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The Effect of Adding Guided-Inquiry to Laboratory Activities in
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Kendon Douglas Smith

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THE EFFECT OF ADDING GUIDED-INQUIRY TO LABORATORY ACTIVITIES IN AN ACID BASE UNIT IN A HIGH SCHOOL CHEMISTRY CLASSROOM

By

Kendon Douglas Smith

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ABSTRACT

THE EFFECT OF ADDING GUIDED-INQUIRY TO LABORATORY ACTIVITIES IN AN ACID BASE UNIT IN A HIGH SCHOOL CHEMISTRY CLASSROOM

By

Kendon Douglas Smith

This research project studied the effectiveness of adding guided inquiry sections to laboratory activities in an acid base unit in a high school Chemistry classroom. The goals were to promote student interest and understanding of unit content through the addition of guided inquiry sections at the end of each activity. Students were asked to investigate teacher's questions by designing their own procedure in an effort to engage them more deeply in the process of pursuing answers. Efforts were also made to connect these sections with the chemicals and materials already familiar to students in their daily lives in the expectation of generating higher levels of individual interest in the subject of acids and bases. The effectiveness of this unit was determined using surveys, subjective data, and pre/post test comparisons. The results from these assessments show that the unit was effective. This document also examines and critiques each of the six lab activities developed and how they fit with the unit.

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INTRODUCTION

Statement of Problem and Rationale for the Study

Chemistry is one of the most challenging classes that many students undertake during their high school education. It is also one of the most challenging classes to teach, and while doing so with seemingly good success over the past nine years, I have continually found myself searching for better methods for teaching Chemistry to what seem to be increasingly unmotivated students. Chemistry is most often taught through lectures supported by laboratory activities. Lecture is a teacher-centered mode of instruction that allows large amounts of material to be covered, but does not ensure that students learn or understand the material (Francisco, Nicoll, & Trautmann, 1998). In fact, Horowitz has shown that after a few minutes of a lecture, 50% of students tune out and never again in the course of the lecture are more than half of the students attentive (Horowitz, 1988 from Spencer, 1999). Spencer also points out that the best methodology to enable students to grasp and retain a concept begins with an exploration or data collection (ibid). Laboratory experiments present an opportunity for students to not only practice techniques, but also to bring concepts to life as they move from the page to the real world.

The laboratory setting has the potential to be the most engaging and enticing facet of the Chemistry classroom; however, after nine years of teaching, it is the laboratory aspect of my classroom with which I find myself most dissatisfied. Students seem to be able to follow the list of instructions to complete a group laboratory exercise; however, they do not seem to be meaningfully connected to the experience in a way that promotes inquiry and learning. Hofstein and Lunetta (2003) point out that studies have shown that during many laboratory experiments teachers and students consume time and energy preoccupied with technical and manipulative details, which seriously limits the time they can devote to more meaningful, concept driven inquiry. For this reason, the research reported here, on the development of a modified laboratory experimental protocol, was expected to promote higher thinking and increase learning through forms of guided inquiry.

The Historical Role of Chemistry Laboratories

Almost thirty years ago, in an review entitled "The Role of the Laboratory in Science Teaching: Neglected Aspects of Research," Hofsteing & Lunetta (1982) reported that

> for over a century, the laboratory had been given a central and distinctive role in science education, and science educators have suggested that there are rich benefits in learning that accrue from using laboratory activities. In the late 1970s and early 1980s, some educators began to seriously question both the effectiveness and the role of laboratory work, and the case for laboratory was not as self-evident as it seemed.

While many teachers and researchers recognized the potential for learning science concepts and skills through laboratory activities, there was uncertainty as to whether the goals and objectives of such experience were being reached. Novak (1988 from Tobin 1990) articulated the problem:

> The science laboratory has always been regarded as the place where students should learn the process of doing science. But

> summaries of research on the value of laboratory for learning science did not favor laboratory over lecture-demonstration... and more recent studies also show an appalling lack of effectiveness of laboratory instruction... Our studies showed that most students in laboratories gained little insight either regarding the key science concepts involved or towards the process of knowledge construction.

Tobin (1990) further suggested that meaningful learning is possible in the laboratory if the students are given opportunities to manipulate equipment and materials in an environment suitable for them to construct their own knowledge of phenomena and related scientific concepts. Hodson (1993 from Hoffstein & Lunetta 2003) emphasized that the principle focus of laboratory activities should not be limited to learning specific scientific methods or laboratory techniques, but rather, students should use the methods and procedures of science to investigate phenomena, solve problems, and pursue inquiry and interests.

Over time research into the laboratory experience began to focus on aspects of inquiry and providing opportunities for students to engage in metacognitive activities. Metacognitive knowledge consists primarily of knowledge about what factors or variables act and interact in what ways to affect the course or outcome of cognitive enterprises (Flavell, 1979). Flavell further suggests that metacognitive experience can help in the process of assimilating observations to existing knowledge structures and accommodate the knowledge to the observations. In other words, metacognition is a higher level of thinking that involves elaboration and application of one's learning, which can result in enhanced understanding (Hoffsteing & Lunetta, 2003). This concept is also found in the current Michigan science Grade Level Content Expectations (2007), which state that teachers can prepare students for academic success by applying knowledge to new situations, to solve problems by generating new ideas, and to make connections between what they learn in class and the world around them.

This concept as applied to science teaching and learning also drives the modern theory of constructivism, an underlying doctrine that replaced objectivism in the 1990s. Objectivism holds that reality is external, and the role of teachers is to interpret events for students. The learners are simply told about the world and expected to replicate its content and structure into their thinking (Jonassen, 1991). Jonassen further states that constructivism, on the other hand, claims that reality is in the mind as the knower constructs his or her reality, or interprets it. Teaching strategies based on constructivism should focus on providing students with physical experiences that induce cognitive conflict and encourage students to develop new knowledge schemes (Ketpichainarong et al, 2009).

The constructivist approach often incorporates inquiry based learning as a method to promote greater student engagement in the learning process. This may include the implementation of guided inquiry approaches, which require a change in the traditional roles of students and instructors (Landis et. al. 1998). The NSF-supported New Traditions Project of reform in teaching chemistry stated the following (Landis et. al 1998 from Spencer 1999):

> The overarching vision of the New Traditions Project is that we can facilitate a paradigm shift from faculty-centered teaching to student-centered learning throughout the chemistry curriculum, such that students obtain a deeper learning experience, improve their understanding and ability to apply learning to new situations, enhance their critical thinking and experimental skills, and increase their enthusiasm for science and learning.

Enthusiasm for science and learning is the most powerful motivating force for any student to learn. A constructivist, and/or inquiry-based, perspective is based on the premise that the heart of science education is the involvement of the students in the process of conceiving problems and scientific questions, forming hypothesis, designing experiments, gathering and analyzing data, and finally drawing conclusions (Hofstein et al. 2005). Scientific inquiry is a fundamental principle in the current Michigan High School Content Expectations for Science (2006), which describes inquiry as a complex process that involves many aspects of designing experiments and collecting and analyzing data. It also describes inquiry as being more flexible than a rigid set of steps. It involves developing habits of the mind, such as openness and curiosity, which engage students in logical reasoning and the application of imagination as they devise hypothesis, design experiments, and generate explanations.

Definitions of Inquiry

Inquiry may appear to be a simple process or state of mind at first glance, but it is in fact a more complicated issue, if it is to be completely described. In fact, many teachers do not even use inquiry in their classrooms as a method of teaching. Some of the most common reasons for this include confusion about the meaning of inquiry, belief that is only works with high achieving students, as well as feelings of inadequate preparation for such instruction or that it will be very difficult to manage (Colburn, 2000). The fact is that although inquiry is a core concept in teaching standards nationwide, teachers are still uncertain as to its true meaning, and even more uncertain of how exactly to put it into practice.

The National Research Council (1996) states that "scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world."

So what is inquiry? Inquiry is a highly involved and motivating process for both the students and the teacher, or at least it can be. Inquiry, as practiced in classrooms, can be described on four different levels according to Herron (1971 from Windschitl, 2002). The lowest level is *confirmation* experiences, sometimes called "cookbook labs", which do not contain any inquiry opportunities since students are simply required to follow a written procedure in order to verify a known answer. The next level is called *structured inquiry*, in which students search for the answer to a question posed by the teacher by following a given procedure. In the third level, referred to as *guided inquiry*, students must design their own investigation to a question provided by the teacher. In *open inquiry*, students generate their own questions and design their own investigations. Each of these levels requires that the teacher play a slightly different role in the process. One study suggests that higher levels of inquiry require a more active participation by the teacher than simply a facilitator or guide through the process. The teacher must not only carefully develop the initial question, but also orchestrate the instruction and mentor the students, modeling how scientists work, as they grapple with data, ask questions, and generate conclusions (Crawford, 2000).

Inquiry activities have also been described as being "close-ended" or "open-ended". Close-ended inquiry provides students with a very limited experience because they simply follow specific instructions given in a laboratory manual. In an open-ended inquiry experience, students are much more involved in choosing a question for further investigation, planning and conducting the experiment, and analyzing the findings and arriving at conclusions (Hofstein et al., 2005). Structured inquiry activities would be examples of more close-ended inquiry activities, while open inquiry activities are designed to be open-ended in nature. Guided inquiry activities, however, fall somewhere in between, by providing some structure to get students started, but ending with student generated sections of more open-ended style.

Inquiry is a broadly defined construct in science education, associated with a wide range of intellectual activities (Windschitl, 2002). I took on essentially two specific goals for the inquiry activities in the research documented here. The first objective was to engage students in investigations that stimulate curiosity or provoke wonder in a way that produces meaningful learning as they seek answers or explanations (Haury, 1993). The second objective was to involve students in the process of designing an investigation, giving them opportunities to explore and understand the natural world around them by themselves, thus establishing connections between their prior knowledge and the science of the natural world (Panasan et al., 2010). It is the expectation that these real world connections can lead students to experience more authentic learning.

Review of Scientific Principles

Acids and bases can be described and defined in multiple ways. Arrhenius described acids as compounds that release hydrogen ions, H^+, in aqueous solutions, while bases release hydroxide ions, OH^-, in aqueous solutions. Hydrogen ions are protons, and according to Bronsted's definition, acids are any compounds that donate protons, while bases are any compounds that accept protons. This broader definition accounts for some acid base reactions with compounds that are not traditionally thought of as acids or bases. Water, for example, is neutral on the pH scale, but has the ability to either donate a proton or accept a proton, making it an amphoteric substance that can behave as either an acid or a base, according to Bronsted.

Acids and bases can change the color of chemicals known as acid-base indicators. These chemical indicators are weak acids or bases that change their structural conformation, resulting in a visual color change, at specific pH ranges as the molecules donate or accept a proton. By knowing the range at which color changes occur for a specific indicator, it is possible to estimate the unknown pH of solutions. Anthocyanins are a group of naturally occurring plant pigments that can change their colors depending on pH. They are found in the flowers, leaves, stems, fruits, and even roots of many different plants. For example, as the pH in the cytosol of cells changes, the anthocyanins may change color, signaling that the fruit is becoming ripe for harvest.

pH itself is a calculated value equal to the negative logarithm of the hydrogen ion (or proton) concentration. The pH scale is made up of values from 0 to 14, and each step in the scale represents a change by a power of 10 in the concentration of hydrogen ions in a solution. For example, an increase of 3 steps on the pH scale signifies an increase of 1000 times in the concentration of hydrogen ions. Likewise, the pOH scale represents the same thing for the concentration of hydroxide ions. Generally, acidic solutions are those with a higher concentration of hydrogen ions than hydroxide ions, while basic solutions have a higher concentration of hydroxide ions than hydrogen ions. In neutral solutions, the concentration of hydrogen ions is always equal to the concentration of hydroxide ions. The product of the hydrogen and hydroxide ion concentrations is always equal to a value of 1.0×10^{-14}, called k_w, the ion-product constant for water.

Titration is a laboratory testing procedure that involves the addition of a base to an acid solution until the solutions are neutral. If the volumes of both solutions are carefully measured, and the concentration of one of the solutions is known, the concentration of an unknown solution can be determined. At the endpoint, the neutral solution will have equal moles of hydrogen ions and hydroxide ions, so by calculating the moles of the known solution, and dividing by the liters of the unknown solution, the molarity of the unknown is determined.

Buffers are solutions made with a mixture of a weak acid and its conjugate base, or a weak base and its conjugate acid. An acid and its corresponding conjugate base will differ only by the presence or absence of a hydrogen ion. According to Le Chatlier's principle, if a chemical system at equilibrium experiences a change, then the equilibrium shifts to counteract the imposed change and a new equilibrium is established. A buffered solution is able to react with both acids and bases, to the extent of their buffering capacity, in order to maintain the equilibrium of hydrogen ions. By doing so, the solution's pH is not changed, so buffers enable solutions to resist changes in pH. This is critical in many life systems, including the blood stream and lakes, where changes in pH could cause problems to organisms or other processes being carried out.

Demographics

Columbia Central High School is a rural school with a population of approximately 550 students located in Brooklyn, Michigan. The village of Brooklyn has a population of approximately 13,000 people. However, the Columbia School District services many of the smaller outlying communities and families. The average household income for Brooklyn was $49,000 in 2008; Estimates for the surrounding areas, which are more rural, would be slightly lower. 29% of high school students qualify for free or reduced lunch. There is very little diversity within the student body, with 95% white, 2% Hispanic, 1% Asian, 1% American Indian, & 1% African American. The high school graduation rate in 2009 was 96.27% with 57% of students graduating "with honors". 70% of the graduates were college bound.

Columbia Central High School operates on a standard two semester school year, with two marking periods per semester. Students are required to complete three years of science credit in order to graduate, including Science 9 (Physical and Earth Science), Biology, and Chemistry. Columbia also offers several advanced science courses such as Anatomy and Physiology, Physics, A.P. Biology, and Chemistry II. The second year Chemistry course in which this study was conducted, is an honors class that requires the completion of Chemistry I with a grade of C or higher. A typical school day is composed of seven periods, with duration of 49 minutes each.

I chose to teach my unit to my first and second hour Chemistry II class. These students consist of mostly high achieving students who successfully completed the first year of Chemistry. A majority of these students were also enrolled or planning to enroll in more of the advanced science courses offered at our school. All of the students had successfully completed Algebra II, with some enrolled in Pre-Calculus or Calculus I. All forty-six students participating in the study were juniors and seniors.

IMPLEMENTATION

Explanation of Unit Sequence and Purpose

The unit studied addressed acid/base chemistry, and incorporated many different teaching and assessment techniques. Forty-six students completed student assent forms (Appendix A) and their parents completed parent consent forms (Appendix B) to be a part of this research study. All students completed a pre-test on the first day of the unit. The unit was taught in much the same way it had been taught previously, with the addition of the newly developed laboratory activities. General information and explanations were presented through classroom lectures with fill-in-the-blank style lecture outlines provided by the teacher. Lectures lasted no more than 20 - 30 minutes in length in order to better hold student attention. Some concepts and calculations presented during these lecture periods were practiced and reinforced with worksheets and short quizzes not included in this study.

For this research project, current and new laboratory activities were adapted for a high school Chemistry classroom, that were a blend of both close and open-ended activities. High school students lack the technical knowledge of laboratory procedures, and they require detailed step-by-step instructions so that they learn how to use basic tools. This is especially true when safety is a concern in a procedure, such as adding acid to water, and not the other way around. In this paradigm the teacher is initially more focused on the students' ability to follow directions and answering questions about the methods being introduced, such as how to fill, read, or use a buret. At the point when many of the more structured labs are complete, the activities described here continued with a problem for further investigation of a more open-ended inquiry. In this phase, students were not given specific instructions, but rather a question was posed. Students used the knowledge acquired during the structured phase of the activity to design a simple experiment, set up tables, collect data, and draw conclusions about the unknown problem. The role of the teacher during this phase was as a facilitator, encouraging students to consider multiple methods for collecting or displaying data. Direct answers to student questions were also avoided by pointing students to resources or reminding them of prior experiences from the structured portion of the laboratory activity. Another focus in the open-ended phase is the was the use of materials familiar to students in their daily lives, such as soda pop or vinegar, and to involve students in connecting the activities with familiar materials found in their daily lives. These connections are intended to make the lab experience more real, more personal, increasing student interest and motivation, and ultimately producing more authentic learning.

The adapted laboratory activities were spaced evenly throughout the unit, never allowing students more than a few consecutive days in the classroom without a day or two of hands on lab work. Table 1 shows the general sequence of the unit activities and their objectives.

Activity Description	Objectives
Rainbow Connection Demo	To generate interest in the unit through visual changes of acid base indicators.
Observing Various pH Indicators	To observe an array of pH indicators and use them to estimate pH of unknown solutions.
Making pH Test Strips	To create pH test strips using natural compounds and use them to estimate the pH of unknown solutions.
Simple Acid Base Titration	To learn the basics of titration and observe differences between monoprotic and diprotic acids.
Analytical Acid-Base Titration	To use titration to determine the accurate molarities of unknown solutions.
Graphing a pH Curve	To observe and create a pH curve on a logarithmic scale.
Effects of Acid Rain on Lakes	To observe the buffering effect of limestone and dissolved carbonates in a solution.

Table 1: Unit Activities and Objectives

DESCRIPTION OF AND ANALYSIS OF ACTIVITES

Teacher Demonstration - The Rainbow Connection

The teacher demonstration titled "The Rainbow Connection" (Appendix F) was not an activity developed by me. The title and procedure were given to me by MSU professor, Dr. Merle Heidemann, and it was performed without any adaptation the first day of the unit. Five beakers were pre-treated with mixtures of three different acid base indicators and a base solution was added to each beaker. Stirring of each beaker instantly turned each colorless solution into a distinct color of the rainbow as the indicator mixed with the base. Students were impressed with the sudden nature of the color change, as well as the bright spectrum of colors that resulted. When all five beakers, now brightly colored, were poured together into a large beaker containing a small, unseen amount of a strong acid, the resulting mixed solution returned to a completely colorless state. Again, students showed wonderment and expressed amazement at the process and began to ask questions immediately. This demonstration, however, was intended to pique student interest, so questions were not answered in full with the promise that the upcoming unit would provide them.

Activity #1 - Observing Various pH Indicators

The purpose of this activity (Appendix G) was for students to observe an array of natural and synthetic indicators and use them to estimate the pH of unknown solutions. Students were asked to bring in red, blue, or purple flowers, leaves, or fruits in order to extract the pigments for testing. Student provided samples included grapes, blueberries, red cabbage, roses, poinsettias, carnations, and an array of other unknown flower samples they found around their homes. Plant materials were then boiled briefly to extract the natural anthocyanin pigments into solution. Buffer solutions with a pH range of 1 - 12 were provided for testing and observing the color changes in the extracted pigments, as well as those of a wide range of synthetic indicators provided by the teacher. Students tested a total of 6 natural and 6 synthetic indicators in each of the 12 buffer solutions, recording the resulting color spectrums onto their papers using colored pencils. Students then tested four solutions of unknown pH with their choice of chemical indicators. Color changes of each indicator in the unknown solutions were compared to their color spectrums in order to estimate the pH of the unknown solutions.

This activity proved to be very engaging, and yet some students found the procedure and data recording to be a bit tedious. Students spent a lot of time adding drops of solution to tiny wells in their reaction plates, as wells as coloring their lab paper. The activity took two days, as most students were only half done at the end of the first day. Some students reported feeling rushed to complete the activity at the end of the hour. I was very pleased with the results as students obtained very colorful trays showing a multitude of color spectrums and variations in chemical indicators. Students seemed to really enjoy that part of the activity, but some were discouraged by the tedious nature of the procedure.

There are several solutions that could eliminate the time problems, keeping the activity to a single day and allowing students to enjoy the observation a bit more. Reducing the number of indicators each group tests and allowing groups to pool their results together would save time and possibly allow for students to see the results from more indicators. Another option would be to replace coloring with a digital photograph that each student could attach to their lab sheet. This would require some technology, but would record the exact results better than student coloring could show. Another solution would be for the teacher to prepare solutions of all the natural indicators, however, that part of the process is intended to generate student interest by creating connections between the natural indicator pigments and plant products around their homes.

Activity #2 - Making pH Test Strips

The goal of this activity (Appendix H) was to introduce students to the concept of pH testing strips by allowing them to make their own that they could use to test solutions. The pH strips were made by soaking a piece of filter paper with the juice extracted from red cabbage leaves. Once the paper had been allowed to dry overnight, students then cut it into strips which they used to test pH buffers from 1 - 12. The red cabbage anthocyanins show a broad spectrum of colors over this pH range. Once the colors were associated to their pH levels, students made multiple testing solutions using vinegar, ammonia, sodium hydroxide, orange juice, and even soap, and recorded the estimated pH of the unknown solutions. Students were then given a small vial of their pH test strips and asked to design an experiment in which they tested at least 15 different solutions found at home. Students were required to generate a table or chart in which to record the results of their tests and identify the solutions as acidic, basic, or neutral.

Students were very engaged with the hands on approach to making their own test strips. The strips worked very well, showing distinct color changes across the pH scale, which were easy for students to observe and record. The most important objective to this activity was to get students thinking about acid base chemistry around the house. Students found many different solutions to test, including juices or sauces from their refrigerator, household cleaners, and toiletries. Some students tested their make-up, saliva, and even their urine. Students involved members of their family in this at home chemistry experiment as they explored the house searching for solutions to test. After this activity, students were better able to categorize general types of solutions and materials as acids or bases.

Activity #3 - A Simple Acid Base Titration

Acid-base titrations and the required calculations can be complex, so this simple activity (Appendix I) was designed to introduce students to the concept of titration, while eliminating some of the complexity. In this stripped down version, the titration was performed by simply counting the number of drops required to neutralize each of the acid solutions provided. Students measured out exactly 1.0 mL of acid and added drops of a prepared sodium hydroxide solution until the phenolphthalein indicator showed a persistent pink color. Students tested three concentrations of hydrochloric acid, a monoprotic acid, and three concentrations of sulfuric acid, a diprotic acid. The concentrations of the acid were 0.2M, 0.4M, and 0.6M, so the number of drops required to neutralize the solutions was expected to double and triple with the more concentrated solutions. Also, the diprotic acid was expected to require double the number of drops as the monoprotic acid. The resulting numbers of drops were plotted on a simple graph, which revealed two lines with different slopes for the monoprotic and diprotic acids. In a further investigation, students were asked to estimate the molarity of vinegar. Students were further required to determine if vinegar was monoprotic or diprotic in order to make the estimation.

This activity provided very consistent data for almost every group. During the initial stage of testing the various acid solutions, students were asked to show their final data to the teacher. At a quick glance, anomalies in data were able to be spotted and some groups were told to repeat some of their trials. This seemed to fix the problems, most of which were attributed to inconsistent technique or simple errors in counting or measurement. It was noted that answers varied greatly between individuals due to the size of the drops, but this did not affect the data as long as the same individual performed all the dropping. The resulting graphs showed a nearly perfect linear relationship, with the diprotic acid having double the slope of the monoprotic acid as expected. In the further investigation, students were able to identify the acetic acid in vinegar as a monoprotic organic acid. Most students performed 3 - 4 trials with samples of vinegar and averaged the result. When the average number of drops was plotted on the extrapolated line formed by the monoprotic acid on the graph, a consistent result of 0.8M - 0.9M was obtained by most groups. Students were successfully able to explain difference in hydrogen ion concentrations between monoprotic and diprotic acids after completion of this lab.

This activity also raised awareness of simple issues associated with titrations. Students learned that a single drop is all that is needed to show the endpoint of a titration. Some students were frustrated at times, particularly with the stronger acid concentrations, as the solution would turn pink and then go back to colorless when stirred. They learned that patience and stirring are important to finding accurate endpoints of titration. They also were able to explain simple associations between the amounts of base required to neutralize increasing concentrations of acids, as the number of drops always increased with concentration. They also were able to note that if a more concentrated base had been used, fewer drops would have been required.

Activity #4 - Analytical Acid Base Titration

This activity (Appendix J) allowed students to work through the entire process of a titration on a much more analytical level, since they were required to make accurate base solutions of very precise concentration. Students also had to make accurate volume measurements using a buret, which was a new piece of lab equipment to them. They carried out four titrations on two HCl solutions of unknown concentration. The resulting volumes were then used to perform higher level calculations, including finding the moles of OH^- and H^+, and ultimately the molarity of each of the unknown acid solutions. In a related investigation, students titrated fresh carbonated soda, uncarbonated soda, and lemon juice in order to calculate the concentration of H^+ in each solution. Students performed two trials with each solution for comparison and conducted all the calculations required for moles and concentration.

This activity was the most challenging activity for the students in terms of math and calculations. They were much more cautious with their techniques, measurements, and data as they were being graded on their accuracy. The first trials went more slowly as students worked through only four titrations the first day, with some groups unable to complete all the trials. However, all groups to complete their work on the second day. Students found a definite difference between the acidity of the fresh soda and the flat soda, and were able to explain that presence of carbon dioxide in the soda produces carbonic acid, making the fresh soda more acidic. The carbon dioxide was also associated with commonly experienced flavor differences between fresh and flat soda. Students were also able to diagram the molecular structure of citric acid found in the beverages and identify it as a triprotic organic acid. The lemon juice titration produced very consistent results; however, the soda titrations varied due to changes in the carbonation. It was also very difficult to measure out exactly 10mL of the initial carbonated soda with a pipet due to the fact that CO_2 bubbles being produced continuously displaced the volume of the liquid. Students did the best they could and understood that their data may not be reliable, but were intended to show a trend.

They main purpose of the extension to the activity was to generate more interest by allowing students to titrate familiar solutions. Most titration experiments are performed with stockroom supplied chemicals, but every student has had soda or lemonade to drink, so the experiment became much more relevant to them. Each titration also gave students another chance to practice the more complex mathematical processes involved in calculating moles and concentrations.

Activity #5 - Graphing a pH Curve

The main purpose of this activity (Appendix K) was to model the concept presented in lecture that pH is a logarithmic value, and not linear in nature. Students worked in groups of 3 - 4 to collect data as aliquots of 0.1M sodium hydroxide were added to a sample of 0.1M hydrochloric acid. The pH of the acid solution was tested with a digital meter after the addition of each aliquot and recorded. The results were placed on a graph generated by the students.

This activity was one of the simplest to perform by students, and yet the results seemed to surprise most of the students. The pH of the original acid changed very little at the beginning, only going up a fraction at a time with the addition of the base. No chemical indicators were used to visually show the endpoint of neutralization, so students were surprised as the pH shot up very suddenly past neutral and the solution became basic. When the seemingly strange data was graphed by the students, a typical pH curve for the addition of a strong base to a strong acid emerged.

Many students lacked knowledge of logarithms and what a logarithmic curve is all about. This simple activity was an introduction to them and reinforced the concept that each change in pH is actually a tenfold change in the concentration of H+ ions in the solution. It attacked student misconceptions that a steady addition of base would have a linear effect on the pH of the solution. It also allowed students to see how pH changes during a titration, and why a single drop is all that is needed to reach the endpoint of titration, while any additional drops quickly raise the pH level above neutral.

This activity did not contain any particularly inquiry driven sections; however, the sequence and method in which it was approached allowed for some inquiry to take place through the process. Students were not told what the expected outcome would be. Rather, students were given a simple procedure and asked to come up with reasons for the surprising results they observed. These unknown and unexpected results generated a certain level of curiosity and interest in the students, most of who thought they had done something wrong until they began to notice other groups getting the same results. They were successful in developing hypotheses for what they were observing as they gained new understanding about pH and the pH scale.

Activity #6 - Effects of Acid Rain on Lakes

This activity (Appendix L) was challenging because the concept of buffers was completely new to students. This unit did not delve deeply into the complex calculations pertaining to buffers, but rather introduced the concept in some simple real-world examples, such as the buffers in you blood stream and also those found in lakes. Students compared the buffering ability of distilled water to solutions containing limestone and granite. Drops of 1.0M hydrochloric acid were added to each solution and the pH was measured to observe any changes. Distilled water and water with granite chips showed no buffering and the pH dropped dramatically. The calcium carbonate found in limestone became slightly more soluble as it reacted with the acid, and was able to keep the pH from changing as much as it reacted to neutralize the acid. Bromcresol green indicator was used in order to visualize the pH changes taking place. The water and granite solution turned yellow and stayed yellow, however the limestone solution turned yellow immediately but slowly turned back to greenish blue as it reacted with the acid. Students were then asked to crush up rock samples and test them for the presence of calcium carbonate. They were to design the experiment, describing the procedure, record their data and observations in a table, and finally write out their conclusions for each rock sample analyzed. Students were able to successfully explain how a carbonate buffer system works as carbonate reacts with hydrogen ions to become bicarbonate and ultimately carbonic acid. Students were also able to describe how carbonic acid can break down into water and carbon dioxide, explaining the bubbles they saw during the reaction. Finally, students were able to explain how pH might or might not fluctuate in a lake, depending on whether or not the lake bed consisted of limestone or granite.

This procedure was somewhat effective, and was able to show very simple reactions between limestone and acid that were not present with the granite. However, further extensions of this were not as successful. Students had trouble finding good clean rock samples to test and had further trouble crushing up the samples to be tested. Smashing rocks with a hammer was hazardous and produced flying debris. Students were able to test some crushed up bricks, but none of the rocks tested appeared to have any noticeable calcium carbonate. In the future, it would be better if clean rock samples were obtained and crushed and provided for students to investigate.

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RESULTS AND EVALUATION

Objective data for this unit were collected with a fifteen question test (Appendix C) administered at the start of the unit. The same test was again administered upon completion of the unit, immediately following the standard chapter test. The test consisted of ten multiple choice questions and 5 short answer questions, which focused on the key objectives covered in the six adapted guided-inquiry laboratory activities. Subjective data were also collected by way of a post-unit survey (Appendix D) that was administered upon the completion of the unit. Both the objective and subjective data were used to determine the overall effectiveness of the adapted lab activities in the unit. The objective data were statistically analyzed using a paired t-test to show effectiveness.

Pre/Post Test Analysis

Forty-six students were involved in this study, completing both the pre-test and post-test for the unit (Appendix C). Data from the test were divided and analyzed separately in two sections, due to the nature of the responses. In the multiple choice section, students were encouraged to guess if they did not know the answer, so the possibility exists of variability due to guessing. In contrast, each of the five short-answer questions was scored out of a possible four or five points, which eliminated the element of guesswork. While most students did their best to come up with answers on the pre-test, in some cases students simply left them blank or responded with "I don't know".

It is also important to note that all students involved had previously completed one year of general Chemistry. A majority of the class entered Chemistry II having completed Chemistry I the previous year, meaning they should have some prior knowledge of the fundamental concepts of acid-base chemistry. A few of the students completed Chemistry I two years prior, and did not complete the acid-base unit during that year. Two students transferred from other school districts, having completed Chemistry at their previous schools, and it is unknown how much prior knowledge they may had.

Pre/Post Test Statistical Analysis: Multiple Choice

Figure 1 shows the combined results of the 10 question multiple choice section of the pre-test and post-test. 45 students scored higher on the post-test, with only one student scoring lower on the post-test. Out of 10 points possible, the mean score on the pre-test was 3.9, while the post-test was 7.4, giving a mean difference of 3.5.

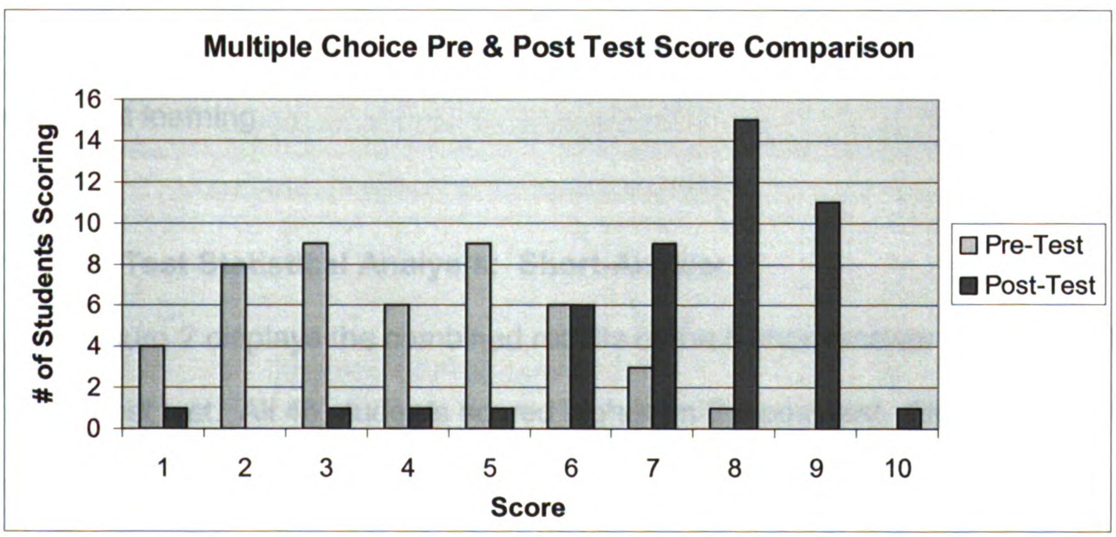


Figure 1: Comparison of Student Pre/Post Test Multiple Choice Scores

A paired t-test was used to determine if the unit results were statistically significant. The null hypothesis was that the implemented experiments and activities would have no effect on student learning as indicated on the pre and post-test comparisons. Statistical data and calculations are shown in Table 2.

Mean of Difference Scores	3.5
Standard Deviation of Difference Scores	1.9292
Estimated Standard Error	0.2844
Hypothesized Mean of Difference Scores (Null Hypothesis)	0
Degrees of Freedom (n - 1)	45
t-value	12.23
p-value	0.000

Table 2: Pre/Post Test Multiple Choice Statistical Data

The p-value for the pre and post-test comparison was equal to 0.000. Therefore, the null hypothesis is rejected indicating that the increase in student scores was significant, suggesting that the unit with these activities had an effect on student learning.

Pre/Post Test Statistical Analysis: Short-Answer

Figure 2 displays the combined results of the 5 short-answer questions of the pre/post test. All 46 students scored higher on the post-test. Out of 21 points possible, the mean score on the pre-test was 7.2, while the post-test was 12.9, giving a mean difference of 5.7.

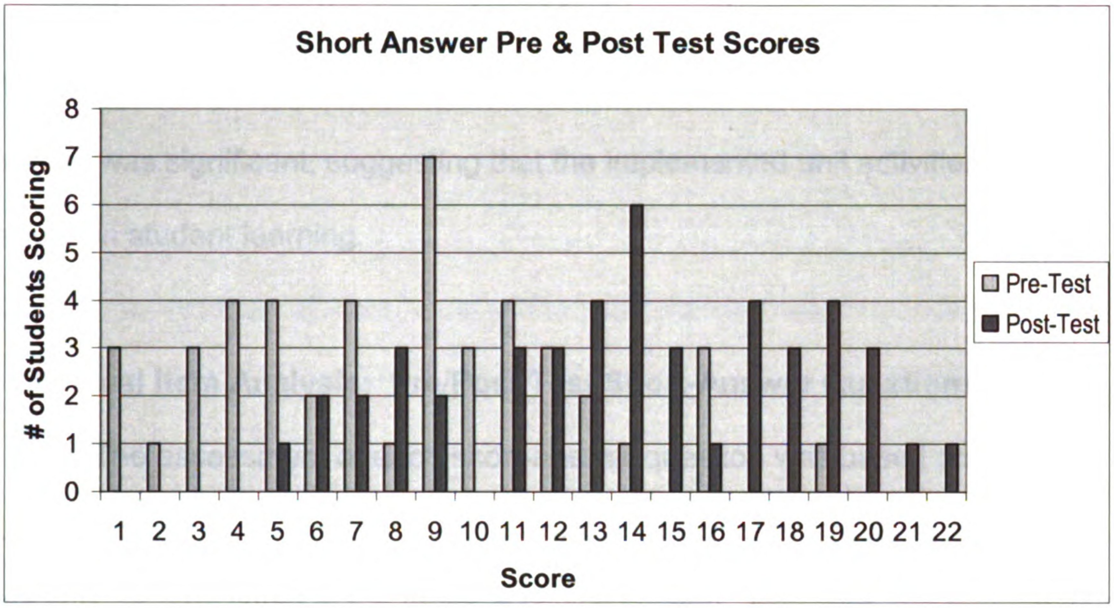


Figure 2: Comparison of Student Pre/Post Test Short Answer Scores

A paired t-test was used to determine if these results were statistically significant. The null hypothesis was that the implemented experiments and activities would have no effect on student learning as indicated on the pre and post-test comparisons. Statistical data and resulting calculations are shown in Table 3.

Mean of Difference Scores	5.7
Standard Deviation of Difference Scores	3.0903
Estimated Standard Error	0.4556
Hypothesized Mean of Difference Scores (Null Hypothesis)	0
Degrees of Freedom (*n* - 1)	45
t-value	12.50
p-value	0.000

Table 3: Pre/Post Test Short Answer Statistical Data

The p-value for the pre and post-test comparison was equal to 0.000. Therefore, the null hypothesis is rejected, indicating that the increase in student scores was significant, suggesting that the implemented unit activities had an effect on student learning.

Individual Item Analysis: Pre/Post Test Short-Answer Questions

The assessment of each short-answer question was based on 4 or 5 points for each question. Students were not able to guess at answers in this section, as they could in the multiple choice section. However, the teacher was able to give partial points for answers. It was interesting to note trends and misconceptions in each of these sections, as students attempted to explain their answers on the pre-test. A breakdown of overall scores for each individual question gives a good picture of the prior knowledge or ideas each student brought to the unit, and clearly shows areas where substantial knowledge was gained. It also exposes specific areas of weakness that would merit further focus and attention by the teacher in future units.

Question #11: Acid Base Definitions

Figure 3 shows the overall student scores on the pre and post-test for question #11. In this 4 point question, students were asked to explain standard definitions of acids and bases, specifically according to Arrhenius, Bronsted, and Lewis. It was expected that many of the students would recall definitions from material covered in the first year of Chemistry. Observation of individual scores

(Appendix E) shows that while 11 students increased their scores on the post-test, 8 students actually scored lower on the post-test (Appendix C). Many of the incorrect answers on the pre-test centered on descriptions of acids and bases, such as their taste, or pH, or other physical characteristics, but they lacked actual definitions. On the post-test, most of the students attempted to give those definitions, with some mixing up which were the "proton acceptors" or the "proton donors". As the question asked students to give two definitions of acids and bases, many were only given partial credit for only giving a single definition and failing to contrast the multiple definitions. In all, this question did not reveal significant progress, and these definitions should be given more attention in the future.

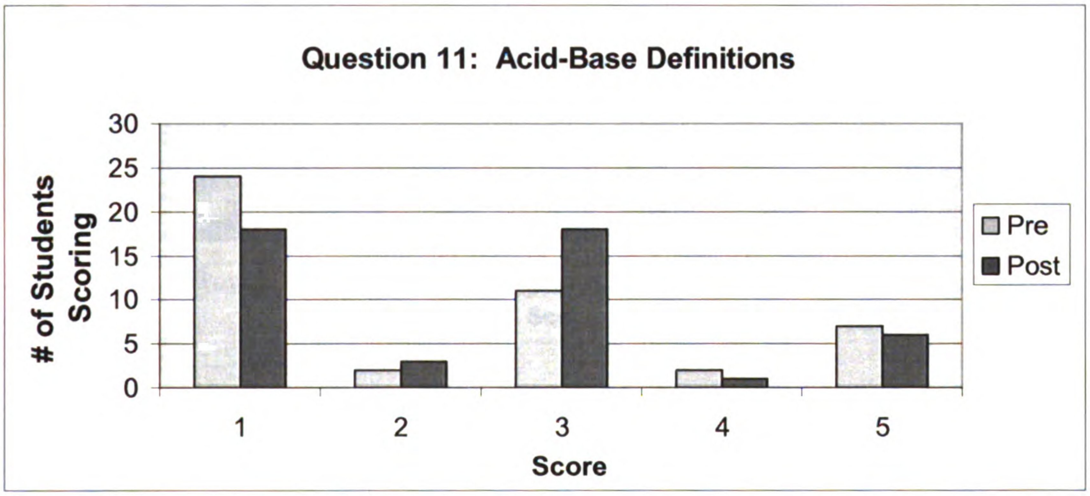


Figure 3: Comparison of Pre/Post Test Scores for Short Answer #11

Question #12: Definition of pH and the pH Scale

Figure 4 shows the overall student scores on the pre and post-test for question #12. In this 5 point question, students were asked to explain pH and describe the pH scale. Very few students were able to describe pH as a calculation derived from the concentration of hydrogen or hydronium ions in a solution. However, most students had some knowledge of the pH scale and were able to describe, or at least come close to describing, where acids, bases, and neutral solutions fall on the scale. Post-test scores show dramatic increase in scores with nearly half of the students scoring 5 points (See Appendix E). This result was expected since first year Chemistry students engaged in a more descriptive acid-base unit, in which they were taught the pH scale, but did not go into detail about logarithms and hydrogen ion concentrations.

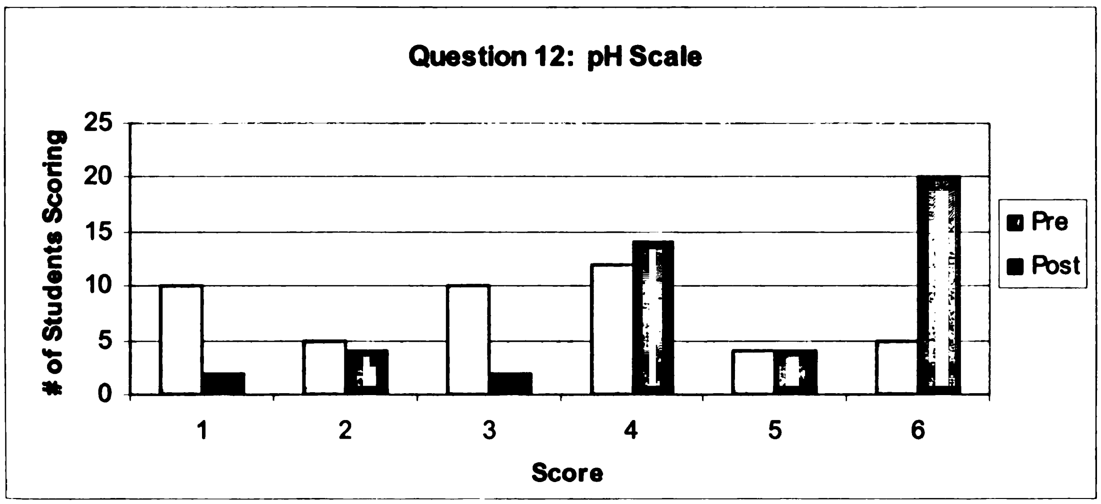


Figure 4: Comparison of Pre/Post Test Scores for Short Answer #12

Question #13: Acid-Base Indicators

Figure 5 shows the overall student scores on the pre and post-test for question #13. In this 4 point question, students were asked to explain what acid-base indicators were and how they are useful. The most common answer on the pre-test, which was not accepted, was that "Acid-base indicators indicate whether something is an acid or a base." A few students were given partial points for stating that indicators change color or help us understand the pH of a solution. Post-test scores were much higher, with almost all students able to describe that color changes occur at specific pH ranges. Only one student was able to use detail to describe that they are weak acids or bases that change their color as they undergo conformation changes from the gain or loss of a proton.

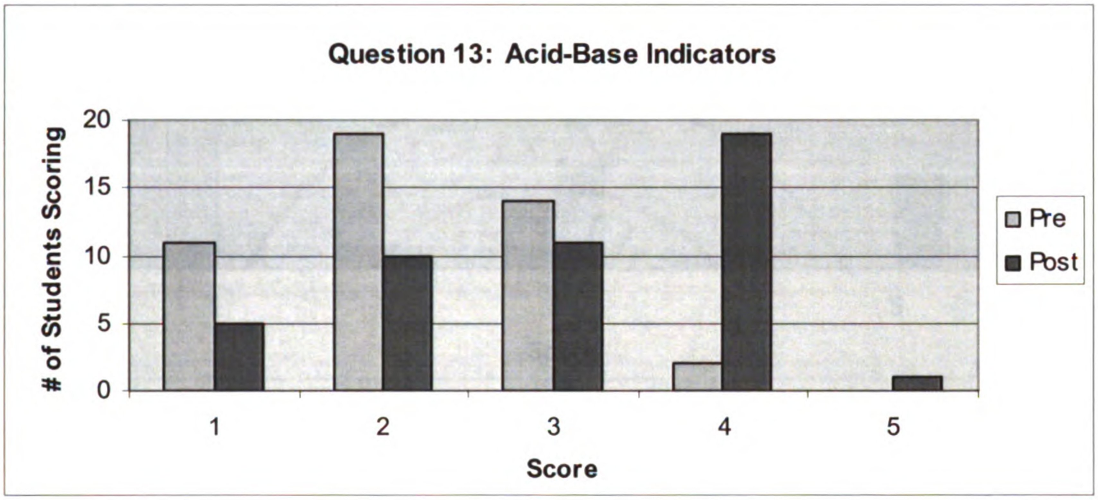


Figure 5: Comparison of Pre/Post Test Scores for Short Answer #13

Question #14: Buffers

Figure 6 shows the overall student scores on the pre and post-test for question #14. In this 4 point question, students were asked to explain what buffers are and how they work. 35 of the 46 students scored 0 points on the pre-test. Post-test scores were dramatically higher. This was expected because most students had never even heard of buffers before this unit. On the post-test, most students were able to describe the role of buffers in maintaining equilibrium of pH levels. However, many still could not describe the composition of a buffer as a solution of a weak acid and its conjugate base. Some students also came away with the misconception that all buffers are neutral, probably due to the fact that most of the buffer examples we discussed, like those found in lakes or your bloodstream, do maintain pH levels close to 7.0.

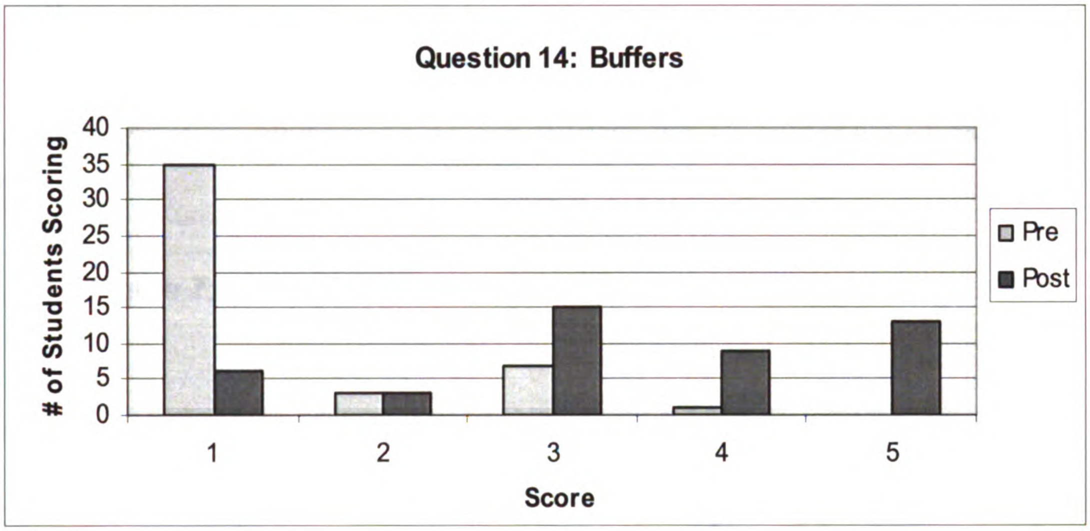


Figure 6: Comparison of Pre/Post Test Scores for Short Answer #14

Question #15: Neutralization Reactions

Figure 7 shows the overall student scores on the pre and post-test for question #15. In this 4 point question, students were asked to complete a neutralization reaction for the production of water and a salt. Students were also asked to identify the reaction as a double-replacement reaction. This topic was covered in the first year Chemistry course, as noted by the distribution of scores on the pre-test. The post-test showed a dramatic increase in scores, with nearly two-thirds of the class scoring 4 points.

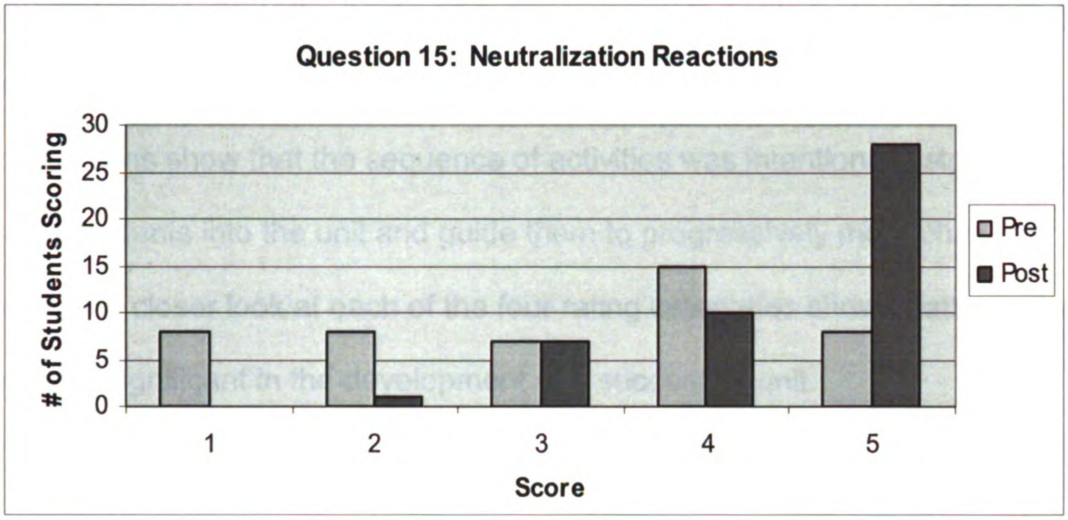


Figure 7: Comparison of Pre/Post Test Scores for Short Answer #15

Analysis of Post-Unit Survey Results

Upon completion of the unit, students were given a post-unit survey (Appendix 4) as a method of gathering feedback about each of the seven activities performed throughout the unit. Students were also asked for personal feedback about their favorite and least favorite parts of the unit and given permission to give any other comments. Students ranked individual activities in 4 different categories shown in Table 4 on a scale of 1 to 5 (1 = low, 5 = high).

Criteria	Description
Physically Engaging	Students ranked how physically involved they felt in this lab activity.
Mentally Engaging	Students ranked how much the activity seemed to engage them in thinking about the process.
Interesting	Students ranked how interesting or enjoyable they felt the activity was personally to them.
Learning	Students ranked how much they felt the activity helped them learn about the topic.

Table 4: Student Post-Unit Survey Activity Rating Categories

The results of the post unit survey, shown in Table 5, show some very interesting correlations in student opinions in the various categories. These correlations show that the sequence of activities was intentionally structured to bring students into the unit and guide them to progressively more challenging topics. A closer look at each of the four rating categories shows patterns that may be significant in the development of a successful unit.

Activity	Physically Engaging	Mentally Engaging	Interesting	Learning
Rainbow Connection Demo	1.1	2.7	3.8	3.2
Observing Various pH Indicators	3.8	3.2	3.7	3.5
Making pH Test Strips	3.7	2.9	3.4	3.3
Simple Acid-Base Titration	3.3	3.3	2.7	3.2
Analytical Acid-Base Titration	3.5	3.6	3.2	3.8
Graphing a pH Curve	3.2	3.3	3.1	3.6
Effects of Acid Rain on Lakes	3.1	3.3	3.4	3.6

Table 5: Average Student Activity Ratings on Post-Unit Survey

Category #1 - Physically Engaging

In the first rating category, students rated how physically engaging each of the activities was to them. This rating was not intended to rank student learning, but rather as an observation of how much each individual student felt they participated in the activity. As expected, the opening demonstration received a very low rating as students were merely observers as the teacher performed the activity. The first two activities following the demonstration were rated most physically engaging by the students. The activity "Observing Various pH Indicators" was a two day activity that kept students involved in combining many different indicators and buffers, and recording their results with colored pencils. I believe both the mixing process and the coloring, although viewed as tedious by some, definitely allowed each student to physically participate in the activity. The third activity "Making pH Test Strips" also presented each student with individual hands-on work as each student created their own pH test strips. Each student then took the strips home that night and tested solutions found around the house. Each student was intentionally asked to complete their own work in both of these activities so as to increase physical participation and avoid dependency on a lab partner to complete the assignment.

Each of the final four lab activities were completed in groups of two or three partners. A successful lab group shares the responsibilities of the work in a lab activity. However, this can decrease the feeling of physical involvement as students find themselves once again playing the role of observers as their partner completes a step in the activity. For example, in the activity "Graphing a pH Curve" there were a limited number of digital pH meters. Not only did groups share the pH meters, but only one individual in each group was involved with addition of aliquots and the use of the pH meter while the other student recorded the data. Therefore, the data pattern taught them something very important about pH curves, in spite of the fact that the collection of data itself was viewed as less physically engaging.

Category #2 – Mentally Engaging

Student opinions of the most mentally engaging activities were exactly the opposite of the physically engaging activities. The opening demonstration and first two activities were rated least mentally engaging, while the last four lab activities were rated most mentally engaging. The first two activities, while the most physically engaging, were not rated to be most mentally challenging. They involved strictly observations of color and recording visual results in a table. There were no complex calculations or high level comprehension questions with these activities. However, as the unit progressed, the complexity of the activities and the difficulty of the concepts increased, resulting in activities that were rated by students to be more mentally engaging. The most mentally engaging activity was the "Analytical Acid-Base Titration". This activity challenged students not only to make very careful measurements, but then process the resulting data using multiple calculations to discover the molarities of unknown solutions.

These results show an important pattern that is worth mentioning and studying further in the future. Students do not need to be highly physically engaged to feel mentally engaged. Teachers often look for hands-on activities as a way to physically engage their students in a topic, hoping to produce higher levels of cognitive engagement. However, students in the past have commented that when they are too focused on the mechanics of completing a procedure, they sometimes don't have time to really think about what is taking place. For example, several years ago I modified my lectures to be "fill in the blank" style note taking when students reported that they had trouble listening because they were too busy writing. Being both physically and mentally engaged may create a cognitive overload, so it makes sense that as a unit progresses students may become more mentally involved without requiring as much physical stimulus.

Category #3 - Interesting

The third category simply asked students to rank how interesting they felt each of the activities was. One of the goals of the adapted activities was to increase student interest in the topic and the activities. Simply being physically or mentally engaged does not necessarily reflect how each student personally feels about each activity, especially with honor students at this level who are willing to complete almost any task put before them, whether they like it or not. I feel that a real connection with the topic and concepts can only take place if there is a genuine interest held by the student. However, interest can be generated through a multitude of pathways, which can vary from year to year with different groups of students.

In these lab activities there is a definite progression of interest that seems to be tied to specific elements from each activity. The opening demonstration seems to have accomplished its objective, generating the highest level of interest on the first day. The primary purpose of this demonstration was to capture their attention and generate interest in the unit. The first activity "Observing Various pH Indicators" was also ranked as very interesting to the students. This activity followed on the heels of the demonstration and allowed students to produce bright rainbows of colors using a multitude of indicators. "Making pH Test Strips" also rated as very interesting to students, possibly because of the fun colors involved and also the exploration involved in the at home investigation. Students really seemed to be fascinated by the "magic" of indicator color changes.

Least interesting to the students were the activities that involved titrations. These three activities involved more complex concepts surrounding acid base reactions and required more data collection and calculations by the students. This suggests that students do not find these types of activities and calculations to be as fun as the more observational activities. It is also interesting to note that these three activities were ranked as the least physically engaging, suggesting that students feel they are having more fun if they feel they are physically participating in an activity.

Category #4 - Learning

The final category asked students to rate how much they felt the activities promoted learning about topics. A very distinct pattern emerged once again in which the last three activities rank the highest. These responses correlate almost exactly to the rankings in category #2 - mentally engaging. Quite simply, this means that students felt they learned the most from the activities that were the most mentally engaging. While they found some of the more physically engaging activities to be more fun, they did not report feeling that they learned as much from them. The "Analytical Acid-Base Titration" was the most complex activity in terms of data collection and calculations. Some students struggled to understand and complete that activity, but in the end, they felt they learned the most from it.

The results of the post-unit survey provided valuable feedback. The activities were structured and organized in a sequence that produced a desired pattern of student participation, cognitive engagement, interest and learning. Early activities were meant to introduce topics and generate interest, while later activities were meant to really challenge students on the topic with information being covered concurrently in classroom lecture. In the end, students felt they learned more when they were challenged to be mentally engaged in an activity. In the future, this progression will be used in all units.

Feedback and Student Quotes

The post unit survey also included three questions where students were asked to give feedback. In the first question students were asked to share what part of the unit they felt helped them learn the most. In the second question they were asked what their least favorite part of the unit was. In the final question they were asked if they would change anything about the unit.

The first question had an overwhelmingly common response. Most of the students felt that the lab activities were the part that helped them learn the most during the unit. One student wrote, "Doing all the labs. I like doing hands-on experiments." Another student responded by saying, "I am a very hands-on learner and by doing labs it helps me remember things." A third student put it this way, "Labs also showed me certain concepts that weren't portrayed through the lecture." A few students responded more specifically about the labs, stating a particular lab or activity that they thought helped the most. "Making the pH strips and taking them home. It was fun to find out things at home and got me more interested," stated one student. Several students mentioned the pH strips activity and the fact that actually doing chemistry experiments at home was very interesting. A few students also pointed out the titration and buffer labs because they were new topics to them and very challenging, again pointing out that the more mentally engaging material that challenges students helps them learn the most. Only two students responded that they felt they learned better from lectures than labs, with one of them stating that it was just faster to do lecture than do an activity.

There were a variety of responses to the second question about their least favorite part of the unit. A majority of the responses stated that lectures, notes, or homework were their least favorite. Most students find lecture and note taking to be the most boring part of any unit. These responses make sense considering most students had already responded in the first question that labs were their favorite part of the unit. It was interesting to note the responses of a few students focused most specifically on certain aspects. One student wrote, "The graphing. Graphing isn't all that exciting." Another student responded with "The least favorite would be all the equations," while yet another student said, "The math because math is just icky." Students who struggle with mathematical concepts usually find those parts to be their least favorite. Another student made a comment about how they felt rushed to complete the labs in the time allotted.

Periods are only 49 minutes in length, so we often found ourselves rushing to complete labs before the bell rang, and sometimes students stayed after to finish. The length of the labs was one of the greatest challenges teaching these activities for the first time.

In the final question, students were given a chance to respond with anything they felt should be done differently in the future. Most of the responses echoed a student who said, "Not have the unit take so long because it was difficult to remember everything." Another wrote, "Make the unit go more quickly." The unit was spread over almost two months, including two long holidays, and this made it even more challenging to students. A few students also noted that "some of the labs could be tweaked" because they "kept running out of time". Many of the labs were forced to be stopped and continued the second day, breaking up the pacing and stretching out the unit, which some students didn't like. However, a few students responded by saying "I felt the chapter was well taught and also fun at the same time." "I thought the unit was pretty good, I would keep it the same." While the positive feedback about the activities was encouraging, there are many adaptations that should improve the flow of the unit and activities in the future.

DISCUSSION AND CONCLUSION

The data collected (Appendix E) suggest that the adapted activities (Appendices G - L) implemented in an acid base chemistry unit in a second year chemistry class were successful in guiding students into the processes of inquiry, helping to generate more interest through relevance to their daily lives. Data also suggest that the activities helped students understand and remember the chemistry concepts that they were intended to teach. Students reported that the activities that were most physically engaging were the most interesting, however, they also reported that the activities that were most mentally engaging helped them learn the most (Table 4). This follows the constructivist principles that believe that students learn better when they are actively engaged and thinking in class (Farrell *et al.*, 1999).

As the teacher and developer of this unit, I believe, on the evidence collected, that the unit was a successful teaching tool and that activities showed a greater level of participation, interest, and ultimately learning by the students. Students were also observed to be facilitating each other's learning as the activities presented opportunities for guided inquiry to occur. The implementation of guided inquiry approaches altered the traditional role of students and instructors, increasing the use of peer instruction to help students achieve authentic learning (eg Landis *et al.*, 1998). However, the unit is still a work in progress and after only the first year teaching it, I found items that could be tweaked to increase the overall effectiveness of the activities and the unit. I was very open with the students throughout the unit and encouraged them to give feedback. Their post-unit survey included many comments, both positive and negative, which I found helpful and will do my best to apply in the future when teaching this unit.

The most common problem throughout the unit appeared to be the timing of the unit activities. As previously stated, the unit fell at a difficult time, being interrupted by two major holidays, Thanksgiving and Christmas. Upon returning from these holidays, I felt it was important to spend a day reviewing the material with students before moving on, which extended the length of the unit. In general students felt the unit took too long, counting from the first day we started to the day we finally tested, and it was challenging for them to keep their focus and remember all the information over that vacation time.

Another timing issue was that each of the labs was originally designed to take one day to complete, with the exception of the pH test strips lab which required the overnight period to dry the strips. However, students ran out of time on 4 of the 5 other activities, requiring a second day in the lab. The activities still worked with good success, but overall, students reported feeling the unit took too long to complete. In the future, there are some simple modifications and preparations that could be done to promote the completion of the activities within the 45 minute time period. Two of the activities, "Analytical Acid Base Titration" and "Graphing a pH curve" seemed to work better over two days. Students would be very rushed to complete an analytical titration in a single day, and the further investigation section is a valuable learning tool. With the pH curve activity, the students learned the process slowly on the first day, allowing them to obtain more consistent data in their second trial the next day. However, perhaps combining class data would provide a good representative data set, allowing the concept to be conveyed in a single day.

Another activity that I believe will be modified will be the Rainbow Connection demonstration. In order to successfully perform the demonstration, all the beakers must be prepared the day before. This means that many beakers are required in order to perform the demonstration for multiple classrooms during the day. I have come across several different ways to perform the same demonstration of color and acid base indicators that may require minimal preparation with the same enticing outcome. In one variation, the beakers, all filled with colorless solutions, could be transferred to another set of beakers in which they would change color. Transferring them back would return them to a colorless state. In another demonstration, a single solution is poured from beaker to beaker in a long sequence, displaying a new color or reaction each step of the way. Other chemicals can be added as well that would produce some other reactions, including bubbles or foam, which might add even greater interest to the demonstration.

The final experiment on the effects of acid rain on lakes was probably the weakest activity, producing inconsistent results that were difficult for students to interpret. The rock samples used may be to blame. More time needs to be spent experimenting with different types of rock of in a variety of granule sizes in order to ensure more consistent results. A better technique is also needed for smashing rocks that does not have the risk of flying rock particles and keeps the sample cleaner. It may be easier to visit a landscape store and purchase pre-crushed samples of specific rock and provide those for students to use. In spite of the problems encountered during the activity, students reported this activity helped them better understand the concepts of buffers.

One of the most beneficial activities for generating interest and producing learning was the activity in which students were able to make pH test strips and take them home to do some chemical testing of their own. Rarely, if ever, are students able to take any chemicals or chemistry equipment home, so this was a rare treat for them and a chance to make a real connection between their daily life and the science we were studying. Students, and parents, expressed that this was one of their favorite parts, and ranked that lab experiment as one of the most interesting.

Connections to materials and substances found in their daily life appeared successful in generating higher levels of student interest. Students expressed interest in exploring for flowers and plants to bring in for the indicator. They also thought it was very cool that things like soda pop and lemon juice could be titrated in a Chemistry lab. I find that anytime chemical experiments involve food or other items familiar to students, that real world connections take place that promote interest and learning about the subject. It is a goal of science education to enable students to observe their natural environment in order to develop the skills required to understand and explain both themselves and their environment (Marx *et al.*, 2006, from Panasan *et al.*, 2010.) It helps eliminate that age old question that every teacher has heard, "When in my life am I ever going to need to know this?" While most of chemistry taught in high school falls under the heading of "pure" chemistry, chemistry simply for the sake of knowing it, any time it can become applied chemistry, chemistry used to solve problems, students are likely to make better connections with the material. According to Crawford (2000) it can be beneficial for teachers to engage students in pursuing answers to questions important in their lives, as well as questions important to scientists.

There were some student complaints about lectures, note taking, homework, and especially the math involved in this unit. However, as a whole, the complaints seemed to be fewer than previous years as students spent more of this unit working in the lab with the hands-on activities. While lecture and note taking were still important, they became less of a focus in a unit filled with activities that gave the students some freedom to perform experiments and explore their surroundings.

Overall this was a very successful unit, as evidenced by the student responses on the post-test (Appendix C) and post-unit survey (Appendix D), and the activities adapted for the unit were essential for increasing the interest and effectiveness of the unit compared to previous years. Students were successful in designing and developing simple investigations. The initial guided procedure played a key role in teaching the students' techniques that they later used in the inquiry portions of the activities. The initial phase of each activity resembled structured inquiry, where students were given a procedure to follow. This was followed by a guided inquiry phase that involved students in designing their own investigations, or ways to collect data, processes that often involves creativity, as well as knowledge of the content and methods of data collection, in order to carry out analysis (Crawford, 2000, Coburn, 2000 Windschitl, 2002). An open inquiry activity may be a possibility for taking the students deeper into the process of inquiry, allowing them to develop their own questions and design their own investigations (ibid). In the future, I would keep the general structure of this unit intact, only slightly modifying the activities for smoother performance. As the lab activities were the main focus of the research, it would also be helpful to spend some time focusing on the other aspects of the unit, such as the lectures and worksheets. Behaviorism is the traditional belief that an idea can be transferred intact from the mind of an instructor to the mind of a student through lectures. But the best methodology to enable students to grasp and retain a concept begins with exploration or data collection (Spencer, 1999). The lecture method misses the opportunity to actively involve students in learning the material during class by showing students how to engage in chemistry (Francisco *et al.*, 1998). Lectures in this unit could be reexamined in terms of topic, length, and format, in order to reduce the amount of time students spend in lecture and increase the quality of the learning provided by the lecture. Perhaps the addition of class discussion, or self-guided reading and response might be another way to accomplish the goal of conveying topical information without spending time in class lecturing. If students had good resources to work with at home that allowed them to read through the information, then perhaps class time could be spent explaining and discussing and performing the activities. However, in the future it would be expected that the lab activities would be implemented the same way to produce similar success.

APPENDICES

APPENDIX A

Student Assent Form

Improving Student Comprehension Through Inquiry-Based Laboratory Activities

Student Assent Form

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education (DSME). For my thesis research, I have developed a unit on acid-base chemistry that focuses on incorporating inquiry-based learning into laboratory activities. This means that laboratory activities will contain more than step-by-step guidelines for completing procedures. They will also provide you with opportunities to design some of your own experiments that expand on what we've learned. There will also be post lab questions designed to stimulate thinking and application to real-world problems. As a student enrolled in Chemistry II for the 2008 school year, you may participate in my research study.

Data for the research study will be collected from standard student work generated in the course of teaching this unit. These will include pre and post tests, lab activities, and quizzes. I am asking for your permission to include your data in my thesis. Your privacy is a foremost concern. Your identity will be protected to the maximum extend allowable by law. During this study, I will collect and copy student work. However, all names will be removed from assignments prior to use in the study. All of the work being collected will be stored in a locked cabinet until my thesis is finished, and will be shredded at that time. In addition, your identity will not be attached to any data in my thesis paper or any images used in the thesis presentation.

Participation in this study is completely voluntary. Students who do not participate will not be penalized in any way. Students who choose not to participate in this study will still be expected to participate in class and complete all the assignments. Those students choosing to participate will not be given any extra work to complete. You may request to not participate in this study at any time and your request will be honored. There are no known risks associated with participating in this study as all activities involved will be a part of normal classroom and laboratory procedures. Participation in this study may contribute to determining better methods of incorporating inquiry into chemistry laboratory activities for high school students.

If you are willing to participate in this study, please complete and sign the attached form and return it to Mr. Mike Dickens by September 19, 2008. Please seal it in the provided envelope with your name on the outside of the envelope. The envelopes will be stored in a locked cabinet and opened after the unit is completed and grades have been assigned. Any work from students choosing to not participate in the study will be shredded.

If you have any questions about the study, please contact me by email at smith@myeagles.org or by phone at (517) 414-4945. Questions about the study may also be directed to Dr. Merle Heidemann at the DSME by email at heidema2@msu.edu, by phone at (517) 432-2152, or by mail at 118 North Kedzie, East Lansing, Michigan 48824.

If you have questions or concerns about your role and rights as a research participant, 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 e-mail irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

Thank you,

Mr. Kendon Smith
Chemistry Teacher
Columbia Central High School

Please print Student Name: ____

I voluntarily agree to participate in this thesis project.

____   ______________________
(Student Signature)   (Date)

APPENDIX B

Parent Consent Form

Improving Student Comprehension Through Inquiry-Based Laboratory Activities

Parent Consent Form

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education (DSME). For my thesis research, I have developed a unit on acid-base chemistry that focuses on incorporating inquiry-based learning into laboratory activities. This means that laboratory activities will contain more than step-by-step guidelines for completing procedures. They will also provide your child with opportunities to design some of their own experiments that expand on what we've learned. There will also be post lab questions designed to stimulate thinking and application to real-world problems. As a student enrolled in Chemistry II for the 2008 school year, your child may participate in my research study.

Data for the research study will be collected from standard student work generated in the course of teaching this unit. These will include pre and post tests, lab activities, and quizzes. I am asking for your permission to include your child's data in my thesis. Your child's privacy is a foremost concern. Their identity will be protected to the maximum extend allowable by law. During this study, I will collect and copy student work. However, all names will be removed from assignments prior to use in the study. All of the work being collected will be stored in a locked cabinet until my thesis is finished, and will be shredded at that time. In addition, your child's identity will not be attached to any data in my thesis paper or any images used in the thesis presentation.

Participation in this study is completely voluntary. Students who do not participate will not be penalized in any way. Students who choose not to participate in this study will still be expected to participate in class and complete all the assignments. Those students choosing to participate will not be given any extra work to complete. You may request that your child's information not be included in this study at any time and your request will be honored. There are no known risks associated with participating in this study, as all activities involved will be a part of normal classroom and laboratory procedures. Participation in this study may contribute to determining better methods of incorporating inquiry into chemistry laboratory activities for high school students.

If you are willing to allow your child to participate in this study, please complete and sign the attached form and return it to Mr. Mike Dickens by September 19, 2008. Please seal it in the provided envelope with your child's name on the outside of the envelope. The envelopes will be stored in a locked cabinet and opened after the unit is completed and grades have been assigned. Any work from students choosing to not participate in the study will be shredded.

If you have any questions about the study, please contact me by email at smith@myeagles.org or by phone at (517) 414-4945. Questions about the study may also be directed to Dr. Merle Heidemann at the DSME by email at heidema2@msu.edu, by phone at (517) 432-2152, or by mail at 118 North Kedzie, East Lansing, Michigan 48824.

If you have questions or concerns about your role and rights as a research participant, 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 e-mail irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

Thank you,

Mr. Kendon Smith
Chemistry Teacher
Columbia Central High School

I voluntarily agree to allow ________________________________ to participate in this study.
(Print Student Name)

Please check all that apply.

____ I give Mr. Smith permission to use data generated from my child's work in Chemistry II to be used in the thesis project. I understand that all data from my child will remain confidential.

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

____ I give Mr. Smith permission to use pictures of my child during his work on this thesis project. My child will not be identified in these pictures.

____ I do not wish to have my child's picture used at any time during this thesis project.

____ ____________________

(Parent/Guardian Signature) (Date)

APPENDIX C

Acids and Bases Pre/Post Test

Name: ____ Date: __________ Hour: ____

✂ --

Acids and Bases Pre-Test

Directions: Read each of the following questions carefully and select the correct answer.

___ 1. Which of the following general properties describe bases?
- a. Sour taste, corrosive, turn litmus from blue to red
- b. Sour taste, corrosive, turn litmus from red to blue
- c. Bitter taste, slippery, turn litmus from blue to red
- d. Bitter taste, slippery, turn litmus from red to blue

___ 2. A substance that can behave as both an acid and a base is called ____.
a. binary b. amphoteric c. dibasic d. diprotic

___ 3. A substance that has a pH of 5.6 would be considered ____.
- a. very basic
- b. slightly basic
- c. neutral
- d. very acidic
- e. slightly acidic

___ 4. By definition, weak acids are ____.
- a. substances that do not completely dissociate in water.
- b. substances that do completely dissociate in water.
- c. substances that don not dissociate at all in water.

___ 5. What is the pOH of a solution with a pH of 10.5?
a. pOH = 3.5 b. pOH = 5.5 c. pOH = 7.0 d. pOH = 10.5

___ 6. What is the pH of a solution if $[H^+] = 3.2 \times 10^{-5}$ *M*?
a. pH = 3.2 b. pH = 4.5 c. pH = 5.0 d. pH = 5.5

___ 7. What is the concentration of hydrogen ion in a solution if $[OH^-] = 1.0 \times 10^{-5}$ *M*?
- a. $[H^+] = 1.0 \times 10^{-5}$ *M*
- b. $[H^+] = 1.0 \times 10^{-9}$ *M*
- c. $[H^+] = 1.0 \times 10^{-10}$ *M*
- d. $[H^+] = 1.0 \times 10^{-14}$ *M*

___ 8. If $[H^+] = 1.0 \times 10^{-7}$ *M,* then the solution is ____.
a. a base b. an acid c. neutral

___ 9. Which of the following shows a conjugate acid/base pair?
- a. $H_2PO_4^{-1}$, PO_4^{-3}
- b. H_2SO_4, HSO_4^{-1}
- c. NH_3, NH_4OH
- d. HCl, NaOH

___ 10. How many milliliters of 0.1*M* NaOH would be needed to neutralize 15.0 mL of 0.3*M* HCl?
a. 5.0 mL b. 15.0 mL c. 30 mL d. 45 mL

Short Answer: Read each of the following statements and answer the questions as completely as you possibly can.

11. Acids and bases have multiple definitions, including those proposed by Arrhenius, Bronsted, and Lewis. What are acids and bases? Explain the difference between them using multiple definitions, if possible.

____
____
____
____
____

12. The most common method for comparing acids or bases is by measuring pH levels. What is pH? What does it measure? Describe the pH scale and what it means for a solution to be acidic, basic, or neutral.

____
____
____
____
____

13. There are many different types of acid-base indicators. Some are found naturally in things like flowers and fruits, while others are man-made. What are acid-base indicators? Why are they so useful? In simple terms, how do they work?

____
____
____
____
____

14. Buffers are found in many places in nature, including lakes, plant fluids, and even your blood, where they are important in maintaining homeostasis. What is a buffer? What is its job? How does it do its job?

____
____
____
____
____

15. Complete the neutralization reaction: $HNO_3 + NaOH \rightarrow$

a. What type of reaction is it? ______________________________
b. What kinds of products are formed in neutralization reactions? Describe the nature of these products and where they come from.

____
____
____

APPENDIX D

Acids and Bases – Post Unit Survey

Name: ____ Hour: ______________

✂ --

Acids and Bases – Post Unit Survey

Directions: This survey will be kept completely anonymous. Names will be cut off once study participants have been identified. Please answer the following questions as honestly as possible. Remember, the more truthful and complete you are in your responses, the more helpful it will be to the research study.

Part 1: Activity Ratings. In the table below, rate each of the activities in this unit on a scale of 1 – 5 (1 = low, 5 = high) according to the following criteria.

Column 1 – Physically Engaging. How physically engaging was this activity? Were you actively participating throughout this activity?
Column 2 – Mentally Engaging. How mentally engaging was this activity? Did you find yourself really thinking through the process as you performed the activity?
Column 3 – Interesting. How interesting did you find this activity? Did you enjoy the activity and find it to be fun?
Column 4 – Learning. How much did you learn from this activity? Did you feel that it helped model the topic for you in a way that helped you learn?

Activity	Physically Engaging	Mentally Engaging	Interesting	Learning
1. Rainbow Connection Demonstration				
2. Observing Various pH Indicators				
3. Making pH Test Strips				
4. A Simple Acid Base Titration				
5. Analytical Acid Base Titration				
6. Graphing a pH Curve				
7. Effects of Acid Rain on Lakes				

Part 2: Feedback. Answer the following questions, including specific examples or details.

8. What part of this unit do you think helped you learn the most? Why?

____

____

9. What was your least favorite part of this unit? Why?

____

____

10. Is there anything you think should be done differently about this unit in the future?

____

____

(Please feel free to use the back of this sheet if you need more space or have other comments.)

APPENDIX E

Individual Student Pre/Post Test Scores

		Pre-Test Multiple Choice											Post-Test Multiple Choice										
Hour	Code	1	2	3	4	5	6	7	8	9	10	Score	1	2	3	4	5	6	7	8	9	10	Score
1	A0707	1	X	1	X	X	X	X	X	X	X	2	1	X	1	1	1	1	1	1	X	1	8
1	C0907	1	X	X	X	X	X	X	X	X	X	1	1	X	X	X	X	X	X	1	1	X	3
1	D0322	1	1	1	1	1	X	X	X	1	1	7	1	X	1	1	1	1	1	1	1	1	9
1	E0917	1	X	1	X	1	X	X	1	X	1	5	1	1	1	1	1	1	1	1	X	1	9
1	J0130	1	1	1	X	1	1	X	X	X	1	6	1	X	1	X	1	1	1	1	1	1	8
1	J0323	X	X	1	1	X	X	X	1	X	X	3	X	X	1	1	1	1	1	1	1	X	7
1	J1026	1	X	1	1	X	1	X	X	1	1	6	1	X	1	1	1	1	1	1	1	1	9
1	L0610	1	X	1	X	X	X	X	X	X	1	3	1	X	1	X	1	1	1	1	X	1	7
1	L0724	1	X	1	1	X	X	1	1	X	1	6	1	X	1	1	1	1	1	1	X	X	7
1	L0910	X	X	X	X	X	X	1	X	X	1	2	X	X	1	1	1	1	1	1	1	1	8
1	M0124	X	X	1	X	X	X	X	1	1	X	3	X	X	1	1	1	X	1	1	X	1	6
1	M0314	1	1	1	X	X	1	X	X	X	X	4	X	X	1	X	1	X	X	1	X	1	4
1	M0323	1	X	1	X	1	X	X	1	X	1	5	1	X	1	1	1	1	1	1	X	1	8
1	M0531	1	X	1	1	1	X	1	X	X	X	5	1	1	1	X	1	1	1	1	1	1	9
1	M0612	X	X	1	X	X	X	X	1	X	X	2	X	X	1	1	1	X	1	1	X	1	6
1	M0919	1	X	1	X	1	X	X	X	1	1	5	1	X	1	X	1	1	1	1	X	1	7
1	M1114	1	1	1	1	X	X	X	1	X	X	5	X	1	1	1	1	1	1	1	1	1	9
1	N0408	X	X	1	1	X	X	X	X	X	X	2	1	X	1	1	1	1	1	1	X	X	7
1	P0224	X	X	1	X	X	X	X	X	X	X	1	1	X	1	1	1	X	1	1	1	1	8
1	P0725	1	1	1	1	1	X	X	1	1	1	8	1	X	1	1	1	1	1	1	1	1	9
1	R0719	1	X	1	X	X	X	X	1	X	X	3	1	1	1	X	1	1	1	1	1	X	8
1	R0926	X	X	1	1	X	X	X	X	X	X	2	1	X	1	1	1	1	1	X	1	1	8
1	S1003	X	X	X	X	X	X	1	X	X	X	1	X	X	1	1	1	1	1	X	X	1	6
2	A0508	1	1	1	X	1	X	X	1	1	X	6	1	1	1	1	1	1	1	1	X	1	9
2	A1025	1	X	1	1	1	X	X	X	X	1	5	1	1	1	1	1	X	1	X	X	X	6
2	D1007	X	X	X	1	X	1	1	X	1	X	4	X	1	1	1	1	1	1	1	1	1	9
2	F0104	X	X	X	1	X	X	X	1	X	X	2	1	1	1	1	1	1	1	1	1	X	9
2	J0408	1	X	1	1	X	X	X	1	X	1	5	1	1	1	1	1	X	1	1	X	X	7
2	J1220	X	X	1	1	X	X	X	X	X	1	3	1	X	1	1	1	1	1	1	1	X	8
2	J1225	1	X	1	1	X	X	X	1	X	1	5	1	1	1	X	1	1	1	1	1	1	9
2	K0108	X	X	1	1	X	X	X	X	X	X	2	1	X	1	X	1	X	1	1	X	X	5
2	K0331	1	X	X	1	X	X	X	X	X	X	2	1	1	X	1	X	X	1	1	X	1	6
2	K0612	1	X	1	1	X	X	X	X	X	X	3	1	X	1	X	1	1	1	1	1	1	8
2	L0101	1	1	1	1	X	X	X	1	X	X	5	1	1	1	1	1	X	1	1	X	1	8
2	L1112	1	X	1	X	X	X	X	1	X	X	3	1	1	X	X	1	1	1	1	X	1	7
2	L1226	1	1	1	1	1	X	X	1	1	X	7	X	1	1	1	1	X	1	1	1	1	8
2	M0525	1	X	1	1	X	X	X	1	X	X	4	1	1	X	1	1	1	X	1	1	1	8
2	M0613	1	X	1	1	X	X	X	1	1	1	6	1	1	1	1	1	1	1	1	X	X	8
2	M0730	X	X	1	X	X	1	X	1	X	X	3	1	X	1	1	1	1	1	1	X	1	8
2	M0803	X	X	X	1	X	1	X	X	X	1	3	1	X	X	1	1	1	1	1	X	X	6
2	M1106	X	X	1	1	X	1	X	1	X	X	4	1	X	X	X	X	X	X	X	X	X	1
2	N0517	1	X	1	1	X	1	X	1	1	X	6	1	1	X	1	1	1	1	1	X	1	8
2	R0418	X	X	X	1	X	X	X	X	X	X	1	1	1	X	1	1	1	1	1	X	X	7
2	R0924	1	X	1	X	X	X	X	1	X	1	4	1	1	1	X	1	X	1	1	1	X	7
2	W0531	1	1	X	X	1	X	X	1	X	X	4	1	1	X	1	1	1	1	1	1	1	9
2	W0703	1	X	1	1	1	X	1	1	X	1	7	1	1	1	1	1	1	1	1	1	1	10
Column Totals		30	9	37	27	12	8	6	24	10	18		37	21	37	33	43	33	42	42	22	31	
											Average Score	3.9										Average Score	7.4

Table 6: Individual Student Pre/Post Test Scores – Multiple Choice

		Pre-Test Short Answer						Post-Test Short Answer					
Hour	**Code**	**11**	**12**	**13**	**14**	**15**	**Score**	**11**	**12**	**13**	**14**	**15**	**Score**
1	N0408	0	0	1	0	3	4	0	3	0	0	2	5
1	M0612	0	0	0	0	0	0	0	3	0	1	2	6
1	M0314	0	1	1	0	0	2	0	0	1	3	2	6
1	P0224	0	0	0	0	0	0	0	3	1	0	3	7
1	C0907	0	0	1	0	2	3	0	1	3	2	1	7
1	E0917	2	3	2	0	3	10	2	3	2	0	4	11
1	S1003	0	1	2	0	0	3	0	4	3	3	2	12
1	J0323	0	4	2	0	3	9	0	5	2	1	4	12
1	L0724	0	2	1	0	1	4	2	5	1	2	3	13
1	A0707	2	0	0	0	2	4	2	0	3	4	4	13
1	M0531	2	2	2	0	0	6	0	4	3	2	4	13
1	L0910	0	2	1	0	1	4	2	3	3	3	3	14
1	R0719	2	2	2	1	3	10	2	3	2	3	4	14
1	R0926	2	0	0	0	4	6	2	4	3	4	3	16
1	M0124	2	3	0	0	3	8	2	5	3	3	4	17
1	J0130	1	1	2	2	4	10	2	5	3	3	4	17
1	P0725	0	3	1	2	4	10	2	4	3	4	4	17
1	L0610	2	4	1	0	1	8	2	5	3	4	4	18
1	M0919	2	5	3	2	3	15	4	5	2	4	3	18
1	M1114	4	5	2	0	4	15	2	5	3	4	4	18
1	M0323	4	3	1	2	1	11	4	5	3	3	4	19
1	J1026	4	2	3	0	4	13	4	5	3	4	4	20
1	D0322	4	4	1	0	3	12	4	5	4	4	4	21
2	K0331	0	1	0	0	1	2	0	2	0	0	2	4
2	N0517	0	3	0	0	0	3	0	1	1	0	3	5
2	K0108	0	0	0	0	0	0	0	3	1	0	3	7
2	M1106	0	0	1	0	0	1	0	1	2	1	4	8
2	W0531	0	0	1	0	1	2	2	1	0	2	3	8
2	M0803	0	2	1	0	2	5	0	3	1	2	4	10
2	M0730	0	3	0	2	3	8	0	3	1	2	4	10
2	L1112	2	3	2	0	2	9	0	3	2	2	3	10
2	J1220	0	2	2	0	2	6	1	5	0	2	3	11
2	F0104	0	3	2	0	3	8	0	3	2	4	2	11
2	D1007	1	1	2	0	3	7	0	2	3	3	4	12
2	R0418	0	3	1	0	4	8	0	3	3	2	4	12
2	M0613	2	2	2	1	2	9	2	3	2	2	4	13
2	R0924	3	4	2	0	2	11	1	5	1	2	4	13
2	A1025	3	3	1	2	3	12	1	5	1	2	4	13
2	L0101	0	0	1	0	4	5	2	5	1	4	2	14
2	M0525	0	2	0	0	1	3	2	5	2	2	4	15
2	J1225	0	3	0	0	3	6	2	5	3	2	4	16
2	J0408	4	2	1	0	1	8	2	3	3	4	4	16
2	K0612	0	3	1	1	3	8	2	5	3	2	4	16
2	A0508	4	5	1	2	3	15	3	5	3	3	4	18
2	L1226	2	5	1	0	3	11	4	5	2	4	4	19
2	W0703	4	5	2	3	4	18	4	5	2	4	4	19
Column Totals		58	102	53	20	99		66	166	93	112	157	
		Class Average Score					**7.2**	**Class Average Score**					**12.9**

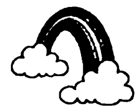
Table 7: Individual Student Pre/Post Test Scores – Short Answer

APPENDIX F

The Rainbow Connection Demonstration

The Rainbow Connection Demonstration

An acid/base demonstration using colorful indicators



Overview: Acid/base indicators change color in response to changes in pH. Each indicator has characteristic color forms and a narrow pH range over which color change occurs. By using a combination of indicators, we are able to create a colorful palette that changes over desired pH ranges. The three indicators used in this demonstration are colorless in acidic solutions, but produce the three primary colors in basic solutions.

Objectives: To vividly show reversibility of indicator colors in response to pH changes.
To show the formation of new indicator colors through the combination of indicators.

Materials: This demonstration requires that a series of solutions be prepared in advance. "Doctored" beakers must also be prepared in advance.

A. Indicators: Each of these recipes makes 15 mL of indicator solution, which is plenty for lots of go arounds of the demo. If you think you'll need more, please adjust accordingly. Please note that the indicators should be made up at least one day ahead of time so that the solutes are fully dissolved. Dissolve each indicator combination in 15 mL of 95% ethanol. Store in properly labeled dropper bottles.

a. Red	- 0.44 g phenolphthalein, 1.0 g *m*-nitrophenol
b. Orange	- 0.15 g phenolphthalein, 2.0 g *m*-nitrophenol
c. Yello	- 2.0 g *m*-nitrophenol
d. Green	- 0.2 g thymolphthalein, 2.0 g *m*-nitrophenol
e. Blue	- 0.5 g thymolphthalein
f. Violet	- 0.3 g phenolphthalein, 0.13 g thymolphthalein

B. Solutions

a. <u>Acid-alcohol solution</u> – Mix 250 mL of 0.05M sulfuric acid* and 250 mL of 95% ethanol. Transfer into a vessel from which you can easily pour this solution.
*Add 0.7 mL of 18*M* H_2SO_4 to 250 mL of distilled water.

b. <u>0.012*M* NaOH solution</u> – Prepare 1,200 mL of 0.012*M* NaOH** in a large flask or beaker. Can transfer into a large water pitcher for pouring.
**Add 0.58 g of NaOH to 1200 mL of distilled water.

c. <u>0.2*M* NaOH solution</u> – Prepare 100 mL of 0.2M NaOH*** in a beaker. Transfer to dropper bottle.
***Add 0.8 g of NaOH to 100 mL of distilled water.

d. <u>H2SO4/glycerine solution</u> – Dissolve 10 mL of 18M H_2SO_4 in 20 mL of glycerine. Transfer to a dropper bottle. This allows for drops to sink readily to the bottom and not mix quickly so that the colors will not change until stirred.

C. Preparing the Beakers

Arrange six clean 250 mL beakers in a row in clear view of the class or audience. Carefully place 2 drops of the proper indicator solution into each of the beakers. Be sure not to splash the indicator solutions on the sides. The vessels should be line up in proper rainbow sequence: ROYGBV. The drops take about 30 min to dry and the beakers should be prepared ahead of time. You now have six beakers, each with the appropriate dry indicator on the bottom.

D. The Demo

a. An equal volume, about 35 mL, of the acid-alcohol solution is carefully poured into each glass vessel. Tilt the beaker and pour the solution in carefully down the side so as not to disturb the dry indicator on the bottom of the glass. This will give the best results.

b. Slowly fill each beaker about ½ full with 0.012M NaOH solution, again being careful to pour the solution slowly down the side and not disturb the indicator. This volume of NaOH is weak enough that it should not yet make the solution basic. All beakers should appear as though they are filled with a clear solution.

c. Rapidly pour in just enough of the 0.12M NaOH solution to the beakers to almost fill them. The rainbow colors should appear as the excess base is added to each beaker. Try not to add too much base past the endpoint. You may need to stir with a glass rod if the acid solution has not fully dissolved the indicator.

d. Add 2-3 drops of H2SO4/glycerin solution to each beaker. The drops should sink to the bottom so that the solutions only change back to clear after vigorous stirring. Try to sneak a few drops of H2SO$ into your original large container that held the 0.012M NaOH to turn it acidic. This will be used in the last step.

e. "Titrate" each beaker back to its basic color by adding drops of 0.2M NaOH while stirring vigorously.

f. The contents of each beaker can now be poured back into the original large beaker or pitcher (now made acidic) one at a time. Because of the acid/glycerin "sneaked" into this container, the solutions should all turn colorless when they are poured.

Based on: JChemEd, Feb 84; p. 172-173, adapted from Hedemann, MSU by K. Smith

APPENDIX G

Activity #1: Observing Indicators

Observing Indicators	Name:	Hour:

Objective: To observe a wide array of natural and synthetic indicators and use them to estimate the pH of unknown solutions.

Introduction:

Acid-base indicators can be found almost anywhere. They are very common in plants and are often found in petals, leaves, and even fruits. These naturally occurring chemical indicators largely belong to a group of special compounds called *anthocyanins*. Some plants contain only a single anthocyanin compound, while many contain several anthocyanins that may change into a variety of colors. Most anthocyanins are found in fruits or leaves or petals that contain red, blue, or purple colors.

There also exist a wide array of specific chemical indicators that change various colors at narrow, known pH ranges. Today you will be placing indicators, both natural and synthetic, into solutions of various pH ranges, to develop a sense of the color spectrum exhibited by each indicator. This will allow us to identify the pH ranges over which specific color changes occur. You will then use these indicators to estimate the pH values of several unknown solutions.

Materials:

96 well reaction plate
pH 1 – 12 standard solutions
various indicators

Part 1 – Natural Indicator Extraction

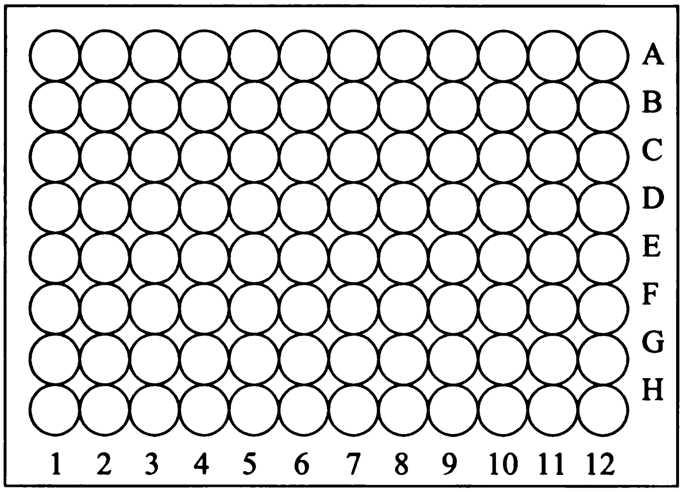
1. Obtain a sample of a fruit or flower to extract the color from. Your teacher will tell you how much you need in order to get enough color to test.
2. Break up, cut up, or crush your sample into your 125 mL Erlenmeyer flask.
3. Pour just enough water into your flask to cover your sample. You want to ake sure you will have enough liquid to use for your experiment and share with neighbors.
4. Heat your flask over a Bunsen burner on medium heat until it begins to boil, or the color appears to be extracting into the liquid. Shut off the burner as soon as it begins to boil or the extraction appears to be completing.
5. Allow the extract solution to cool for a few minutes before using.

Part 2: Observing Indicators

1. Obtain and rinse a 96 well reaction plate.
2. At the bottom of the plate are the numbers 1 – 12. These are to represent the pH of each well. Add two drops of the appropriate pH buffer solutions to each well.
3. Add 1 or 2 drops of an indicator solution to each cell in row A. Repeat for various indicator solutions in each row. Record your results.

Data and Observations:

Label the contents of each row of wells on the right. Then use colored pencils to record the colors and color changes you observe as best as you can.



A. ____________________

B. ____________________

C. ____________________

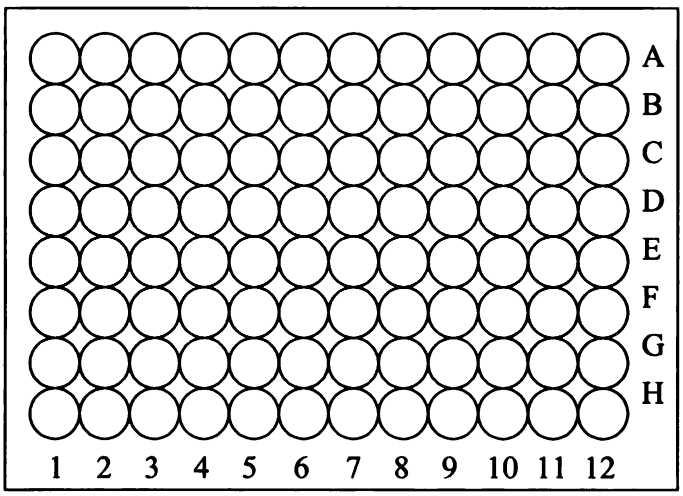
D. ____________________

E. ____________________

F. ____________________

G. ____________________

H. ____________________



A. ____________________

B. ____________________

C. ____________________

D. ____________________

E. ____________________

F. ____________________

G. ____________________

H. ____________________

Part 3: pH of Unknown Solutions

1. Rows G & H should be empty. Obtain an unknown solution and place two drops into each of the cells in row G. Repeat with a second unknown solution in row H and rows G & H on the second reaction plate.
2. Add two drops of each of the 12 different indicator solutions you tested into each indicator and record your results. Record the estimated pH values for the unknown solutions below.

Unknown #1: ______________	Unknown #3: ______________
Unknown #2: ______________	Unknown #4: ______________

APPENDIX H

Activity #2: Making pH Test Strips

Making pH Test Strips Name: Hour:

Objective: To create pH test strips using natural anthocyanins and generate a color coding chart that can be used to find the pH of unknown solutions.

Introduction:

pH can be easily estimated using strips of paper that contain acid-base indicator dyes. pH strips can be made using a variety of indicators that function over different pH ranges. Litmus paper is a simple indicator that changes from red to blue at a pH of about 7.0. Other indicating strips contain a mixture of various chemical indicators that give multiple color changes over a broader spectrum. Universal indicator, for example, contains chemicals that produce virtually all the colors of the rainbow across a pH range of 2.0 – 12.0, making it possible to identify a more specific pH within that range.

Anthocyanins are a class of water-soluble plant pigments that are most often found in flowers or fruits, but may also be found in leaves, stems, and even roots. These pigments manifest different colors depending on pH levels. These pigments can easily be extracted and applied to paper to form a natural pH test strip.

In this lab you will be extracting anthocyanins from red cabbage leaves and using the extract to create red cabbage pH test strips. The strips will be dipped in to solutions of known pH in order to create a color chart that can be used to find the pH of unknown solutions.

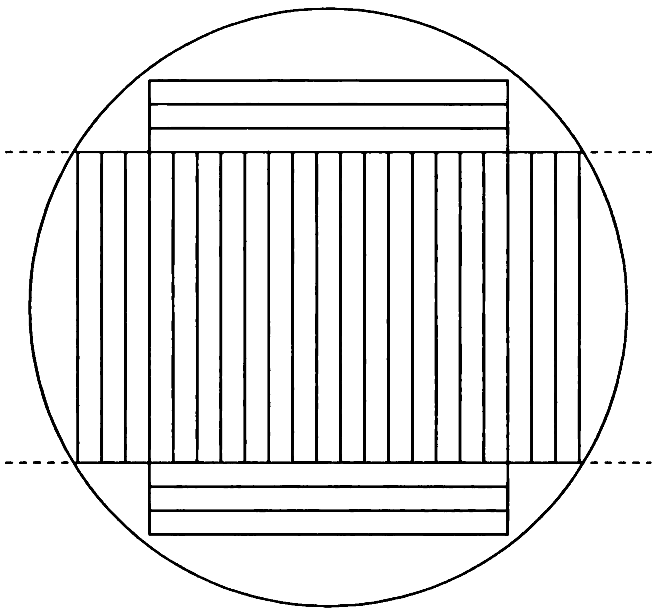
Materials:

Red cabbage leaves
Distilled water
9.0 cm filter paper circles
Small foam plates
pH 2.0 – 12.0 buffers
1.0*M* HCl solution
Various acid/base unknowns

Day 1 Procedure:

1. Weigh out about 30 grams of red cabbage leaves. Tear them into small pieces and add them to a clean 250 mL Erlenmeyer flask.
2. Add 100 mL of distilled water to the flask. Using a Bunsen burner, heat the mixture on high until it begins to boil vigorously. Shut off the burner immediately and stir the contents for a few minutes as the solution cools, allowing the water to extract as much of the pigment as possible.
3. Decant the liquid into a clean 125 mL Erlenmeyer flask and discard the boiled cabbage leaves.
4. Label two small foam plates with your name and place a 9.0 cm filter paper circle in the center of each.

5. Using a disposable pipet, add about 70 – 80 drops of red cabbage extract to each of the filter paper circles. You should add enough to completely saturate the paper without overflowing onto the plate. Carefully set the plates in an area designated by your teacher to dry overnight.
6. Label your flask of cabbage extract with your name and place foil over the opening. Place it in the refrigerator to save for later use.



pH Strip Cutting Template

Use the template on the left as a guide as you cut your circular filter papers into strips. You should be able to get 20 – 24 strips from a single piece of filter paper.

Start by cutting off the top and bottom of the filter paper as shown by the two dotted lines. This center section can now be cut into strips that are about 5.0 cm long and 0.4 cm wide.

The top and bottom sections you cut off can be cut into 2 – 3 strips of the same size as those from the center section.

Day 2 Procedure:

1. Use the template and instructions in the box above to cut your dry filter paper circles into strips. Place your strips in a small vial for storage.
2. Obtain and wash a 24 well reaction plate. After washing, rinse the plate with some distilled water and dry it.
3. Into the first cell, add 10 drops of 1.0*M* HCl. Into the next 11 cells, add 10 drops of each buffer solution, from 2.0 – 12.0.
   *Note: It is important to keep track of which solutions are in each cell. You may want to place the reaction plate on a blank piece of scrap paer and make notes about which solutions are in each row of cells.
4. Obtain a 5 inch wide piece of plastic coated bench liner paper. Lay it on your lab bench with the plastic side facing upward.
5. Dip a single test strip into each of the twelve wells, starting with the 1.0*M* HCl and proceeding in order up to pH 12.0. Lay the test strips side by side on the plastic coated paper. Use a marker to label the pH of each solution tested by each strip. (1.0*M* HCl = pH 1.0) This is your color chart to be used with testing your unknown solutions. Complete the table on the following page describing with words the colors you see the indicator form at each pH.

Red Cabbage Indicator Colors at Various pH Levels				
pH	Color of Indicator		pH	Color of Indicator
1.0			7.0	
2.0			8.0	
3.0			9.0	
4.0			10.0	
5.0			11.0	
6.0			12.0	

Estimating pH of Solutions Using Strips

Use your pH test strips to estimate the pH of the following solution in the remaining 12 wells of your reaction plate. Make up each of the solutions as described in the table below. Be sure to GENTLY SWIRL the plate in order to mix the solutions before dipping your test paper. Dip your test strips in each solution and compare them to the 12 standards previously made and estimate the pH of the solution. Use only distilled water to prepare your solutions.

Estimated pH of Various Unknown Solutions	
Solution	Estimated pH
10 drops vinegar	
5 drops vinegar, 5 drops water	
1 drop vinegar, 9 drops water	
10 drops ammonia	
5 drops ammonia, 5 drops water	
1 drop ammonia, 9 drops water	
10 drops water	
10 drops 0.2*M* NaOH	
5 drops 0.2*M* NaOH, 5 drops water	
1 drop 0.2*M* NaOH, 9 drops water	
10 drops orange juice	
10 drops soap solution	

Design an Experiment: Testing pH of Solutions at Home

There are many different household solutions that may be acids or bases. Take your remaining pH paper strips home in a small sealed vial and see how many solutions you can find. Create a table or chart in the space below to present all the data you collect. Be sure to identify all the solutions you test and record the results of your tests, even for solutions that may not appear to be acids or bases.

Post Lab Questions:

1. What general types of solutions or materials did you find to be acidic? Alkaline?

____

____

____

2. How is it possible for red cabbage anthocyanins to show so many different color changes across the pH spectrum when most indicators only show two colors?

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APPENDIX I

Activity #3: A Simple Acid/Base Titration Lab

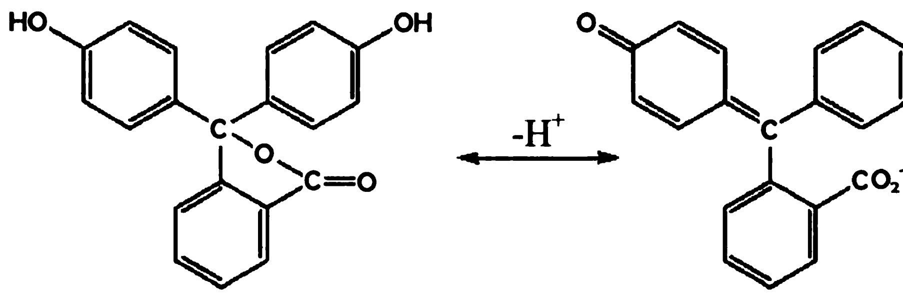
A Simple Acid/Base Titration Lab	Name:	Hour:

Introduction:

Acid-base indicators are weak acids and bases that change their color at specific pH ranges. Most indicators have two molecular forms that differ only by the presence or absence of a hydrogen ion. What makes an indicator useful is that each of its forms appears as a different color. Indicators change their molecular structure in the presence of acids and bases and allow us to see by their color when a solution reaches a certain, specific pH.

$$\underset{\text{Acid Form}}{HIn} \rightleftharpoons H^{+1} + \underset{\text{Base Form}}{In^{-1}}$$

Phenolphthalein is a very commonly used indicator in reaction that involve neutralizing an acid by adding a base to it. In the presence of an acidic solution, phenolphthalein is completely colorless. However, once a solution is neutralized to a pH of around 8.0, the indicator turns a very bright pink color.



phenolphthalein pH < 8.2 (clear)

phenolphthalein ph > 8.2 (pink)

Acids have low pH values, less than 7.0, while bases have high pH values, from 7.0 to 14.0. The addition of a base to an acid will begin to neutralize the acid and raise the pH level. Bases neutralize acids by absorbing the extra hydrogen ions in solution. The most common bases contain the hydroxide ion, which can join together with the hydrogen ions from acids to form water, a completely neutral substance, as shown in the reaction below.

$$OH^{-1} + H^{+1} \rightleftharpoons H_2O$$

In this lab exercise you will be titrating various acid solutions with sodium hydroxide, a strong base. Titration is a process in which a titrant of known concentration is added to unknown solutions until an endpoint is reached or exceeded. The endpoint is usually signaled visually by use of a chemical indicator. Comparison of the volume of titrant used to the volume of unknown allows for the molarity of the unknown to be calculated. How will you know that you have added enough base to neutralize the acid? What would happen if you continued to add more base even after the solution was neutralized?

Safety: Acid and bases are corrosive chemicals and may cause irritation or severe burns to skin and eyes. Wear safety goggles at all times when handling acids and bases. Move carefully around the lab to avoid accidents or spills. Wash your hands thoroughly before leaving the laboratory. Acids and bases may bleach or destroy clothing on contact.

Procedure: Read through ALL steps carefully before beginning.

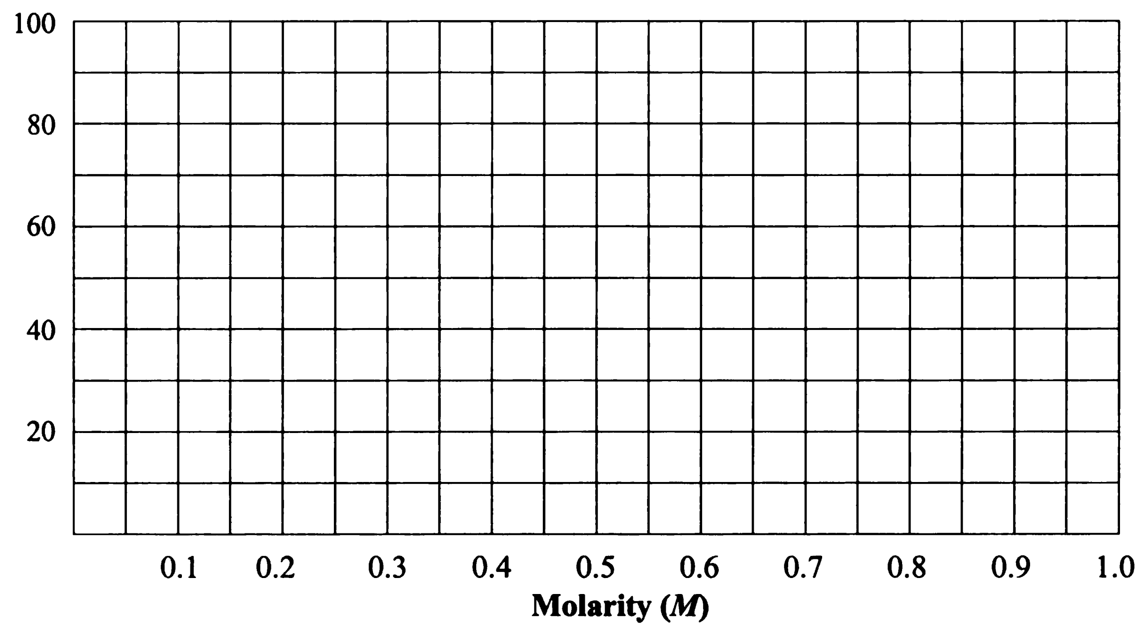
1. Carefully clean and dry 6 large test tubes. Label each 1 – 6 with a marker.
2. Add 1.0 mL of 0.2*M* HCl, 0.4*M* HCl, and 0.6*M* HCl to tubes 1 – 3 respectively.
3. Add 1.0 mL of 0.2*M* H_2SO_4, 0.4*M* H_2SO_4, and 0.6*M* H_2SO_4 to tubes 4 – 6.
4. Add 1 drop of phenolphthalein indicator to each test tube.
5. Add 20 mL of 0.35*M* NaOH solution to a clean 150 mL beaker.
6. Count the number of drops of NaOH solution required to turn the solution pink. Slow to ONE DROP AT A TIME when you see the pink begin to persist, making sure to swirl and mix the contents between each drop. Stop when it STAYS pink. Repeat with the other five test tubes and record your results in the table.
7. Add 2 drops of vinegar to one of your test tubes and stir.
8. Add 10 drops of sodium hydroxide solution to this test tube and stir.
9. Pour all solutions down the drain and clean and wash your equipment.

Data Table:

Solution	Number of Drops of NaOH Added		
	0.2 *M*	**0.4 *M***	**0.6 *M***
Hydrochloric Acid **HCl**			
Sulfuric Acid **H_2SO_4**			

Create a Graph: On the chart below, graph the number of drops required to titrate each acid molarity. Create a separate line for each of the two acids by connecting the three points as best as possible and extend the lines beyond your data points up to 1.0 *M*.

Drops of NaOH vs. Molarities of Given Acids



Design an Experiment: Molarity of Vinegar

Set up an experiment to test the molarity of vinegar using the solutions provided in this lab. Run the test on a vinegar sample and use the graph you made on the previous page to associate the number of drops with the concentration of acid in vinegar.

Note: Vinegar contains acetic acid, a two carbon organic acid that contains a carboxyl group.

a. Draw the structure of acetic acid in the box to the right.

b. Is acetic acid a strong or weak acid? ____________

c. Is acetic acid monoprotic or diprotic? ____________

Data and Observations: Use the space below to record your data and observations or create charts or tables for your vinegar investigation.

Graphing the Molarity of Vinegar: Plot a point to the graph on the previous page that shows your estimation of the molarity of vinegar.

a. What do you estimate the molarity of vinegar to be? ________________

Post-Lab Question: Answer the following question as completely as possible.

1. Explain why the titration of sulfuric acid, H_2SO_4, did not require the same amount of sodium hydroxide as the titration of hydrochloric acid, HCl.

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APPENDIX J

Activity #4: Analytical Titration Lab

Analytical Titration Lab Name: Hour:

Acid/Base Review:

In a neutralization reaction, an acid and a base are combined to form a neutral product, usually a salt and water. The combination of hydrochloric acid and sodium hydroxide is the best example of a neutralization reaction. Hydrochloric acid is a strong acid and sodium hydroxide is a strong base. They combine to form sodium chloride (table salt) and water in the following reaction:

$$HCl + NaOH \rightarrow NaCl + HOH$$

Today we will be observing this reaction with a technique known as titration. In titration, we add the base solution to the acid solution until it is completely neutralized. In order for us to tell when we have completely neutralized the acid, we will use an indicator called phenolphthalein. Phenolphthalein indicator remains completely colorless when it is mixed with an acid solution. When the solution reaches a pH level of about 8.0, the phenolphthalein indicator undergoes a color change and remains pink.

You will be preparing your own base solutions for this experiement. Be careful when handling acid and base solutions. *Always wear safety goggles*!

Materials:

Acid solutions of unknown concentration
NaOH pellets
Phenolphthalein indicator solution
50 mL buret
Buret Clamp
100 mL volumetric flask

Step 1: Preparing a Base Solution of Known Concentration

Prepare a solution of sodium hydroxide by weighing out 5 pellets and adding them to a 100 mL volumetric flask of distilled water. Use the exact mass of the 5 pellets to calculate the exact concentration of your sodium hydroxide solution before starting the lab.

Step 2: Testing Your Unknown Solutions

1. Rinse your buret with distilled water and drain it completely.
2. Add your sodium hydroxide solution to the buret. DO NOT fill it above the zero mark. Never allow it to drain below the 50 mL mark. Pour enough in so that it is filled between the 0 – 5 mL marks. *You don't have to start exactly on zero!* Record the initial volume in the buret in your data table to the nearest 0.01 of a milliliter. (Remember to estimate between the lines!)

3. Measure out exactly 10 mL of your acid solution into a clean and dry 50 mL beaker. Add a drop of phenolphthalein indicator to this acid solution before testing.
4. Begin slowly adding the sodium hydroxide solution to the acid. You may add the solution more quickly at first, but you should slow it down to drop by drop as soon as you begin to see pink forming. Gently swirl the beaker continuously to mix it thoroughly as you add the base. Stop adding your solution as soon as the acid *barely turns pink* and *stays pink.*
5. Record the final volume in the buret in your table and discard your pink solution. Clean your beaker to try another sample.

Data Table: Record your data below and show your work on a separate piece of paper.

Sample	**HCl Trial 1**	**HCl Trial 2**	**H_2SO_4 Trial 1**	**H_2SO_4 Trial 2**
Initial Volume of NaOH in Buret				
Final Volume of NaOH in Buret				
Total Volume of NaOH Used				
Molarity of NaOH Solution				
Volume of Acid Sample Tested				
Moles of NaOH Used				
Moles of Acid Tested				
Molarity of Acid Solution				

Data Table: Titration of Soda and Lemon Juice

	Fresh Soda		Flat Soda		Lemon Juice	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Initial Volume of NaOH in Buret						
Final Volume of NaOH in Buret						
Total Volume of NaOH Used						
Molarity of NaOH Solution						
Volume of Acid Sample Tested						
Moles of NaOH Used						
Moles of Acid Tested						
Molarity of Acid Solution						

Questions and Calculations:

1. Use your notes to write the complete structural formula of citric acid below. How many ionizable hydrogen atoms does it have? Circle them in the structure below.

2. Write the balanced equation for the complete neutralization of citric acid with sodium hydroxide using the condensed chemical formula for citric acid.

3. In the space below, show the work you would do to solve for each of the values in the data table for trial 1 of your lemon juice titration. Circle each answer that was recorded in the table as you arrive at it below.

4. Carbon dioxide reacts with water in a synthesis reaction to form carbonic acid. Write the equation for that reaction below. (It will balance with 1:1 ratios.)

5. Explain the difference observed between the titration of the fresh soda and the flat soda.

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APPENDIX K

Activity #5: Graphing a pH Curve

Name: ______________________________ Date: __________ Hour: _____

Graphing a pH Curve

Procedure:

1. Set up a buret on a ring stand with a buret clamp.
2. Fill the buret to just over the 0 mL mark with 0.1*M* NaOH solution.
3. Place a 250 mL beaker below your buret and drain out the excess NaOH solution until the meniscus is exactly on the 0 mL line. Discard this NaOH in the sink.
4. Add exactly 18.0 mL of 0.1*M* HCl to a clean 150 mL beaker.
5. Place the beaker of acid below the buret and adjust the height so the tip of the buret is about even with the top of the beaker.
6. Use a digital pH meter to measure the pH of the acid in the beaker before adding any NaOH and record it in the chart as the first pH at 0 mL. Submerge only the tip of the pH probe and stir. Wait for the pH meter to stabilize before recording.
7. Fill a 400 mL beaker about halfway with distilled water and set it aside for rinsing your pH meter.
8. Between measurements, rinse your pH meter's electrode under a stream of tap water and dip it into the beaker of distilled water. Gently shake off the excess water on the electrode before making your next measurement.
9. Begin adding aliquots of NaOH to the acid solution as shown in the chart below, starting with 1 mL aliquots. Note that part way through the aliquots change to 0.5 mL.
10. After the addition of each aliquot, use the pH meter to check the pH of the solution and record it in the table.
11. Continue until 37 mL of NaOH have been added to the acid. If there is time, refill your buret and get a fresh sample of acid to repeat for a second trial.
12. Dispose of all solutions down the sink when done and wash all your glassware. Flush the buret completely with tap water AND distilled water and leave it with the valve OPEN to dry.

Buret Volume	pH	Buret Volume	pH	Buret Volume	pH
0		15		23	
1		15.5		24	
2		16		25	
3		16.5		26	
4		17		27	
5		17.5		28	
6		18		29	
7		18.5		30	
8		19		31	
9		19.5		32	
10		20		33	
11		20.5		34	
12		21		35	
13		21.5		36	
14		22		37	

Day 2: Repeat the procedure from the first day and obtain a second data set to compare with.

Buret Volume	pH	Buret Volume	pH	Buret Volume	pH
0		15		23	
1		15.5		24	
2		16		25	
3		16.5		26	
4		17		27	
5		17.5		28	
6		18		29	
7		18.5		30	
8		19		31	
9		19.5		32	
10		20		33	
11		20.5		34	
12		21		35	
13		21.5		36	
14		22		37	

Graphing pH Curves: Carefully graph your data from day 2 in the space below. Be sure to label your x-axis and y-axis values.

pH

Volume of NaOH added in milliliters

APPENDIX L

Activity #6: Effects of Acid Rain on Lakes

Effects of Acid Rain on Lakes Name: Hour:

Objective: To explain why lakes with limestone or calcium carbonate beds experience less adverse effects from acid rain than lakes with granite beds.

Introduction:

Limestone is a sedimentary rock composed largely of the mineral *calcite*, which is calcium carbonate. *Calcium carbonate* ($CaCO_3$) is also found in materials such as marble, chalk, and the shells of marine organisms. It is a mineral that is slightly soluble in water, and its solubility is affected significantly by factors such as pH, water temperature, or concentration of dissolved ions. Calcium carbonate exhibits a unique property known as *retrograde solubility*, which means that it becomes less soluble as the temperature of the water is increased. Marble is made up of calcium carbonate that has been transformed through the process of metamorphism, in which it is exposed to great amounts of heat and pressure.

Granite is a type of igneous rock, formed from the solidification of cooling magma. Granites vary in their crystalline compositions, producing many different color combinations depending on the minerals contained. *Quartz* is the most abundant mineral in most granites, along with many other metal oxides. Quartz is composed of silicon dioxide (SiO_2), which is the main component of sand and glass. Quartz, as well aas most minerals in granite, is insoluble in water.

Compounds containing the carbonate ion react with strong acids to form carbonic acid, a weak acid, as shown in the reaction below:

$$CaCO_3 + 2HCl \rightleftharpoons CaCl_2 + H_2CO_3$$

Carbonic acid exists in equilibrium with carbon dioxide (CO_2) in aqueous solutions. Water can only hold a given amount of CO_2 at any given moment, depending on its temperature. As carbonic acid builds up in water, it separates into water and CO_2. These excess levels of CO_2 will then be released to the air in order for water to maintain its maximum CO_2 level. The reversible equation is shown below:

$$H_2CO_3 \rightleftharpoons H_2O + CO_2$$

In this lab, you will be observing the buffering effect of carbonate on aqueous solutions. You will then design a test to determine if various rock samples contain the carbonate ion.

Materials:

Limestone chips
Granite chips
1.0*M* & 0.01*M* HCl solutions
Bromcresol green solution
3 x 150 mL beakers
Distilled water
100 mL graduated cylinder
pH paper or pH meter

Procedure – Limestone vs. Granite:

1. Clean and dry three 150 mL beakers. Label the beakers 1 – 3.
2. Add 20 mL of distilled water to each beaker.
3. Add 2.00 grams of limestone chips to beaker #1 and stir for about 10 seconds.
4. Add 2.00 grams of granite chips to beaker #2 and stir for about 100 seconds.
5. Test and record the initial pH of the solutions in each beaker using pH paper.
6. Add 5 drops of bromcresol green indicator to each beaker. Stir and record your initial observations in the table.
7. Add 2 drops of 1.0M hydrochloric acid to beaker #1. Swirl the contents for about a minute. Record your observations in the table. Repeat with each of the beakers.
8. Repeat step #7 with each beaker 2 more times. Swirl and record your observations in the table.
9. Test the final pH of the solutions using pH paper and record it.

Data and Observation Tables:

	Beaker #1: Limestone	Beaker #2: Granite	Beaker #3: Distilled H_2O
Initial pH of solution			
Final pH of solution			

	Initial Observation	2 drops HCl	4 drops HCl	6 drops HCl
Beaker #1: Limestone				
Beaker #2: Granite				
Beaker #3: Distilled H_2O				

Design an Experiment: Testing Unknown Rocks

Obtain crushed samples of several different rocks. Design an experiment to test for the presence of calcium carbonate in these samples. You will have the following materials at your disposal: 0.01*M* HCl, bromcresol green indicator, distilled water. Write up your experiment on a separate piece of paper and include the following:

I. Procedure – Describe the steps you took in the experiment.
II. Data & Observations – Create a table in which to record data and observations from your experiment.
III. Analysis – Give your results and explain your conclusions.

Post-Lab Questions:

1. What did you see happen in the beaker containing limestone when the drops of acid were added to it? Explain these changes.

2. What is the pH of the initial solution containing the calcium carbonate mineral? Consider the effect calcium carbonate has on the pH of solutions. Is calcium carbonate an acid or a base? How can this be? Explain.

3. If a strong acid is added to a solution containing solid calcium carbonate, bubbles are generated. What are these bubbles? Where do they come from?

4. Explain why lakes with limestone beds experience less adverse effects from the acid rain than lakes with granite beds.

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