to represent room conditions.

What changes can be made to condense butane?

How can this be done in class?

Record your observations of the iodine in the beaker.

Draw the iodine molecules (use the letter I to represent each iodine atom) before and after heating.



Now draw your prediction of the possible phase diagram for iodine.

How does your prediction compare to the actual? How is this diagram similar and different to water and butane?

Write a summary of the demonstration and the chemical concepts involved.

Phase Changes Demonstrations
Teacher Version

Part 1
Fill a large, glass container with water and connect to a vacuum pump. Use the vacuum pump to decrease the vapor pressure over the water cause it to boil at room temperature.

Part 2
Fill a 60 mL syringe with butane and seal it with a syringe cap. Students can compress the plunger until the butane condenses and release the pressure and see it boil.

Part 3
Place some iodine crystals in a 150 mL beaker and cover with a watch glass. Gently heat on a hot plate until sublimation occurs. A few ice cubed added to the watch glass will cause solid iodine crystals to deposit on the surface.

Demonstration Notes Sheet

Name:

Demo Title:

Give a description of the demonstration set-up.

Record your observations and any relevant data.

Summarize the demonstration and the chemical concepts involved.

Demonstration Summary Sheet

Name:

Summarize today's demonstrations and the chemical concepts involved.

Demonstration Summary Sheet

Name:

Summarize today's demonstrations and the chemical concepts involved.

APPENDIX E

College Chemistry 09/10 DEMO SURVEY RESULTS

Do you think it is important to include chemical demonstrations in a chemistry class?
A. Yes 97.7%
B. No 2.3 %
C. Unsure at this point. 0%

What is the purpose of chemical demonstrations in chemistry class?
A. to get students excited about learning chemistry 20.9%
B. for entertainment only 1.2%
C. to help students learn concepts 77.9%

Which activity is the best for helping students learn material?
A. class notes/lecture 32.1%
B. labs 22.6%
C. demonstrations 42.9%
D. homework 2.4%
E. reading the textbook 0%

There are four ways of doing demonstrations that will generally be used in this class. They are:
1. demonstrations for entertainment only
2. demonstrations that show a concept currently covered in class
3. demonstrations with a worksheet to record and analyze observations
4. demonstrations that are an introduction to a lab or group activity

Of the four types, which do you feel:

A. is the style you most prefer
    1. 29.1%
    2. 50.0%
    3. 10.4%
    4. 10.5%
B. is the best for learning the material
    1. 0%
    2. 43%
    3. 32.6%
    4. 24.4%

C. **is the most helpful for answering test questions**
   1. **0%**
   2. **30.2%**
   3. **52.3%**
   4. **17.4%**

D. **is the most memorable**
   1. **62.8%**
   2. **12.8%**
   3. **14.0%**
   4. **10.5%**

PROJECT DATA

Pretest (Pre), Posttest (Post) and Improvement (Imp) data by engagement method for each demonstration.

Demo	Control %			SW Group %			GW Group %			NW Group %		
	Pre	Post	Imp	Pre	Post	Imp	Pre	Post	Imp	Pre	Post	Imp
LR & CO_2	45	45	0	57	69	12	58	72	14	72	79	8
Properties of Gases	60	55	-5	50	85	35	54	84	30	52	86	34
PVT Relation-ships	40	80	40	35	77	42	23	64	41	32	72	40
Graham's Law	43	85	42	14	86	72	23	92	69	21	57	36
Hot air Balloons	42	58	16	44	67	23	37	81	44	18	82	64
Gas Density	81	81	0	43	77	34	53	72	19	58	77	19
Mg + HCl	10	55	45	34	49	15	31	64	33	27	63	36
Rate of Evapora-tion	0	13	13	8	35	27	13	57	44	4	33	29
Phase Diagram	28	50	22	29	67	38	21	53	32	31	57	26

Comparison of Improvement Data Between Groups

	Control	Specific	Control	Generic	Control	None
	0	12	0	14	0	8
	-5	35	-5	30	-5	34
	40	42	40	41	40	40
	42	72	42	69	42	36
	16	23	16	44	16	64
	0	34	0	19	0	19
	45	15	45	33	45	36
	13	27	13	44	13	29
	22	38	22	32	22	26
p value		0.040198		0.005355		0.03864

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