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IMPROVING HIGH SCHOOL STUDENTS' PERFORMANCE IN CHEMISTRY
WITH A HANDS-ON APPROACH

presented by

Mary L. Fredell

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IMPROVING HIGH SCHOOL STUDENTS' PERFORMANCE IN CHEMISTRY
WITH A HANDS-ON APPROACH

By

Mary L. Fredell

A THESIS

Submitted to
Michigan State University
in partial fulfullment of the requirements
for the degree of

MASTER OF SCIENCE

DIVISION OF SCIENCE AND MATH EDUCATION

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ABSTRACT

By

Mary L. Fredell

This project was based on the premise that students' performance in high school chemistry would improve with a outcomes-based, hands-on approach. The students became active participants in the learning of acid-base chemistry. They learned through the increased use of laboratory work and a project-based investigation rather than the standard lecture, discussion, and reading. Emphasis was on collaborative rather than individual learning.

The teacher acted as a guide focusing students on the inquiry, challenging them to devise their own methods for problem solving, encouraging all students to participate fully, and modeling the skills of scientific inquiry. The teacher was the primary but not the only evaluator of the students' progress and learning. Partial assessment was based on rubrics created by the instructor and presented to students prior to their attempting the activities. The students engaged in self-assessment and peer evaluation.

Having students actively involved, making connections between what they are learning in chemistry and their lives allowed them to have a better understanding of the acid - base concepts presented, to make connection between the scientific process and the skills needed for lifelong learning, and to find more enjoyment in the process of learning chemistry.

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ACKNOWLEDGMENTS

A special thank you is extended to Dorothy Horan, Herbert Henry Dow High School Science Department Head for her unending encouragement and support whenever I try "something new, different, and exciting" to help improve my students' knowledge and enjoyment of chemistry.

Thanks also to my family who encouraged and endured while I was writing this paper. You were the guiding light to get me through this process.

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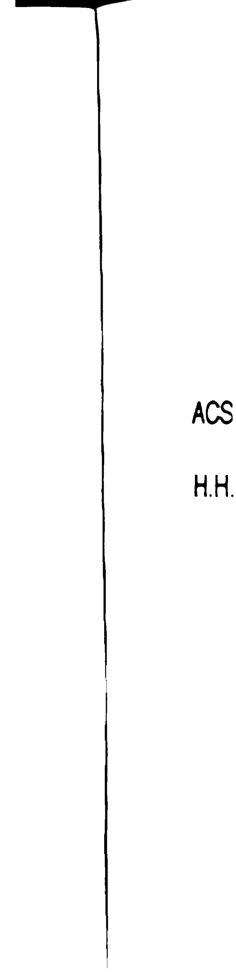
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LIST OF ABBREVIATIONS

ACS..American Chemical Society

H.H. Dow High School...Herbert Henry Dow High School

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INTRODUCTION

The United States of America established a goal (National Research Council, 1996) that all students should achieve scientific literacy. This would enable people to use scientific principles and processes in making personal decisions and to participate in discussion of scientific issues that affect society. "A sound grounding in science strengthens many of the skills people use everyday, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing life-long learning" (National Research Council, 1996). I attempted to meet this established goal by having students actively engaged in their own learning of acid-base chemistry. They developed answers to open-ended questions through performing observable tasks and creating products.

This study focused on a hands-on approach to learning the acids, bases, and salts unit of chemistry. The core content (Appendix A-1) was established district-wide in compliance with Public Act 25, reviewed by the school board, and needed to remain consistent with the second high school in the district. This component of chemistry is in the middle of the second semester of the first-year accelerated (.3) chemistry course at Herbert Henry Dow High School in Midland, Michigan. The acids, bases, and salts section is a culmination of many earlier units in the course and has been notoriously the most difficult unit of the cours

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course. In an effort to improve students' performance, see chemistry's "real world" application, and enjoy chemistry more than the traditional lecture, laboratory, and test format, the method used here was an outcomes-based approach.

Outcomes-based education seeks to prepare students for life, not necessarily for college or employment (Spady, 1988). It incorporates authentic assessment which engages students in applying knowledge and skills in the same ways they are used in the "real world". The learner outcomes (Appendix A-2) established by Midland Public Schools (the district where the study was conducted), the State of Michigan, and The National Science Education Standards were also centered in the study's focus. Science teachers should help students not only acquire scientific knowledge about the world but also scientific habits of mind at the same time (Instructor, 1990). Learner outcomes are measuring tools for assessing lifelong skills such as being information processors, complex thinkers, and effective communicators.

The Midland community is Michigan's sixth largest city in area and its population is over 40,000 (Herbert Henry Dow High School, 1997). The average income is 54% higher than the national average. The Dow Chemical Company and the Dow Corning Corporation are the largest employers in the city. Education is strongly supported. No doubt this is because there are an exceptional number of residents who possess college degrees, many with advanced and professional degrees (Herbert Henry Dow High School, 1998). Given the nature of the community, college preparatory programs are

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encouraged. The accelerated courses are designed to challenge academically talented students. An accelerated course, .3 designation, earns six tenths (.6) of an additional honor point per credit hour. During the time of this study, 96 out of a total student population of 1377 students were enrolled in accelerated first year chemistry that is an elective, college preparatory class. The course is generally offered only to sophomores through seniors, with sophomores making up the majority of the students with 77% in this study. There were 18% juniors, 1% seniors, and 4% freshmen. The freshmen in accelerated chemistry were allowed to enroll with a parent request, exceptional math and science scores, and their academic counselor's approval. Of all students enrolled in .3 chemistry, 71% were involved in school sports, and 44% were involved in more than one after-school activity. Only 4% had no job, volunteer work, or school related activities listed on their class registration card. Generally most students enrolled in this level of chemistry at H. H. Dow High School are academically talented, highly competitive, planning to continue their science education, and concerned with maintaining their academic class ranking. Most of the students enrolled in the accelerated chemistry course continue their education beyond high school in four-year, or more, science related university programs. My study gave students a creative new approach for preparing for their future studies.

The National Science Education Standards (1996) envisioned a change in science education with less emphasis on learning science by lecture and reading and more emphasis on learning through investigation, inquiry, and collaboration. A Profile of Science and Mathematics Education in the United

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States: 1993 (Weiss, 1993) cited statistics that more than 60% of high school science students never worked in class on science projects that last at least a week. In addition, looking across all science classes, the largest proportion of class time was devoted to lecture and discussion (38%). Several projects undertaken by the Discovery Center of the College of Staten Island (Carlin, et al., 1997) explored the question of why boredom in the classroom was so typical among average high school students. They found this boredom often resulted from a teacher-centered instructional method. Many teenagers perceived the information presented in their classes to be irrelevant to their lives. To address this problem, this study of acids, bases, and salts was formatted to have students engaged in hands-on activities which were also minds-on experiences. It was an attempt to challenge them to higher level thinking skills.

The Third International Mathematics and Science Study (TIMSS) provided a comparative picture of education in the United States to the 21 countries participating in the study at the 12th grade level (National Center for Educational Statistics, 1998). The results reported in February, 1998 placed U.S. students 19th in the math and science skills worldwide. The U.S. Secretary of Education, Richard W. Riley, said America must dramatically accelerate and fundamentally change its efforts to improve academic performance. Currently high school curriculum has less depth and rigor than other countries and less focus on building understanding of major concepts.

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We as science educators attempt to teach many topics without challenging students to understand in depth what is taught.

Most effective learning occurs when students are able to use knowledge to perform meaningful tasks (Marzano, et al., 1993). For science teachers this means we must keep our science experiments relevant and remove some of the mystery from the world. If students come to us without scientific intuition, let us provide them some before they leave us (Salzsider, 1993). The National Science Education Standards (1996) call for more than "science as process" in which students learn skills such as observing, inferring, and experimenting. Students need to communicate their ideas to others, use critical thinking, and consider alternate strategies to solve problems. In my study, students were expected to solve real life problems within the context of acid-base chemistry.

Part of challenging students to be critical thinkers and problem-solvers is to get them to take responsibility for their learning. This study shifted the focus of control from teacher-centered to student-centered instruction. Students should be involved in designing activities and managing time to execute them. They should have responsibility for space and materials (National Research Council, 1996). In this study, students were accountable for choosing their own group, its size, developing a method and materials list, then managing their time when conducting their exploration. The final task was to orally present the results of their exploration to the class using a visual or audiovisual aid. An option was to present their findings again at a parent-community open house.

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Additional student responsibility came with students engaged in peer and self assessment. The National Science Education Standards (1996) states that students should review each others work, challenge mistakes in investigation methods, faulty reasoning or poorly supported conclusions. This strategy deepens each student's understanding of content and application. Making journal entries is a method for students to self-assess by recording their progress, skills, and thinking. In self evaluation many students make important realizations about themselves (Adamchik, 1996). It gives them an opportunity to personally evaluate and consider something that might work better in helping achieve their goal in a project or improving their understanding of content.

William Spady (1988) argues that educators must broaden their educational goals to include outcomes that relate to lifelong learning. To accommodate this, assessments were expanded beyond chemistry content to include group performances and interpersonal skills. A Nation At Risk (National Commission on Excellence in Education, 1983) found that American students soon discover that all things learned are not equal. They are tested on some "bits" of knowledge and not on others. It is not surprising that most students choose to ignore things on which they are not tested (Marzano, et al., 1993). Moreover, standardized tests require students to recognize fragmented bits of information. They rarely ask students to apply information, and almost never ask students to exhibit proficiency in complex reasoning and self-directness. (Marzano and Costa, 1988) Testing is only one facet of assessment and is not necessarily sufficient.

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Traditional testing in chemistry has been through mathematically based questions. This method assumes that this type of problem-solving ability indicates an understanding of chemical concepts when it fact students often solve problems successfully without understanding. They simply used memorized algorithms. Smith and Metz (1996) conducted a study, based on prior research, using molecular representations to test for undergraduate students' conceptual knowledge of acid strength and solution chemistry. They also tested faculty and graduate students to see if conceptual weaknesses persisted. This study suggested teaching these chemical concepts with these visual aids prior to applying the mathematics. They thought this methodology might increase comprehension and retention of the concepts by allowing students to picture the chemistry. One of the focal points of my study was to have students increase their understanding of chemical concepts and retain the knowledge longer.

Assessment needs to move beyond what has historically been "test what is easy to test" using the multiple choice or a short answer format based on context alone. Assessment should be anchored in authentic tasks, supplementing with a typical test as needed. All curricula should address both content and performance standards. Reform in education is not an either/or but a balance. The aim of assessment should be to improve performance, not merely audit it (Wiggins, 1998). Students should be able to exhibit performance in content using written, oral, and displayed techniques. Currently, the State of Michigan along with other states are attempting to test for proficiency. The new format pos

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format poses open-ended science problems in addition to the traditional multiple choice questions of the past Michigan assessment test. In a constructed responses format, students are expected to perform tasks such as developing experimental methods and plotting and interpreting data in order to achieve proficiency in science. This study was an effort to prepare students for such evaluation and beyond. This study also included performance assessments of laboratory skills and evaluation of project group work that involved written and oral presentations of what was learned. Working in groups on a project (Sanger and Greenbowe, 1996) provides students the opportunity to identify relevant issues or problems, develop tasks that will help solve the problem, examine solutions, and debate alternative viewpoints. These activities are seen as being closer to how scientists go about doing science. I gave students opportunities to demonstrate their understanding of content and apply their knowledge and skills in a variety of contexts. Many of these activities challenged students to think differently. They were required to gather information in the laboratory and interpret and synthesize the data into a report that was understandable to their peers.

Reports from the National Assessment of Educational Progress (Burns, 1986) have warned that students do poorly on tasks that involve "higher order thinking". Thirteen of the most commonly identified processes of higher order thinking (Marzano, et al., 1993) are in the following listing.

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- Abstracting
- Analyzing Perspectives
- Decision Making
- Investigation
- Experimental Inquiry
- Problem Solving
- Invention

The project based approach developed in this document addressed many of these skills requiring students to take responsibility for their own learning.

Current models of learning based on cognitive psychology contend that learners gain understanding when they construct their own knowledge and develop their own interconnections among facts and concepts. Real learning cannot be spoon-fed one skill at a time (Shepard, 1989). An effective information processor must consider the information which is not stated as well as that which is. Students must be able to accurately determine whether the information gathered is relevant and valuable to the task at hand. Involving students in a project over an extended period of time helps develop information processing skills (Marzano, et al., 1993).

Wynstra and Cummings (1993) conducted a study of high school students and found six major categories of science studies that made high school students feel anxious. Among these anxieties were math and problem solving, fear of the things that might be dangerous in the laboratory, and anxiety associated with doing activities such as science projects that result in having to explain the results to the class. To meet these concerns, students

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worked in small groups of two to four persons during several facets of this study including laboratory work and answering questions.

Frank Lyman (McTighe and Lyman, 1988) studied how to optimally answer questions cooperatively. The method he developed was called Think/Pair/Share. Classrooms where Think/Pair/Share is correctly used foster deeper thinking, greater student response, a reduction in risk and embarrassment, and less panic among students (Canady, et al., 1996). A modified Think/Pair/Share was used in some of the classroom discussion of this study as well as other methods of collaborative learning.

In a student-centered or a constructivist curricular experience, the teacher creates a learning opportunity based on a specific problem or issue derived from a particular interest of the student (Jacobs, 1998). A collaborative effort was the exploration project, a student-centered design. Students had the opportunity to select from a listing of "real-life" options.

Even though the importance of cooperation and collaboration has been recognized in the workplace for decades, it has only recently been given deserved attention in education (Johnson and Johnson, 1987). Education should model the real world to better prepare students for what they will encounter in the work world. Students need practice in recognizing and applying the natural connection among mathematics, science, and technology to personal and public problem-solving (Selby, 1993). Effective performance within a group involves and develops interpersonal skills such as participating in group interactions with little or no prompting and expressing ideas and opinions

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opinions in a manner sensitive to the knowledge and feelings of others (Marzano, et al., 1993). In cooperative learning groups, instructors are still in control of their classroom. They set expectations and behavior norms. With cooperative learning, students have some control over their own learning, but not over the management of the classroom (Nurrenbern, 1994).

As with most real-world tasks, performance tasks do not have a single correct answer. Therefore student performance assessments must be judged by well defined criteria. This judging is analogous to that used for judging a diving or an ice skating competition. The tool used to guide the judgment is a rubric. This term has its origin from the Latin "rubrica terra", referring to the centuries past use of the red earth to mark something of importance (Marzano, et al., 1993). Today they are considered established rules. Scoring rubrics consist of a fixed scale and list of characteristics describing performance for each of the points on the scale. The best rubrics rely on descriptive language - what quality, or its absence, looks like - as opposed to relying heavily on mere comparatives or value language. They use descriptors that are sufficiently rich to enable student to verify their score, accurately self-assess, and self-correct. (Wiggins, 1998) Obviously, grading procedures should be established in advance. Students should know up front what the expectations are to complete the assigned task exceptionally, minimally, or somewhere in between.

Grant Wiggins, a presenter at the Second Annual Conference on High School Reform (1998), spoke of the need for assessment reform at the high school level. He addressed the need for content and performance assessments but also str

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but also stressed the need for feedback. Learning is about adjustments, "How do I get better?" Feedback indicates what you did or did not do. With feedback and standards, students learn to self-assess and adjust. Students are convinced that their best learning takes place when they have the opportunity to hand in an early version of their work, get detailed criticism and feedback, and then submit a revised final version (Wiggins, 1998). Feedback evaluation was one of the tools used in my study.

Joan Baron, a noted expert on performance assessment in Marzano et al. 1993, explains that for a performance task to be "authentic" it must include five characteristics, one of which is that it be constructed or framed by students. Her five criteria for authentic assessment are:

1. The task is meaningful both to teachers and students.
2. The task is framed by the student.
3. The task requires the student to locate and analyze information as well as draw conclusions about it.
4. The task requires students to communicate results clearly.
5. The task requires students to work together for at least part of the task.

This study used this five step outline to help students devise their plans for exploration. The "problem" scenario was created, and the students needed to develop the plan to solve their scenario. Working cooperatively in small groups, students tested their method, revised as needed, and communicated their results both orally and in written form.

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SUMMARY OF THE INTRODUCTION

The table below summarizes the teaching strategies presented in the introduction of this study and how they were utilized to benefit students.

Pedagogical Strategy	How It Helps Students	How It Is Incorporated into the Acid-base Unit
• Hands-on Inquiry Activities	• More interesting and more clearly relevant to students	• Introduction of a series of laboratory exercises and demonstrations
• Outcomes-based Education	• Gives students and teacher feedback on how well they can use what they can learn in a "real world" situation	• Inquiry based project where students, as "scientists", used the units' ideas to test household products and report their finding to the instructor and their class.

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METHODOLOGY

Overview

The acids, bases, and salts unit extended through 28 school days. It is in the second semester following the unit of ionization and dissociation, and one studying solutions. It is a culmination of these earlier studies. The objectives of the unit are listed in Appendix A-1. Briefly, students were expected to distinguish between the two earliest acid-base theories and apply those theories in their laboratory work. Based on demonstrations and laboratory observations they should be able to predict products for nine different reactions and write balanced chemical formula equations for each. Mastering net ionic equations related to hydrolysis was also required. There were additional acid-base concepts they needed to understand to be able to perform the problems (mathematical and analytical) associated with the unit. These included pH, titrating, and neutralization.

Appendix A-3 is a detailed outline of the unit. Pedagogical techniques used in my study focused on collaborative learning. One of the major thrusts of this study was to have more "hands-on" opportunities for students and less standard lecture - discussion.

Several laboratory exercises were developed as a part of this unit. These "labs" were always performed with a partner, in most cases, someone they had

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they had been working with earlier. The experiments were designed to give the students the opportunity to develop skills and practice techniques that could be used later for their exploration projects.

A laboratory skills assessment, another "hands-on" activity, was used to evaluate students' understanding of the concepts and laboratory techniques. The laboratory exercises and the laboratory skills assessment will be discussed individually addressing the merits and grading criteria of each.

Most of time in the acid-base unit was dedicated to collaborative learning activities. Several days were devoted to planning and development of a laboratory procedure as well as preparation of final written and oral presentations for an exploration project requiring collection of data in the laboratory. Teacher performed demonstrations and students writing journal entries were incorporated into the unit. A minimal amount of time was spent lecturing, and it was interspersed with group learning activities to allow for processing of the information presented.

Assessments varied from "traditional" grading techniques to rubrics developed to evaluate learner outcomes and content objectives. All assessments required students to engage in some higher order thinking. Application questions were also posed on the post test and the final exam to check for understanding and retention of conceptual knowledge. The unit test and a quiz were developed to be similar to assessments from the previous year for aid in comparisons to be used in this study. The scoring of these items was also si

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also similar. The pretest and post test were created specifically for this project and were not graded.

Pretesting and Introduction

The acids, bases, and salts unit began with a pretest over the unit (Appendix B-1). None of the questions in the pretest could be answered with a simple "yes" or "no". The majority of the questions required students to use complex thinking skills and had "real world" application. There were no multiple choice questions. Students were instructed to attempt all the questions even if the response given was only a guess. They also were told to rank the response in degrees of confidence, "1" being least confident (an off-the-wall guess) and "5" being most confident (I could have written the question myself. I know this stuff!).

A demonstration of acid-base indicators using common household products was incorporated into this evaluation tool for students to use their skills of observations to explain as well as describe what they saw. When we reviewed the pretest the next day, students again were encouraged to use their powers of observation when problem solving throughout the unit.

Another skill that was analyzed in the pretest was the students' ability to relate what they see at the macroscopic level to what is occurring on the molecular level. This was a follow-up to the previous units of solutions and electrolytes.

By completing the *Acids and Salts Nomenclature Worksheet* (Appendix C-1), students were able to review the naming of compounds and how the compoun

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compound would be represented in an aqueous solution. To do this they needed to review rules of nomenclature, solubility rules, and whether the acids given were strong or weak acids. This worksheet was revised from the previous year to include the electrolyte review component. It was not graded.

The first day of the unit also included discussion of the exploration project (Appendix D-1). Students chose partners (2-4) for this project and selected a topic from a teacher-generated list and description of scenarios (Appendix D-2).

The second day's discussion was introduced with a video, *The Proton in Chemistry*. (This video is part of a series *The World of Chemistry*. More information is available through the American Chemical Society.) This helps students to visualize what occurs at the molecular level and relate the chemistry to "real world" situations. Students completed as much of the accompanying worksheet, *'The Proton in Chemistry' Video Questions* (Appendix C-2) as possible. This worksheet was not graded but was used for facilitating discussion. A modification of *Think/Pair/Share* was used as the method for classroom discussion. Each person in the classroom was assigned a partner. After four minutes of "wait time" for the students to finish their own responses to the worksheet questions, the students were instructed to "pair" and discuss possible responses for a designated amount of time (7 minutes). During this time they were to make notes of their partners responses. The final step was to "share" their responses "round robin". This means as the teacher randomly called upon students or sought volunteers, the students kept track of responses already made so as to not duplicate a response. This technique keeps students attentiv

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attentive during the discussion. If the teacher seeks volunteers, the hand waving is generally overwhelming as students have confidence in the responses and want to make sure they have an opportunity to respond before their best answers are used up.

Laboratory Exercises

1. *Reactions of Arrhenius Acids & Bases, Acidic & Basic Anhydrides,* (Appendix C-3) was created to provide an opportunity for students to review concepts from the previous units and to expand their understanding of acid-base chemistry by addressing the simplest acid-base theory, that of Arrhenius, first. They conducted thirteen different reactions, recorded their observations (a technique needed for further studies), identified the formulas for the product(s), and then wrote net ionic equations for the reactions that occurred.

One of the advantages of starting with this experiment was that it is microscaled. Students were introduced to concentrated laboratory acids and bases in most cases by working with drops of solutions. The questions and conclusions of this exercise had been revised to involve students in higher level thinking skills of explaining, projecting what they observed to another situation or to the atomic level to understand the concepts of molarity and strengths of acids. This exercise was graded in the same way it was the previous year with points assessed for correct formulas and equations. Also detailed explanations were needed to include not only descriptions of what they would observe but why. Results from this lab was used in the calculation of students' letter grades for this unit.

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2. *Indicators and pH* (Appendix C-4) allowed students to explore various pH indicators. This was an attempt to have them remember pH as a power of ten by creating a colorful pH scale through serial dilutions. This laboratory experience was also microscaled and required students to engage in higher order thinking to answer the questions at the end of the report. These responses could be formulated with their observations, lecture notes, and a textbook reading assignment on pH.

3. Titrating was the topic of the final two laboratory experiences done before students began their exploration project (Appendix C-5). The full-scale technique used was crucial to this unit of study as most of the exploration groups would have to prepare their own solutions and be able to titrate. These experiments gave students the "hands-on" application to the problems they were calculating in class and homework assignments. The first was titrating a standardized sodium hydroxide solution against a known mass of potassium acid phthalate. In the second titration experiment, students used the standardized solution they prepared to determine the mass percent of acetic acid in vinegar. The latter experiment gave the students another example of the real life part of chemistry. Students were encouraged to save any leftover solutions in labeled bottles for possible use in their exploration project. Laboratory drawers were available for each lab team to store items. These experiments were evaluated for completeness of data, correctly performing calculations, and laboratory technique based on the nearness to the correct value for the mass percentage of acetic acid.

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Laboratory Skills Assessment

The laboratory practical portion (Appendix B-2) of this unit was an effort to assess laboratory learning by a means other than paper and pencil. This laboratory skills (thinking and performing) assessment was conducted using microscale techniques. Using small-scale methods reduces the time and expense associated with laboratory practicals, and greatly increases the ability of the teacher to understand what the students know and can do in the laboratory. Students worked individually in performing the task and were familiar with this method of assessment as I had previously evaluated students in this manner.

The problem posed to the students was to describe the method they would use to determine the pH range over which the unknown acid-range indicator changes color. They needed to recall the similar laboratory exercise related to pH. Once they completed writing a method, they checked in with the teacher to show the method, and received appropriate supplies. The method did not have to be correct to gain admittance into the laboratory. Often students would find that their original method developed didn't work, and they would change it. If this occurred, they were required to write the revised method when stating their conclusions and explain why the change was made. To say the original method "didn't work" would give them no points. There were four different acid indicators with varying ranges used, so that once students were in the laboratory they could not simply copy results from their neighbors.

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Rubrics (Appendix B-3) were developed prior to the assessment, but in this case, not shared with the students until after their performance. This task could not be accomplished successfully if the student failed to realized that pH is the concentration of the hydronium ion expressed in powers of 10. Every student should have some measure of success if they recalled some portion of the pH experiment as the rubrics scale was devised to provide a graduated scale of performance. This score was also part of the overall grade for the unit.

Demonstrations and Journal Entries

Several demonstrations were incorporated in this unit to help students develop their observation skills and reinforce lecture and laboratory content. One of the demonstrations, *Salt Hydrolysis* (Appendix C-6) required students to prepare a data table to record their observations. Students observed different salt solutions containing universal indicator. After comparing their observations to a pH standard for universal indicator, they wrote net ionic equations for the hydrolysis that occurred and predicted whether it would occur for various other salts not tested. These were some of the specific objectives for this unit.

Students recorded their observations of the remaining two demonstrations as a journal entries. Students were aware that journal entries were important concepts to be reviewed when preparing for a test or quiz, and that any addition to their journal could be considered for grading. Journal entries were dated and kept in a separate section of their chemistry notebook.

The *Amphoteric Hydroxides Demonstration* (Appendix C-7) gave students the opportunity to hone their observation skills as they reviewed amphote

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amphoterism, balancing equations, predicting products, and Bronsted-Lowry acids and bases and their conjugates.

The second journal entry demonstration was simply the combination of 6 M HCl with ordinary chalk ($CaCO_3$). If colored chalk is used the reaction looks like a soda fizz, which is a good connection for students to make in relating observations with "real life" occurrences. The products of the reaction are water and carbonic acid (H_2CO_3) which immediately decomposes into carbon dioxide gas, CO_2, and water. The products of this reaction are the same components in drinking soda. Hopefully the association would help students retain the knowledge regarding the products of a reaction between an acid and a metallic carbonate and also the writing of net ionic equations which are two of the core content objectives for this unit. As soon as a student had written what they thought to be a correct equation, they could raise a hand to signal the teacher. After being checked the student had the opportunity to revise the equation if it was incorrect.

The *Salt Hydrolysis* demonstration permitted students to observe various salt solutions when combined with universal indicator. The concept of salt hydrolysis seems to be one of the most difficult for first year chemistry students to understand. They already had developed a record of the colors of universal indicator at pH's ranging from 1 to 12 in the "pH and Indicators" laboratory exercise. They were to record their observations, decide whether the salt was acidic or basic (review of pH) and then write net ionic equations for the dissociation of the salts in water (review) and for the reactions of those salts that hydrolyze

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hydrolyzed. This exercise required higher order thinking as students were to predict whether other salt solutions would hydrolyze based on observations, notes from lecture, or the textbook readings. The activity was changed from the original laboratory format to a demonstration to insure that all students would see the same results and to save time.

Journal entries helped students to prepare for tests and quizzes and to reflect on what they do know and how they can improve or change their process for understanding concepts. Two additional journal entries in this unit allowed for this type of reflection.

One of the journal entries occurred midway through the acid-base unit when students were instructed to write in their journal "what they know about acids and bases at this point in the unit". The writing was timed and classified as a Type 2 writing, requiring correct content on the topic. These writings were collected and checked for any misconceptions or lack of progress in their understanding of the content material when compared to the pretest.

The final journal entry was at the completion of the unit. Students were told to reflect on the unit, writing about their likes, dislikes, and suggestions for improving the unit. All the unit's journal entries were collected at the completion of the unit and used in evaluating my study.

The Exploration Project

An important part of this unit was the exploration project. The students were given an opportunity to work in their groups in designing a project plan and developing a material list from their unique "scenarios" (Appendix D-2) they had ch

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had chosen. These topics all involved "real world" tasks for investigation. For example: "You have been selected to analyze a commercial antacid to create an advertisement for the product"; or "You are a chemist in an independent firm that has been contracted by the manufacturer of XXX. There are rumors in their plant that someone may have attempted to sabotage the quality of a batch of their product during a recent employee dispute. Your task is to determine the percent of hydrogen chloride in a given sample of toilet bowl cleaner and calculate the percent error from the amount indicated on the label". Each group was given further instructions and suggestions for analysis and solutions to their task. In each case groups were given their first or second choice of scenario.

There were reference books, texts, Chem Matters CD-ROM Version 1 (available through the ACS), and laboratory manuals for the students to use during class time to prepare their plans. They were also encouraged to look back at previous laboratory experiments and exercises as valuable resource material. A notebook was available for students to request any material they wished to have photocopied from the classroom resources. All due dates were given to the students at this time. These deadlines remained posted on the chalkboard. I reviewed the rubrics (Appendix D-3) for the project plan so the students would be clear on the expectations before they began.

The materials list created by students needed to include two separate parts: 1) supplies they already had in their laboratory drawers or common equipment; 2) items the teacher would need to purchase (antacids, toilet bowl cleaners, aspirins, etc.) or specialty items. Specialty items were those that were limitec

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limited and kept in the stock room such as Buchner funnels and filtration flasks, mortars and pestles. Students were to prepare their own solutions based on their own calculations. If they wanted to prepare solutions from the dilution of a stock solution, they needed to check with the teacher to see what stock concentrations were available and reserve the amount they needed. If they were preparing the solution from a solid reagent they added the mass needed to the specialty needs listing.

Students made final revisions to the exploration plan and materials list in class. The groups were instructed to refer to the rubrics to assure that all the evaluation points were addressed. The exploration plan and materials list were collected and redistributed to groups at random. In essence they were to determine if they could accomplish this laboratory procedure with the method presented and solve the problem that was stated as the objective. The groups attached a paper stating the strong points and positive suggestions for improvement. After evaluation, the plans were returned to the creating group for final revisions based on the critique.

One of the teacher's tasks was to review the final plan to see if it could be done safely. Other than that, students were not advised or coached even if the method developed may have contained some "stumbling blocks". Students needed to experience first hand what worked and what did not. Some had to revise as needed when they got into the proposed procedure. A second time consuming teacher task was to gather the items on the designated portion of the list. If quantities were not indicated the list was returned to the group for revision.

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revision. If groups failed to get their plan in on time they missed working on the first laboratory day. These students were required to purchase their own items available from the grocery store.

Students were given two consecutive days of laboratory time to work on their explorations, and all group members were required to take part. The daily time period was fifty-five minutes which included the time to setup and dismantle equipment and to clean up the group's laboratory space before leaving. Students needed to be organized and ready to work. All groups should have been able to complete the explorations in this time. A third chemistry laboratory day was optional for those students who needed more time, but those groups sacrificed some of the computer time available to prepare the oral and written portions of their exploration project. The chemistry laboratory was available for the students to use before and after school and also during the last period of the day, an optional seventh period.

The written reports in all cases were to be two pages not including tables or graphs. Some of them were to write letters of response to the fictitious company for whom their were doing their analysis. Each report included a summary paragraph describing how the exploration was performed, detailed and organized data tables and, where applicable, graphs. Students needed to include a detailed and organized analysis of data collected and error analysis answering the questions:

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- How could the method be improved?
- How could the error be corrected?

Students were given the rubrics (Appendix D-4) for evaluation of the final report prior to beginning their exploration once again to assure they knew the expectations. They were given two additional class periods (55 minutes) and computers for preparing their documents.

The groups were provided a list of expectations and rubrics (Appendix D-5) that would be used in evaluation prior to preparing their oral presentations. Groups were also given the scoring report (Appendix D-6) several days before the presentations. This allowed them focus their ideas in their by summarizing what they were presenting in a brief abstract of their studies.

Students were given approximately 5 to 7 minutes to present to the class and were required to have some visual or audiovisual aid included in the presentation. If the presentation included a video or demonstration the time allotment could be altered. The presentation was graded partly on the effectiveness of the visual (audiovisual) aid. All members of the group needed to involved in speaking parts. Each student needed to be able to clearly identify and explain the concepts presented so as to respond to any questions posed by the audience.

An optional portion of this unit was for students to prepare a presentation and be available to answer questions at an open house conducted a month after finishing the unit. This was an opportunity for students to showcase what they had learned and make the exploration even more "real world" by showing them

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themselves to be the experts. An invitation to the open house (Appendix A-4) was extended to parents.

Additional Tools for Evaluation

Near the end of the acid-base unit an unannounced quiz (Appendix B-4) was given to the students to prepare them for the upcoming test. When the graded quiz was reviewed in class, students asked questions. Any misconceptions as well as common errors were addressed at this time.

Questions similar to the quiz were posed on the unit test (Appendix B-5). In addition to multiple choice questions, there was a written portion to evaluate students' ability to predict products, write net ionic equations, and perform the calculations associated with this unit. The students were expected to do higher level thinking to be totally successful with the test. They needed to analyze, construct, interpret results, and deduce throughout the test.

Further evaluation of this unit was accomplished through questions on the final examination (Appendix B-6), and an optional post test (Appendix B-7) given after the examination. A review worksheet (Appendix C-8) was given to the students after testing on the unit. It could be equated to an "open-book" or notes quiz to determine if students were able to answer questions (similar to those on the test) using their notes. The review worksheet, final exam questions, post test, unit test, and unannounced quiz were used to draw conclusions and evaluate this study. This was accomplished through comparison of their results to those obtained with the pretest and a similar test and the same exam questions given the previous year.

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EVALUATION AND DISCUSSION

Evaluation Overview

The outcome-based, authentic assessment method used produced rather consistent results in meeting the objectives set forth in this study. These were to improve students' performance in content and lifelong learning skills, see chemistry's "real world" application, and enjoy chemistry more. The evaluating tools used to assess this study included a pretest and unit test, producing immediate feedback about short term retention. The pretest and unit test responses were compared with those from the semester exam and a post test. The two latter were given to the students six weeks after completion of the unit. Test and exam results were compared with those from the previous year, when the unit was presented in the more standard lecture-discussion method of teaching. The questions used for compilation of data were identical from one year to the next.

Also instrumental in the evaluation were the thoughts and opinions of students involved in the study this year. These comments were captured through a journal entry after completion of the unit. The students were instructed to write about their likes, dislikes, and suggestions for improvement in the acids, bases, and salts unit of study.

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All students enrolled in accelerated (.3) chemistry, a first-year program at Herbert Henry Dow High School, participated in the study in that no person was exempt from this unit. The sampling group was reduced to 63% (60 students) of the total enrollment to make the sampling approximately the same size as the previous year's enrollment used in comparisons made in the study. This reduction also made analysis more manageable. The sampling group was chosen prior to beginning the acids, bases, and salts unit. Careful attention was paid to the selection of this group to make certain it was reflective of the whole class. Chosen students were distributed through all the four sections of .3 chemistry. It was comprised of equal numbers of high, low, and middle range students based on their academic achievement in chemistry during the first four six-week grading periods. Generally, if students have not achieved at least a "C" average by the fifth six-week marking period, they would drop the .3 chemistry and finish the school year in the .2 general chemistry course offered. The high students' average grade was 93%, the middle population was 86%, while the lower group's average was 79%.

This study utilized authentic assessments which allowed the students to engage in more "hands-on" and "minds-on" activities instead of the usual lecture method. This technique engaged students in their own learning instead of being fed information without the means or time to process. When comparing the amount of time students were involved in group work and laboratory activities compared to the previous year I found that the students were engaged in some form of collaboration 64% (18/28 days) of the total time. At least 7 days were spe

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were spent in the chemistry laboratory and 2 days in the computer laboratory. Only three days were spent in lectures, and even on those days, the lecture was interrupted for content process time using collaborative learning. In the previous year, 60% of the unit's time was devoted to lecture. The lecture during that year was interspersed with mathematical problem solving that was performed on an individual basis. Students were engaged in collaborative learning, the standard laboratory work, 30% of the time. There was no exploration project. Students were engaged for less time with higher level thinking.

One thing that was evident when making these comparisons was the amount of time needed to complete this revised approach. Using the lecture method, the content material was "covered" in 15 days versus the 28 days with my new approach. The total time needed to teach the unit may be reduced by familiarity of the process and/or the use of block scheduling. If students had a larger block of time to work, there would be less time setting up, taking down, and cleaning up laboratory equipment. However, it is a "fact of life" that constructivist teaching requires more time on a topic.

Performance Improvement

One of the objectives of this unit was to have students improve in their performance of chemistry. All the questions used in the comparison are those testing the specific core content set forth by the school district. Three sets of comparisons were made in Table 1.

Table 1

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Table 1 - Comparison of Test and Final Exam Responses, 1997 and 1998

Question Posed	Correct Responses (%)			
	Unit Test 1997	Unit Test 1998	Exam 1997	Exam 1998
Metallic carbonate + acid ---> ? ($CO_2 + H_2O$ + salt)	63	83	75	82
Active metal + acid ---> ? (salt + H_2)	77	82	100	100
Identify the acidic anhydride given multiple choices.	54	67	50	58
Given multiple choices, what is the pH of 0.01 M KOH ?	51	56	40	66
Given multiple choices, choose the reaction that does not produce a salt.	51	64	not given	67

Results of comparing correct responses on the unit test to those on the final exam during the study year (1998) shows the percentage of correct responses remains fairly constant with some improvement in all but one question. When making a similar comparison of correct responses on the test and exam from the previous year, 1997, similar results can be viewed. With both teaching methods students seem to retain the chemistry content from the unit test to the final exam to a similar degree. Comparisons were also made between the correct responses from the 1997 students compared to those of 1998, in which the change in methodology was used. There was a definite improvement in achievement. Students' understanding of the core content was higher when tested at the end of the unit and they maintained this higher level long term.

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The percentages of correct response were consistently higher on both the unit test and exam questions. It seems evident that students performance in the acids, bases, and salts unit was improved with the outcomes-based, authentic assessment method of content learning. Additional time was also spent with the concepts.

Comparing results from the pretest (Appendix B-1) and post test (Appendix B-7) showed improvement in students' understanding of the concepts of acidic and basic properties, pH, the application of acid-base chemistry, and the confidence in what they knew. They were able to identify more home items which are acidic or basic. In the pretest 24% of the students responding correctly identified four or more home-use substances that were acidic or basic. In the post test 46% of the students could correctly identify the same number or more. The confidence rating of 4 or 5 in this reply was scored by 53% of the students on the pretest. On the post test 85% of the responses were 4 or 5 ranking. The number of incorrect or no responses decreased from 27% to 12%.

When describing the process that results in acid rain, 57% of the respondents used the term acidic anhydride or used a particular nonmetallic oxide in their explanation on the post test compared with 3% explaining the chemistry behind acid rain on the pretest. Most of the pretest respondents that were able to explain acid rain with any degree of correctness were limited to the generic description most of them learned in elementary school: "Pollutants in the air get mixed with rain and change the pH to acidic." Also, their underst

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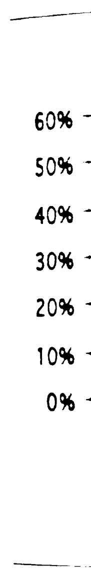
understanding of the pH scale improved. In the pretest many students were confused as to whether the acidic range was a pH of greater than 7 or less than 7, with 30% of those responding incorrectly identified it as greater than 7 versus only 2% of the students on the post test. This showed an increased understanding and application of acids and bases in a "real world" context.

Students understanding of what occurs at the molecular level as related to solutions of strong and weak acids was assessed by comparing the pretest with post test responses. The task on these tests was to draw a picture depicting the particles in aqueous solutions of strong acids and weak acids with the same molar concentration. Similar tasks were used in the previous units of solutions and electrolytes.

A common drawing on the pretest was one in which the total number of particles (generally dots) increased from those in a weak acid solution to the strong. Many of the students who expressed confidence in their responses had misrepresented the concept. A comparison of the correct responses on the pretest and post test is displayed in Figure 1. Not only did the number of correct responses increase but the quality of the drawings increased as well. Depictions became more elaborate and detailed. Less writing was used to explain the drawings.



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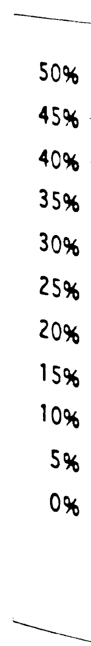

Figure 2

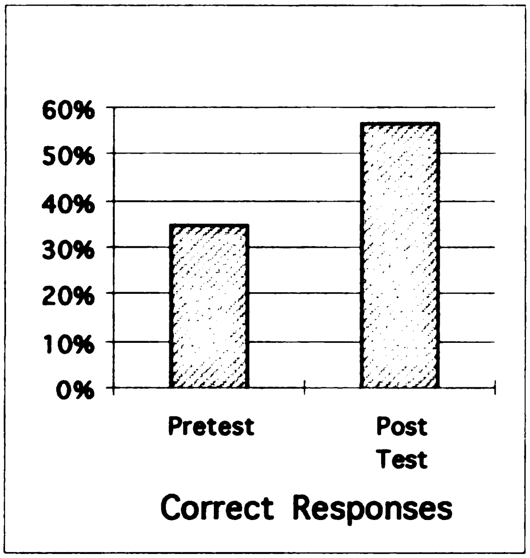

Figure 1 - Comparison of molecular drawing responses

Confidence in the responses to this drawing task also increased in the post test (Figure 2).

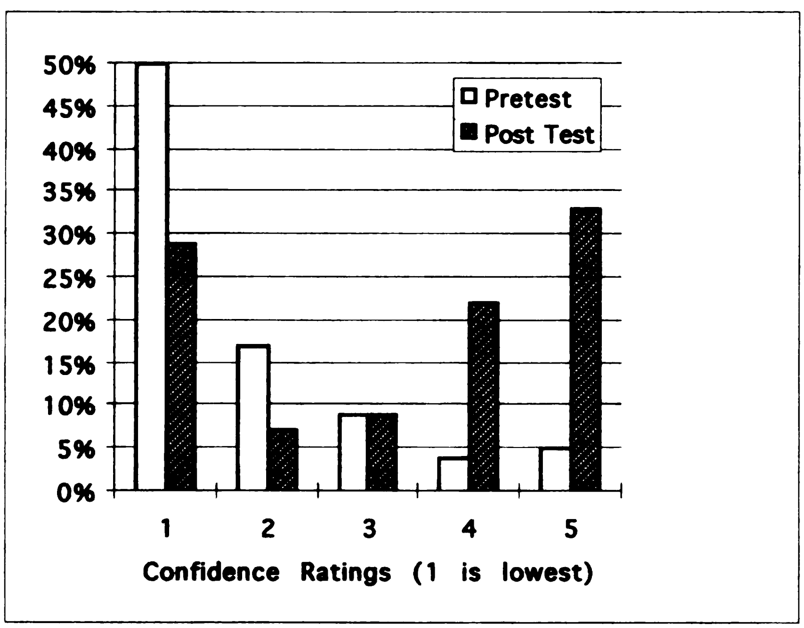

Figure 2 - Comparison of molecular drawing confidence

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It would be difficult in the scope of this study to determine if the use of this molecular drawing technique made any major differences in students' overall conceptual knowledge of acid-base chemistry. That could be a study in itself as could comparing student confidence in chemistry. It would be valid to say this molecular drawing strategy was probably a contributing factor toward student improvement in concepts of this unit.

Overall student performance with this unit, using the hands-on approach, improved compared to previous units. Students in the higher "A" group maintained their "A's". The average percentage was 95.4% which reflects a slight increase. Students in the middle "B" group increased their average to 89%, a 3% increase. One midrange student in the sampling decreased in his grade from 85% to 73%. The greatest improvement was obtained by those students in the lower sampling group with scores changing from 79% to 83%. One student score in this group increased from 86% to 93%. This student was one of the more enthusiastic students during the exploration.

Laboratory Concepts and Skills

The students had two prior experiences with lab practicals to assess what they understood from their laboratory work. Lab practicals are difficult for many students to complete appropriately. Often they ignore the obvious and make it more difficult. In reflecting back they comment, "I didn't think it could be that simple of a method (or that easy)". The students' achievements on the laboratory practical were less than anticipated. All the students but one, who was absent for the "pH and Indicators" laboratory exercise and never made up the w

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the work, were capable of devising a method for and understanding the need for making serial dilutions. When making serial dilutions, they did not connect the need for a power of 10 (pH) in the dilution process, however. The range of the indicator was a difficult concept for students to understand. Many students stated the range as a single pH value. These kinds of laboratory assessments give teachers a clearer picture of what students really know. When students can develop a method and perform the task correctly, they really understand the concepts and are not just using memorized algorithms. Even though students struggled with this component of the unit, I think it is a valid measuring tool that should remain a part of student assessment. In fact, a tool where students struggle somewhat yields more information than a tool where all students get a correct answer.

Another concept students seemed to have a great deal of difficulty understanding was hydrolysis. This approach attempted to increase student understanding through a demonstration. Students needed to predict whether other salts might hydrolyze based on their observations. When comparing questions related to this concept on the unit test, the percentage of students scoring a perfect score was 63% for the thesis study year versus 60% for the previous year. A means of improving students' understanding might be having the demonstration method changed to a laboratory exercise as it was intended. Time should be allowed in class for follow-up and comparison of observations and conclusions. In the journaling at the end of the unit, the greatest amount of misunderstanding was expressed regarding this core concept.

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Review of the Exploration Project

When attempting to assess the "hands-on" exploration portion of this unit, there were several aspects that needed to be considered, including whether students were successful in the completion of the project, enjoyed the process, and if it changed their outlook on chemistry. Did chemistry take on a real world feeling for them? The first item was measurable by looking at the final products: exploration plan, final report, and oral presentation produced by the students all of which were graded.

The exploration plan prepared by the groups was a learning experience for all those involved including the instructor. Students had been accustomed to having everything set out for them, including proper solutions of the correct concentration had been ready for their use. All items needed for a laboratory experiment were listed for them in their laboratory handouts. It was difficult for many of them to plan and develop a materials list. Students commented that it was very challenging but rewarding. One student wrote, "We designed the experiment and method. We weren't told how to do it. That was fun!"

Developing the real life scenarios (Appendix D-2) and all the rubrics were the most time consuming and mind-boggling part of the teacher preparation for this study. Trying to make the application authentic but within the scope of the first year chemistry course was challenging. The exploration needed to assess the chemistry content of the unit and address the learner outcomes of the district. Many ideas were gleaned from the other resources listed at the end of this document. The outcomes-based approach allowed the instru

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instructor to work backwards looking at what students should be able to do and creating rubrics to fit those outcomes.

Teacher preparation for the laboratory portion of the exploration was intensive for two days. The materials lists prepared by students were not clearly and properly developed. This aspect of the project needs to be changed. The materials list should be more carefully formatted to reduce the number of revisions needed and for instructor's ease in gathering materials. A further subdivision would be helpful in knowing what items on the list needed to be purchased from the store.

Purchasing small boxes or plastic containers that could be labeled with the group's name could reduce confusion in the laboratory. Having a designated cleanup time at the end of the unit would reduce the amount of cleanup required by the instructor.

Some students prepared their exploration plans using word processing programs. I will make this a requirement in the future to facilitate revision and correction after peer evaluation and instructor input.

There was no student evaluation during the performance of the exploration. My focus was on assisting students with their problem-solving and frustrations rather than assessing whether everyone was on task. In the future teaching of this unit, a simple check sheet will be devised to quickly note students' involvement. Another possible means for assessing laboratory participation could be achieved through peer evaluation or through self-assessment. When students have the opportunity to evaluate someone else's work

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work they tend to self-evaluate a little more critically as well. Groups could be required to keep time sheets giving a listings of group members and who was doing what.

Because students were busy and genuinely interested in the investigation they were performing, their behavior was exemplary. If students complained it was because they wanted more time to perfect what they were doing. Some students were unhappy if they did not achieve perfect results when conducting their exploration or if the original method did not work. These same students were the ones who never get anything wrong, ever! It was a new experience for them to know that real life doesn't always allow for perfection even if it one tries hard and is very intelligent.

One group was very disappointed and frustrated when their originally planned method wasn't perfect, and the revised plan was still not up to their expectations. In this circumstance I encouraged the group to research and review previously performed experiments similar to theirs. After doing so, they found they were not alone with inconsistent and frustrating results. This became an additional challenge to this group to try to make their results more consistent than others.

Another group became more enthused with the wonder of discovery when their original method failed, producing an unexpected precipitate. They speculated about the cause and, with coaching by their instructor, they reviewed solubility rules and identified the source of the error in their method that caused the precipitate. Their faces were bright with their excitement as they

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altered their method. They were very proud of their revision and reported their error and solution to the class during the oral presentations.

Some of the students with the highest academic rankings in the class lacked the anticipated leadership in the laboratory portion of the exploration. Students who did not always excel on the standard testing format often exhibited higher motivation, creativity, and enjoyed the hands-on part of the project the most. Similar results were obtained in a study at Wellesley College among first year college chemistry students (Varco-Shea, et al., 1996). A group of two students from the lower sampling population really excelled in the exploration project. Their organization in the laboratory was exemplary. The comment was made by one of these students: "It was easier for me to understand something if I can see it."

Examples of the exploration final reports are located in Appendix E. The quality of the documents was excellent in that they addressed all aspects of the rubrics students were provided. The median score was 23.1 out of 25 possible points and the average was 23.0 or 92%. The lowest scores earned were 21.5 points. Each member of the group received the same score. Many groups exceeded the expectations of the rubrics and prepared graphs to help explain their data at a glance. The most common error was insufficient analysis of error and how they would correct those errors or the method if they were to conduct the exploration again. Error analysis is a higher order thinking skill that is difficult for students to achieve in first year chemistry, but one that needs to be established to prepare students for lifelong learning.

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There was no assessment of individual merit on any portion of the exploration project. This again might be a place for revision in the future through the use of peer evaluation and other techniques.

Presentations were well done. The majority of the groups were knowledgeable and prepared to answer questions. All groups earned 5 out of the 5 possible points. All groups had prepared some sort of visual aid that was required for the highest score on the rubric (Appendix D-4). These included videos depicting commercials for antacids or a news report on an investigation of product tampering; overhead transparencies, posters, display boards, props, or demonstrations. However, the presentations did not include as many of the computer programs such as PowerPoint or Hyperstudio (district approved software) as I had anticipated. This is most likely due to some technical complications with a computer project during the first semester that involved the use of multimedia presentations, which caused students to be reluctant to use this form of visual aid.

The enthusiasm over discoveries made was evident in the presentations. One group explained to others their cleanup procedure. as they thought this was very important. The audience was very attentive as they described the disposal of concentrated hydrochloric acid (about 50 mL) through a neutralization process that produced an impressive of reaction. Another group created a demonstration out of their laboratory discovery. Again the audience was captivated as they watched Milk of Magnesia with phenolphthalein change from pink to white and back to pink with small additions of hydrochloric acid.

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Not many of the groups were able to adhere to the 5 to 7 minute presentation time. When the time limit was established, I was concerned that students would become bored with too much lecture. The audience showed no sign of lack of interest given the creativity the presenters displayed.

The open house conducted approximately one month after finishing the unit was an optional activity for students and gave them another opportunity to exhibit their creativity. Even though the event was scheduled in the evening 95% of the students chose to participate. The Midland H. H. Dow community has many parents who are chemists and chemical engineers. Those who attended, posed some very challenging questions to the students. Students were pleased with what they remembered and commented they felt very professional in their presentations. This was an interesting and unexpected addition to the unit of study. It permitted students to communicate to a different type of audience, another authentic application of their knowledge. Parents were pleased with being able to view the showcasing of the students achievements in chemistry. So often high school students don't share their work with parents and public display of understanding is a very potent motivator and esteem builder.

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CONCLUSIONS

Revisions made in the first year accelerated chemistry course at Herbert Henry Dow High School were enthusiastically accepted by the majority of the students. When writing their final journal entry of the unit, students were encouraged to tell what they liked and disliked, what worked for them and what didn't, and what they could suggest to improve the unit for next year. Excerpts of some of these entries are in Appendix F. The letter in the parenthesis following each bulleted entry indicates the second semester letter grade earned by the student making the comments. Semester grades are determined with each six week marking period counting for 25% of the grade and the semester exam as the final 25%. The acids, bases, and salts unit was one of the six weeks grades.

Students likes and dislikes regarding the unit and how it was taught didn't seem to be specific to the letter grade they earned. In general, the majority of the remarks were favorable. All of the comments were valuable in evaluating the methods for the unit and improving them for next year.

Often the better students in earlier science classes achieved that status by memorization rather than by doing or processing what they have observed. Those students seemed to have the most trouble making a transition into analysis and drawing conclusions required of them in this unit. Also the com

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comments show that many of the students in .3 chemistry are motivated not by what they have learned but by the grade they may get. One "A-" student commented, "I have a B this 6 weeks, a whole letter grade down from usual A's. I think we had too many labs. Labs are not my strong area because I always have to come in and get help for the questions at the end." Some of these students are accustomed to having only perfect or near perfect scores and results in all they attempt. This method gave them a real life experience in that all testing doesn't have perfect results even though one does the best he can. Hopefully this method will help some of those students make the transition into higher level thinking.

Some students expressed that they wanted to know what the right answer was to their exploration project, even though there may not have been only one right answer. "I liked the labs... but thought they were kind of difficult, especially the project. I'm not sure that we answered the right question." commented a "B-" student.

There were students who still did not see the activities as valuable tools when preparing for a test or quiz. Some of the same questions posed in worksheet or laboratory exercises were used in an evaluation instruments later. Other students were able to make the connection from the project right through to the test. "Most of the questions on the test I could think back to our project and have some visual idea of what the questions were asking." From other students' comments and their scoring on the laboratory practical, it was evident that students did not see the connection between lab experiences and the objectives

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objectives of the unit. Many of them suggested that the teacher to give more lecture notes or to have a review worksheet. Instead of assigning the *Acids, Bases, & Salts Review Worksheet* after the test as a follow-up, it should be used prior to the test to help those students prepare for the test. The need for a unit test might also be reconsidered. Is a final unit test necessary to assess students in a unit designed this way? Could a worksheet or several small quizzes be sufficient evaluation in addition to the project outcomes? In my opinion we do need to use alternative methods of assessment to evaluate the lifelong learning skills. These should be intermixed with the traditional testing strategies that incorporate constructed responses. If the major thrust of the unit is a hands-on approach, the evaluation tools (a submitted plan, final report, and oral presentation) should parallel the approach.

It was evident that students were engaged in learning. Dorothy Horan, science department head at H.H. Dow High, stated that during this project students were observed as being intensely and enthusiastically involved in their own learning. They were observed questioning each other and problem solving at a very high level of thinking. Their final presentations were done professionally and exhibited a high level of understand of acid-base chemistry.

Most students did enjoy the real world context and the hands-on approach to learning chemistry. They thought it helped them understand chemistry better. Reaching the goal of the study, "enjoying chemistry more", can be summed up in the students' comments. A "C+" student comments included: "This unit was tough, but I liked it a lot. I loved doing the long term project. I can see what

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see what is happening instead of just being told what is happening. This was my favorite unit. I looked forward to coming to chemistry to work on the project or go to the lab." A student wrote in his journal, "(This) unit was probably the most life-applicable unit that we have gone through all year, and I liked that." An "B+" student wrote, "I enjoyed going into lab. The project was very challenging, but being able to run experiments on my own was very helpful in my understanding of the material. Its development took a lot of thinking and planning. Even though I struggled through this unit I did learn a lot - not just new material but also about problem solving, work technique, and study habits."

One of the common student complaints regarding this unit is that it lasted too long. "This unit stretched out too long. . . by test time I had forgotten much of the stuff". The interruptions to this unit were varied and a source of frustration for all. The first interferences were three snow days, not all consecutive. A one week spring break was also in the middle of the unit. The week after the return from spring break, the school closed for Good Friday and Easter Break. Also sandwiched into the unit was a half day disruption with career day. All of these days did extend the unit into the longest one of the school year. It was definitely longer than the students were accustomed to having, encompassing the entire marking period but actually 49 calendar days! Some of these issues of time could be minimized with a block schedule. Having students for a longer period of time may create more continuity.

No one teaching method can improve all students in all areas, but this method does seem to be one that most students seem to enjoy and from which they can

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they can benefit. The TIMSS report (National Center for Educational Statistics, 1998) suggested that the thrust of science teaching should be a smaller number of units to study but covering those topics more in depth. The method I developed and used, provided students with an in depth learning experience. However, one of the problems that exists with a totally hands-on approach is that most college chemistry instructors (Sanger and Greenbowe 1996) are not aware of nor do they subscribe to the constructivist philosophy of teaching and learning. In their view, the aim of the instructor is to transfer knowledge (Davis, et al. 1993). The examinations given to students are evaluated on their ability to correctly answer questions and problems created by their instructors. Many of the students enrolled in .3 chemistry will go on to colleges and universities that still adhere to this method of evaluation. A mixture of evaluation methods would satisfy the needs of students who will encounter these university courses. As high school educators, we cannot let university coursework and evaluation methods determine how we teach at the high school level. So many other skills, in addition to core content, need to be taught and assessed. The methods described in this thesis are a step in that direction. The classroom techniques need to be a melding of hands-on and traditional teaching. The focus, however, needs to be shifted toward the more of the hands-on and collaborative methods used in this study. The work involved in a project based, hands-on unit is intense for students and teachers, but incorporating at least one such project per semester should be an attainable goal.

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I think the student driven exploration project has helped my students gain confidence in themselves as problem solvers and writers. I have helped them realize that their learning is dependent on their own efforts. I found more students thinking beyond the proposed problems, thinking how they could improve what they did. For me, one of the challenges was acting more as a coach and mentor instead of the sole provider of knowledge. It would have been easier to simply tell the students the answer or show them how, but the rewards they have gotten in self-satisfaction for having thought it through far surpassed a quick fix. They have taken greater ownership for what they know and have retained it. I think my students will utilize the skills developed in this unit long after they leave H.H. Dow High.

In my opinion, students' overall achievements in working through real life applications and being information processors, effective communicators, and cooperative and self-reliant learners were attained in this unit of study. A notable improvement was also made in the students' core content performance. Overall the exploration, hands-on, methodology challenged students to higher order thinking, with discovery and investigation as the cornerstones. Analyzing, comparing, error analysis, and refining were some of the building blocks for constructing new knowledge. Assessment for conceptual knowledge is not enough. Chemistry does not need to be a mysterious and intimidating encounter. Let's keep the application "real world" and the assessments authentic.

APPENDIX A

ANCILLARY DOCUMENTS

APPENDIX A-1

Core Content for the Acid-base Unit of Accelerated First Year Chemistry

<u>Acids, Bases, and Salts</u>

The student should be able to:

A. define and identify an acid and a base in the Arrhenius and Bronsted-Lowry theories.

B. define and recognize conjugate acid-base pairs in balanced equations for Bronsted-Lowry acid-base reactions.

C. predict the products of and write correctly balanced equations (normal, complete ionic and net ionic) for the following Arrhenius acid-base reactions:

1. neutralization involving the combinations:
   a. strong acid - strong base
   b. strong acid - weak base
   c. weak acid - strong base
2. metallic bicarbonate + an acid = carbon dioxide + water + a salt
3. metallic carbonate + an acid = carbon dioxide + water + a salt
4. an acid anhydride + an aqueous base = water + a salt
5. an basic anhydride + an aqueous acid = water + a salt
6. an ammonium salt + an aqueous strong base = ammonia + water + a salt
7. metallic sulfite + an acid = sulfur dioxide + water + a salt
8. metallic bisulfite + an acid = sulfur dioxide + water + a salt
9. an active metal + an acid = hydrogen gas + a salt

D. name related acids and salts

E. define pH; state use the relationship between pH and the acidic, basic or neutral nature of a water solution; work pH problems

F. recognize and write an ionic equation for each step in the ionization of a polyprotic acid.

G. perform calculation with titration and neutralization reactions data to determine the concentration of the unknown solution, or the volume of solution needed to neutralized a known solution.

H. interpret or draw the titration curve for the combination of a strong acid with a strong base, strong acid with a weak base, weak acid with a strong base identifying the equivalence point, and approximate starting and ending pH.

I. define the hydrolysis reactions of salts in water; predict whether or not the resulting solution will be acidic or basic; and write the net ionic equation for the hydrolysis reaction.

J. identify and use a few acid-base indicators.

APPENDIX A-2

Learner Outcomes for Midland Public Schools

Knowledgeable Person

a. Acquires and integrates critical information necessary for success as a lifelong learner.
b. Effectively utilizes strategies and skills necessary for success as a productive member of society.

Complex Thinker

a. Examines issues and situations and develops a reasoned response.
b. Selects from a variety of complex reasoning strategies and uses them effectively. Strategies may include the following: classifying, comparison, constructing support, decision making, error analysis, experimental inquiry, extending, invention, investigation, problem solving, structural analysis, supported deduction, supported induction, systems analysis.

Cooperative Learner

a. Works with other to achieve learning.
b. Demonstrates effective interpersonal skills.
c. Assesses and monitors personal contribution to group.
d. Uses expertise of others to extend and refine own learning.

Effective Communicator

a. Actively listens to others.
b. Expresses ideas clearly.
c. Effectively communicates with diverse audiences.
d. Effectively communicates through a variety of mediums.
e. Effectively communicates for a variety of purposes.

Ethical Learner

a. Makes decisions that balance self-interest with consideration for others.
b. Fairly represents own work and work of others.
c. Credits work of others.

Information Processor

a. Skillfully uses a variety of information gathering techniques and resources to locate information.
b. Effectively interprets and synthesizes information.
c. Accurately assesses value of information for a given situation.

Self - Reliant Learner

a. Initiates learning.
b. Exercises independent judgment.
c. Perseveres to accomplish goals.
d. Seeks to improve performance.

APPENDIX A-3

Outlined Teacher Lesson Plans for the Acid-base Unit

Day 1
- Pretest
- Discuss exploration project & objectives of the unit
- Assign: Worksheet (WS) "Acids & Salts Nomenclature Review"

Day 2
- Review homework assignment
- Video (30 minutes) "The Proton in Chemistry"
  - WS "'The Proton in Chemistry' Questions" while viewing
- Discussion of video & worksheet using "Think/Pair/Share" & "round robin"

Day 3
- Review properties of acids & bases; include brief discussion of pH
- Review net ionic equations (NIE)
- Prelab "Reactions of Arrhenius Acids & Bases, Acidic & Basic Anhydrides"
- Choose groups for exploration & group work on scenario selection

Day 4
- Lab "Reactions of Arrhenius Acids & Bases, Acidic & Basic Anhydrides"

Day 5
- Lecture/Discussion
  - Compare strong & weak acid solutions at the molecular level
  - Compare acid-base theories
    - students prepare a Venn diagram to review theories
    - students work #1 of Acid-base WS with AB partners
  - Examples of Bronsted-Lowry acids, bases & conjugates
  - students work #2 of Acid-base WS with AB partners
- Assign: Finish WS & work on laboratory report

Day 6 Teacher monitors and helps students work through their questions as
- Students work with lab partners to finish NIE on lab report
- Post answers to assigned WS & discuss
- Assign: labs due tomorrow

Day 7
- Lecture, discussion, & problem solving examples
  - self ionization of H_2O (p. 605 Merrill Chemistry)
  - pH
  - calculations with pH (p. 609,609 Merrill Chemistry)
- Prelab "pH and Indicators"

Day 8

- Lab "pH and Indicators"

Day 9

- Demonstration "Amphoteric Hydroxides"
  - students record observations and notes into journals
- Lecture & demonstration/lab "Hydrolysis"
  - students record observations on prepared lab WS
  - lab sheet to be completed for tomorrow

Day 10

- Lecture, discussion, & problem solving examples
  - review hydrolysis and lab WS
  - titrations & neutralization
    work through example problems together
- Assign: problems with titrations/neutralization from textbook for homework

Day 11

- Review assignment; more examples
- Journal entry
  - Students write a balanced formula equation & NIE for the demonstrated
    reaction
    between 6 M HCl and chalk ($CaCO_3$)
  - teacher monitors checking for correctness or "try again" for 5 minutes, then reveals correct response & describes why
- Group work
- students work on research & exploration plan
- rubrics presented and discussed
- Assign: WS "pH & Hydrolysis

Day 12

- Journal entry
  - Students write for 4 minutes (Type 2), "All you know about acid-base chemistry"
  - Turned in to be graded; teacher check for misconceptions & progress
- Prelab "Titrations"
  - Prelab calculations
  - Demonstration of lab techniques

Day 13

- Lab - prepare & standardize NaOH solution

Day 14

- Group work - students work on research & exploration plan

Day 15

- Lab - determine the mass percent of $HC_2H_3O_2$ in vinegar
- Group work - students work on research & exploration plan

Day 17

- Review returned labs, discussion of corrections & common errors
- Group work
  - self evaluation of exploration plan with rubrics & their own plan, revise & refine
  - peer evaluation, critique & evaluate the plan of another group
  - revise & refine plan then submit for teacher evaluation

Day 18

- Laserdisc "Indicators & pH" & other review discussion on same topic
- Lab Practical Assessment "pH"

Day 19 & Day 20

- Lab time for exploration project (Lab is also available before & after school.)

Day 21

- Lab time or computer time; refinement & reports (written & oral) preparation
- Labs (chem & computer) are available before & after school

Day 22

- Review of lab practical, discussion of corrections & common errors
- Computer time, preparation of reports (written & oral)
- Lab available before & after school

Day 23

- Unannounced quiz
- Plan completion work, prepare to present

Day 24 & Day 25

- Review quiz, discussion of corrections & common errors
- Student presentations & discussions

Day 26

- Review for test
  - specific review of hydrolysis, titration curves, & buffers

Day 27

- Test

Day 28

- Students work on "Acid-base Review" WS

APPENDIX A-4

Sample of the Invitation to the Open House

APPENDIX B

TESTS AND OTHER STUDENT EVALUATIONS

APPENDIX B-1

Pretest Acids, Bases, & Salts

Name: ______________________________

Date: ________ Hr. _____

Pretest - Acids, Bases, & Salts

Circle your confidence level in each response given, "1" being least confident (an off-the-wall guess) and "5" being most confident (I could have written the question myself. I know this stuff!)

1 2 3 4 5 1. Demo: In the space provided describe the appearance of the substances before and after any changes.

a. Vinegar in a beaker

b. Ammonia cleaner in a beaker

c. 2 drops of grape juice added to each

d. Ammonia added dropwise to vinegar

e. Explain what you have observed.

Complete the following as carefully and thoughtfully as you can. Please attempt all problems and rank your confidence level for each.

1 2 3 4 5 2. What is acid rain and what causes it? Describe how you could test rainwater to find out of it is acidic?

1 2 3 4 5 3. List at least four properties of acids and four properties of bases.

1 2 3 4 5 4. Identify acids and bases you have encountered in and around your home. Give the common name and scientific name or chemical formula for each.

1 2 3 4 5 5. Define the term salt. List at least four different methods for the formation of salts.

1 2 3 4 5 6. Draw a picture depicting the particles of strong acids and weak acids to clarify whether or not they are capable of conducting electricity. (The acids have that same molar concentration.)

1 2 3 4 5 7. Some antacids manufacturers claim their product relieves "heartburn". Chemically describe what the advertisers are referring to with this promotional claim.

APPENDIX B-2

Lab Assessment - Indicators

Name: ______________________________

Date: ________ Hr. _____

Lab Assessment-Indicators

Determine the pH range over which the unknown acid-range indicator changes color. The solutions you have to work with are 0.1 M HCl and water. Be conservative with your solutions as refills will cost you. Describe the method you used to solve this problem.

APPENDIX B-3

Rubrics for the Lab Assessment - Indicators

1. Successfully dilute the acid to make solutions of pH 1-6.
2. Add one drop of indicator to each solution.
3. Determine at what pH the indicator color change starts and finishes. These observations define the range of the indicator.

Suggested Scoring Rubrics (11 points possible)
To obtain full credit a student must understand the use of indicators, the nature of the pH scale, and the fact that a pH change of one unit involves a 10 fold dilution.

4 pts. Preparing solutions of pH 1 through pH 6 by successfully diluting 0.1 M HCl.
3 pts. Attempting to prepare a solution of pH 7 through dilution.
2 pts. Attempting to prepare solutions of greater than pH 7 with an acid solution.
1 pt. Attempting dilutions but failing to realize the 10-fold dilution necessary for a change of one pH point.

4 pts. Adding one drop of indicator, observing the results, and reporting the "change " range in terms of 2 pH units.
3 pts. Adding one drop of indicator, observing the results, and reporting the "change " range in terms of 2 pH units but clearly not matching the indicator used.
2 pt. Reporting only one point as a range.
1 pt. Reporting only one point as a range and clearly not matching the indicator used.

3 pts. Clearly stating a description of method.
2 pts. Stating a description of method but missing key steps.
1 pt. Stating a description of method that probably wouldn't work at solving the problem.

APPENDIX B-4

Quiz Acids, Bases, and Salts

Multiple Choice: On the Scantron answer form blacken the letter preceding the word or expression that best completes each question or statement.

1. The pH of a solution in which the $[H^+] = 1.0 \times 10^{-4}$M is
   a. -4.0 b. 4.0 c. 10 d. -10

2. In the solution in #1 above, the $[OH^-]$ is
   a. 4.0 b. 1.0×10^{-4}M c. 1.0×10^{-10}M d. 10

3. Identify the Bronsted-Lowry acids in this reaction: $H_2S + H_2O \longleftrightarrow H_3O^+ + HS^-$
   a. H_2S & H_2O b. H_2S & H_3O^+ c. HS^- & H_2O d. H_3O^+ & HS^-

4. For a solution to be classified acidic, the
   a. hydrogen ion concentration must be 10^{-7} b. hydrogen ion concentration must equal the hydroxide ion concentration c. hydrogen ion concentration must be greater than the hydroxide ion concentration d. hydrogen ion concentration must be 7 M or greater.

5. NO_2 can be classified as a (n) ____ .
   a. common ion b. acidic anhydride c. neutral substance d. basic anhydride

6. Which of these acids is monoprotic?
   a. $HC_2H_3O_2$ b. H_2SO_4 c. H_3PO_4 d. none

7. How many milliliters of 0.20 M NaOH are required to neutralize 30 mL of 0.50 M HCl?
   a. 12 mL b. 50 mL c. 75 mL d. 100 mL

8. A 100. mL sample of hydrobromic acid, HBr, is titrated to an end point with 24.0 mL of 1.5 M NaOH. What is the concentration of HBr?
   a. 1.4 M b. 0.72 M c. 3.1 M d. 0.36 M

9. On the back of the Scantron answer form, write a balanced chemical formula equation for the reaction between aqueous sodium sulfite and nitric acid.

APPENDIX B-5

Acids, Bases, and Salts Test

Multiple Choice: Choose the letter of the word or expression that best completes each statement or question and darken the corresponding letter on the answer form. (1 pt each)

1. A metal is reacted with a stoichiometrically correct mass of an Arrhenius acid. The water is then evaporated from the mixture. The substance remaining is a. excess acid. b. a metallic oxide. c. a metallic hydroxide. d. a salt.

2. Which of the following applies to a solution with a pH of 4.0? a. It is a base. b. It could be produced by the hydrolysis of sodium carbonate. c. It has a hydrogen ion concentration of 4.0 M. d. It has a hydroxide ion concentration of 1×10^{-10} M.

3. Which of the following bases is classified as amphoteric?
a. $NaOH$ b. $LiOH$ c. $Sn(OH)_2$ d. NH_4OH

4. A salt can be formed through a chemical reaction involving each of the following combinations <u>except</u> a. a metallic oxide and water b. a metallic carbonate and an aqueous acid c. an aqueous acid and a solid base
d. a metallic oxide and an aqueous acid.

5. Which of the following is classified as a weak acid?
a. hydrobromic acid b. hypochlorous acid c. nitric acid d. perchloric acid

6. Hypobromous acid has the formula
a. $HBrO$ b. $HBrO_2$ c. $HBrO_3$ d. $HBrO_4$.

7. The pH of a 0.01 M solution of KOH is about a. 2 b. 8 c. 12 d. 14

8. Hydrolysis does not occur in the presence of the salt of a a. strong acid and strong base. b. weak acid and weak base. c. weak acid and strong base. d. strong acid and weak base.

9. Which of the following is considered to be a basic anhydride?
a. SO_2 b. NH_3 c. CH_3OH d. Na_2O

10. What are the acids in the following reaction? $CN^- + H_2O$ <—> $HCN + OH^-$

a. CN^-, H_2O b. H_2O, HCN c. H_2O, OH^- d. OH^-, CN^-

11. Salts formed when a binary acid neutralizes a metallic hydroxide have the ending a. -ide b. -ite c. -ous d. -ic

12. Which of the following pH's indicates an aqueous solution that is strongly acidic? a. 1 b. 6 c. 8 d. 14.

13. A substance that can act either as an acid or a base is
a. polyprotic. b. neutral. c. anhydrous. d. amphoteric.

14. Ferrous chlorite has the formula
a. $Fe_2(ClO_2)_2$ b. $FeClO_2$ c. $Fe(ClO_2)_2$ d. $Fe(ClO_2)_3$

15. The equivalence point of an acid-base titration is that point where a. the number of moles of the acid equals the number of moles of the base b. the number of grams of the acid equals the number of grams of the base c. the pH of the solution is 7 d. the number of moles of hydronium ions equals the number of moles of hydroxide ions

16. Identify the substance acting as the strong Brønsted acid in the reaction :

$HClO_4 + CH_3OH$ <—> $ClO_4^{-1} + CH_3OH_2^{+1}$

a. $HClO_4$ b. CH_3OH c. ClO_4^{-1} d. $CH_3OH_2^{+1}$

17. Identify the substance acting as the weaker Brønsted base in the reaction:

$OH^{-1} + HCO_3^{-1}$ <—> $CO_3^{-2} + H_2O$

a. OH^{-1} b. HCO_3^{-1} c. CO_3^{-2} d. H_2O

18. Arrhenius concluded that an acid is a substance that releases __?__ ions when added to water.
a. hydroxide b. hydronium c. oxygen d. hydrogen

Refer to the following table when answering questions 19-21.

Indicator	*Acid color*	*Base color*	*pH range of color*
a. bromphenol blue	yellow	blue	3.0-4.6
b. bromthymol blue	yellow	blue	6.0-7.6
c. alizarin yellow	yellow	red	10.1-12.0
d. phenolphthalein	clear	magenta	8.1-10.6

19. Which indicator would be the best choice for a titration with an endpoint of a pH of 4.0? a. bromphenol blue b. bromthymol blue c. alizarin yellow d. phenolphthalein

20. Which indicator would be the best choice for a titration of a weak acid with a strong base? a. bromphenol blue b. bromthymol blue c. alizarin yellow d. phenolphthalein

21. Which indicator would be the best choice for a titration of a strong base with a strong acid? a. bromphenol blue b. bromthymol blue c. alizarin yellow d. phenolphthalein

NAME ________________________________

.3 Chem Acids, Bases, & Salts Part 2 Date: ______ Hr. ______

Completion questions and problems Place your answers on the line provided. Show your work in the space provided. Use significant figures and units properly. Partial credit can be earned.

1. Complete and balance a normal chemical formula equation for each of the following reactions. (2 points each)

a. ____ SO_2 (g) + ____ NaOH (aq) -->

b. ____ $HClO_3$ (aq) + ____ $CaCO_3$ (s) -->

2. Write a correctly balanced normal chemical formula equation for each of the following reactions. (2 points each)

a. potassium (s) + sulfuric acid -->

____

b. sodium oxide (s) + perchloric acid -->

____

3. Write a correctly balanced net ionic equation for each of the following reactions. (2 points each)

a. H_2SO_4 (aq) + $Ba(OH)_2$ (aq)

____

b. HCl (aq) + K_2SO_3 (s)

____

5. Given 2.8×10^{-5} M HCl (aq). Determine the: (2 points each)

________ a. pH of the solution

________ b. $[OH^{-1}]$ of the solution

Application.

6. (2 points) Choose one of the following topics taken from different presentations and summarize. (You may not choose a topic from your study.)

a. buffering b. back titrations c. pH and the blood d. titration of toilet bowl cleaners e. pH meters

7. A 20.0 mL sample of 0.100 M $HClO_4$ (aq) is neutralized using 0.200 M NaOH (aq).

__________ a. What volume (mL) of 0.200 M NaOH are needed to reach the equivalence point of the titration? (2 points)

__________ b. How many grams of NaOH would be required to make 275 mL of the above solution (assume no deliquescence)? (2 points)

c. (3 points) Sketch the titration curve for the neutralization process (proposed in part a) on the axis provided indicating:

I. the approximate equivalence point pH (line to appropriate axis)
II. the equivalence point volume for the NaOH (line to appropriate axis)
III. approximate starting pH and general shape of the curve.

d. Explain hydrolysis using equations or an atomic level picture. Will it occur in this acid / base reaction? What will be the pH of the resulting salt solution relative to pH 7? (4 points)

APPENDIX B-6

Final Exam Questions Regarding the Acid-base Unit

23. According to the Arrhenius theory, one product formed when an acid and a base react is
    a. an anhydride b. hydrogen
    c. a hydride d. water

42. Twenty-five (25) mL of HI solution neutralizes 50. mL of 0.10 M $Ba(OH)_2$ solution. What is the
molar concentration of the HI solution?
    a. 0.10 M b. 0.20 M
    c. 0.30 M d. 0.40 M

45. What is the pH of a 0.0001 M solution of potassium hydroxide, KOH?
    a. 10 b. 8 c. 6 d. 4

59. Which of the following applies to a solution with a pH of 4.0?
    a. It is a base.
    b. It has a hydroxide ion concentration of 1×10^{-10} M.
    c. It has a hydrogen ion concentration of 4.0 M.
    d. It could be produced by the hydrolysis of sodium carbonate.

64. A salt can be formed through a chemical reaction involving each of the following combinations <u>except</u>
    a. a metallic oxide and water
    b. a metallic carbonate and an aqueous acid
    c. an aqueous acid and a solid base
    d. a metallic oxide and an aqueous acid.

67. Which of the following is considered to be an acid anhydride?
    a. SO_2 b. NH_3 c. HCl d. CaO

73. When $MgCO_3$ (s) and HBr (aq) react, the products of the reaction are
    a. CO_2 (g), H_2O, and $MgBr_2$ (aq)
    b. H_2CO_3 (aq) and $MgBr_2$ (aq)
    c. CO_2 (g), H_2O, and MgBr (aq)
    d. H_2 (g), MgO (s), Br_2 (aq), and CO (g)

74. Which statement explains that a water solution of hydrogen bromide, HBr, is an excellent conductor, while pure liquid hydrogen bromide does not conduct electricity?
  a. Hydrogen bromide releases electrons in water.
  b. Hydrogen bromide is a non-electrolyte.
  c. Hydrogen bromide ionizes in water.
  d. Water is an electrolyte.

76. A solution that is protected against a drastic change in the hydrogen ion concentration is said to be
  a. buffered
  b. basic
  c. acidic
  d. at a physical equilibrium position

79. Aqueous hydrochloric acid, HCl, is neutralized with solid CuO. What is the correct net ionic equation for this reaction?
  a. $CuO\ (s) + 2\ HCl\ (aq) \dashrightarrow Cu^{2+}\ (aq) + 2\ Cl^{-1}\ (aq) + H_2O$
  b. $Cu^{2+}\ (s) + O^{2-}\ (s) + 2\ H^{1+}\ (aq) + 2\ Cl^{-1}\ (aq) \dashrightarrow Cu^{2+}\ (aq) + 2\ Cl^{-1}\ (aq) + H_2O$
  c. $CuO\ (s) + 2\ H^{1+}\ (aq) \dashrightarrow Cu^{2+}\ (aq) + H_2O$
  d. $CuO\ (s) + 2\ H^{1+}\ (aq) + 2\ Cl^{-1}\ (aq) \dashrightarrow CuCl_2\ (s) + H_2O$

Refer to the following table when answering questions 83 &84.

Indicator	*Acid color*	*Base color*	*pH range of color*
a. bromphenol blue	yellow	blue	3.0-4.6
b. bromthymol blue	yellow	blue	6.0-7.6
c. phenolphthalein	clear	magenta	8.1-10.6

83. Which indicator would be the best choice for a titration of a weak acid with a strong base?

84. Which indicator would be the best choice for a titration with an endpoint of a pH of 4.0?

APPENDIX B-7

Post Test Acids, Bases, & Salts

Name: ______________________________

Date: ________ Hr. _____

Post Test Acids, Bases, & Salts

Circle your confidence level in each response given, "1" being least confident (an off-the-wall guess) and "5" being most confident (I could have written the question myself. I know this stuff!)
Complete the following as carefully and thoughtfully as you can. Please attempt all problems and rank your confidence level for each. You may use any chemical equations that may apply in your explanations.

1 2 3 4 5 1. What is acid rain and what causes it? Try to be specific with a chemical equation for a reaction that may occur. Describe how you could test rainwater to find out of it is acidic?

1 2 3 4 5 2. List at least four properties of acids and four properties of bases. Include pH in your response if possible.

acids	bases
1.___________________________	1.___________________________
2.___________________________	2.___________________________
3.___________________________	3.___________________________
4.___________________________	4.___________________________

1 2 3 4 5 3. Identify acids and bases you have encountered in and around your home. Give the common name and scientific name or chemical formula for each.

acids	bases
1.____________________________	1.____________________________
2.____________________________	2.____________________________
3.____________________________	3.____________________________
4.____________________________	4.____________________________

1 2 3 4 5 4. Define the term salt. List at least four methods (reactions?) for the formation of salts.

1.

2.

3.

4.

1 2 3 4 5 5. Is it possible for a salt to be acidic or basic? Briefly explain.

1 2 3 4 5 6. Draw a picture depicting the particles in aqueous solutions of strong acids and weak acids to clarify whether or not they are capable of conducting electricity. (The acids have that same molar concentration.)

Strong Acid

Weak Acid

1 2 3 4 5 Tell about your project and specific findings regarding acid - base chemistry.

Thanks for your help! Have a great summer!
Come back to visit and I'll let you know how this all turns out.

APPENDIX C

WORKSHEETS, LABORATORY EXERCISES, DEMONSTRATIONS

APPENDIX C-1

Acids and Salts Nomenclature Worksheet

Complete the following tables. A portion of the grid is completed for examples.

Acid Formula	Name of acid if "pure"	Name of acid in a water solution	Strong or weak electrolyte? \ in a NIE written ...
HCl	hydrogen chloride	hydrochloric acid	$H_3O^+ + Cl^-$ (aq)
HF			
$HClO_4$	hydrogen perchlorate	perchloric acid	
$HClO_3$	hydrogen chlorate	chloric acid	
$HClO_2$			$HClO_2$ (aq)
$HClO$	hydrogen hypochlorite		
H_2SO_4			
H_2SO_3			
HNO_3			
HNO_2			
H_3AsO_3			
HCN			
$HBrO$			
$HC_2H_3O_2$			

Formula of a corresponding salt	Name of the salt, common (old) system	Name of the salt, Stock (new) system
Hg_2Cl_2	mercurous chloride	mercury (I) chloride
KF		
$NaClO_4$	sodium perchlorate	
$Ba(ClO_3)_2$		
$Fe(ClO_2)_3$		
LiClO		
$FeSO_4$		
$CuSO_3$		
$Ni(NO_3)_2$		
$Ni(NO_2)_3$		
$CrAsO_3$		
$Pb(CN)_4$		
$Hg(BrO)_2$		
$NH_4C_2H_3O_2$		

APPENDIX C-2

'The Proton in Chemistry' Video Questions

Directions: Read this worksheet before the video begins. Attempt to answer the following questions while viewing the video. There will be discussion topics following your personal and pair review of the worksheet. You may use the backside of the paper to take any additional notes.

1. What is the species that gives an aqueous solution of an acid the characteristic properties of an acid?

2. Consider the chemical reactions:

$$NaOH\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$$
$$2\ NaOH\ (aq) + H_2SO_4\ (aq) \rightarrow Na_2SO_4\ (aq) + 2\ H_2O\ (l)$$
$$KOH\ (aq) + HCl\ (aq) \rightarrow KCl\ (aq) + H_2O\ (l)$$

Write one net ionic equation that describes the chemical action that occurs in all three equations.

_____ 3. Which of the following gases can dissolve in rain droplets in the atmosphere to produce acid rain? a. ozone b. sulfur dioxide c. nitrogen d. oxygen

_____ 4. Which of the following situations is best described by the phrase, "has a hydrogen ion concentration of 10^{-7} mol/L"? a. a solution with a pH of 7 b. an aqueous acidic solution c. rain water d. an aqueous basic solution e. more than one response is correct

5. Which contains more acid, a green apple or a ripe apple? How do you know?

6. What is the pH of each of the following solutions:

________ a. 0.1 mol/L HCl?

________ b. 0.00001 mol/L HCl?

________ c. 0.01 mol/L NaOH?

7. List as many properties as you can for the following questions.

a. What is an acid? b. What is a base?

APPENDIX C-3

Reactions of Arrhenius Acids & Bases, Acidic & Basic Anhydrides

Purpose:

• Observe and study some typical properties and reactions of acids, bases, acidic and basic anhydrides.

• Write net ionic equations for the reactions observed.

Discussion:

This experiment should aid in the understanding of the properties and reactions of acids and bases, neutralization reactions, single and double displacement reactions, double displacement with product decomposition, and synthesis reactions. It will allow you to view a variety of common reactions involving acids, bases, acid anhydrides, and basic anhydrides. You will be able to observe the effects of acids and bases on indicators. The products of the reactions are to be predicted through the use of the list of general reactions.

1. acid + metal --> salt + hydrogen gas
2. active metal + water --> metallic hydroxide + hydrogen gas
3. acid + base --> salt + water (neutralization)
4. acid + metallic oxide (basic anhydride) --> salt + water
5. acidic anhydride (nonmetallic oxide) + base --> salt + water
6. acid + metallic sulfide --> salt + hydrogen sulfide gas
7. acid + metallic carbonate --> salt + carbon dioxide gas + water
8. acid + metallic bicarbonate --> salt + carbon dioxide gas + water
9. acid + metallic sulfite --> salt + sulfur dioxide gas + water
10. acid + metallic bisulfite --> salt + sulfur dioxide gas + water
11. acid anhydride + water --> acid
12. basic anhydride + water --> metallic hydroxide

Procedure:

<u>General Directions:</u>

• Safety goggles and aprons are needed. Handle acid and base solutions with care, and avoid spills on your clothing or skin.

• All reactions will be carried out in your reaction plate except for reaction 1. Obtain the pipets of solutions to be used from the main supply bench. Obtain a small straw scoop of each of the solids on weigh papers.

• Note your observations regarding each combination on a piece of notebook paper or prepared grid.

• All solutions can be dispensed into the sink, thoroughly rinsing solutions down the drain using city water. Leftover solids should be disposed of in the waste basket.

Reactions:

1. Place approximately 1 mL of 0.01 M KOH (aq) in a large test tube. Add 4 mL of deionized water and a drop of phenolphthalein. With a plastic straw, blow your breath into the solution until a color change occurs. Your breath is a source of CO_2 (g).

2. Place 5 drops of 0.1 M KOH (aq) in a well and add a drop of phenolphthalein. Add 1 M HCl (aq) drop by drop (agitating after each addition) until a color change occurs.

3. Place 5 drops of 0.1 M KOH (aq) in a well and add a drop of phenolphthalein. Add 1 M $HC_2H_3O_2$ (aq) drop by drop (agitating after each addition) until a color change occurs. Compare the number of drops required with the number of drops of acid used in reaction 2.

4. Place a small piece of Zn (s) in a well and add 6 M HCl (aq).

5. Place a small piece of Zn (s) in a well and add 6 M $HC_2H_3O_2$ (aq). Compare the rate of the reaction with that in number 4 reaction.

6. Place a small piece of Cu (s) in a well and add 6 M HCl (aq).

7. Place 6 drops of 3 M H_2SO_4 (aq) in a well. To this add a VERY SMALL mass of $NaHCO_3$ (s). Observe and record.

8. Place 6 drops of 3 M H_2SO_4 (aq) in a well. Add 5 drops of 0.5 M $NaHCO_3$ (aq). Compare the rate of the reaction with that in number 7.

9. Place 6 drops of 6 M HCl (aq) in a well. To this add a VERY SMALL mass of $BaCO_3$ (s).

10. Place 6 drops of 3 M HNO_3 (aq) in a well. To this add a VERY SMALL mass of Na_2SO_3 (s). Carefully note any odor (waft) after the bubbling has stopped.

11. Place 6 drops of 6 M $HC_2H_3O_2$ (aq) in a well. To this add a VERY SMALL mass of Na_2SO_3 (s). Carefully note any odor (waft) after the bubbling has stopped.

12. Place 6 drops of water and a drop of phenolphthalein in a well. To this add a VERY SMALL mass of BaO (s). Agitate until there is a color change.

13. Place a very SMALL mass of BaO (s) in a well and add a drop of phenolphthalein. Add 3 M HNO_3 (aq) drop by drop (agitating after each addition) until a color change occurs.

Name: ______________________________ Hr. _____

Partner's Name: ________________________ Due Date: _____

Equations:

A. Write the correct chemical formula equation for each of the observed reactions, and

B. **the correctly balanced** NET IONIC **equation** (NIE). **Hint: Review how solids, strong electrolytes, weak electrolytes, and molecular substances are represented in NIE.**

1. KOH (aq) + CO_2 (g)

A. ____

B. ____

2. KOH (aq) + HCl (aq)

A. ____

B. ____

3. KOH (aq) + $HC_2H_3O_2$ (aq)

A. ____

B. ____

4. Zn (s) + HCl (aq)

A. ____

B. ____

5. Zn (s) + $HC_2H_3O_2$ (aq)

A. ____

B. ____

6. Cu (s) + HCl (aq)

A. ____

B. ____

7. $NaHCO_3$ (s) + H_2SO_4 (aq)

A. ____

B. ____

8. $NaHCO_3$ (aq) + H_2SO_4 (aq)

A. ____

B. ____

9. $BaCO_3$ (s) + HCl (aq)

A. ______________________________

B. ______________________________

10. Na_2SO_3 (s) + HNO_3 (aq)

A. ______________________________

B. ______________________________

11. Na_2SO_3 (s) + $HC_2H_3O_2$ (aq)

A. ______________________________

B. ______________________________

12. BaO (s) + H_2O (l)

A. ______________________________

B. ______________________________

13. BaO (s) + HNO_3 (aq)

A. ______________________________

B. ______________________________

Conclusions and Questions:

1. What <u>type</u> of reaction occurs between a metal and an acid?

2. What <u>type</u> of reaction occurs between a basic anhydride and an acid?

3. What <u>type</u> of reaction occurs between a metallic carbonate and an acid?

4. <u>Explain</u> the difference in reaction rates of the given metal with the two different acids on the molecular level.

5. Compare the reactivity of zinc with that of copper.

6. In reaction 1, if the 0.01 M KOH solution was replaced by a 0.10 M KOH what would you observe? Why?

APPENDIX C-4

Indicators and pH

Objectives:

- To observe and record the colors changes of acid-base indicators
- To prepare solutions of varying pH
- To relate pH to [H_3O^+] and [OH^-]
- To determine the pH range of each indicator

Discussion:

The acidity (concentration of H_3O^+) or alkalinity (concentration of OH^-) of an aqueous solution is an important factor in describing the solution's properties. The measurement of the H_3O^+ or OH^- concentration in a solution can be accomplished several ways.

1. Use of a pH meter

   The pH meter is an electronic device which compares the voltage in a solution to that of a standard. The acidity or alkalinity is read out directly from a digital or analog meter. The device is accurate and fast but very expensive.

2. Use of indicator paper

   Indicator paper is ordinary filter paper which has been soaked in a solution of a dye called an indicator. This type of indicator is often used for quick biological testing of blood pH levels. This dye changes color when the concentration of H_3O^+ reaches a certain level. While the paper is relatively inexpensive, it is difficult however to follow any continuous change in the pH of a solution since the paper must be dipped in out repeatedly.

3. Use of an indicator solution

An indicator solution, usually a weak acid solution, changes color at a specific pH. Mixtures of indicators can be used to provide a continuously changing picture of changes in pH. In this lab, three individual indicators, bromthymol blue (Btb), phenolphthalein (Hph), methyl orange (MO), will be used. You will investigate the color changes of various acid-base indicators as a function of pH. The various concentrations of hydronium and hydroxide ions will be achieve through serial dilutions. In addition a standard universal indicator (UI) will be used which is a mixture of organic dyes which change color and allow for a fairly accurate approximation of the whole number pH value of a test solution.

Materials:

- Microtip pipet of 0.01 M NaOH
- Microtip pipet of 0.1 M HCl

- a beaker of recently boiled, distilled water (approx. 100 mL)
- Microtip pipet for transfer and diluting procedure
- universal, bromthymol blue, phenolphthalein, and methyl orange indicators
- 2 microplates
- **safety goggles and apron**

Procedure:

1. Place the two microplates end to end on a white piece of paper so the wells of the four rows are lined up. Numbering the paper may be helpful to keep track of the well numbers.

2. Add 9 drops of water to each of the wells #2 through #11 in row A through D.

3. Place 10 drops of 0.1 M HCl to #1 well of each row.

4. Place 10 drops of 0.01 M NaOH to #12 well of each row.

5. Transfer ONE drop of acid from the first well to the second in each row. Mix thoroughly by drawing up the entire contents of the well into the pipet and then returning the liquid to the well.

6. Transfer one drop from the second well to the third mixing and diluting as before (step 5) until you reach well #6 which will be the last of the acidic dilutions. This procedure is known as a <u>serial dilution</u>.

7. Repeat the dilution procedure using the 0.01 M NaOH in #12 wells, working backward from #12 to #8 making #8 the last of the basic dilutions.

8. You now have four rows of diluted solutions containing varying amounts of acid and base, each one having less acid or base from the other by a factor of 10. Careful consideration will reveal that the well numbers indicate the approximate pH of the solutions in each well. For example, well 4 has a pH = 4.
   Add 1 drop of universal indicator to EACH WELL in row A.
   Add 1 drop of methyl orange indicator to EACH WELL in row B.
   Add 1 drop of phenolphthalein indicator to EACH WELL in row C.
   Add 1 drop of bromthymol blue indicator to EACH WELL in row D.

9. How would you make an universal indicator? Try it.

10. How would you make indicator paper? Try it.

11. All solutions may be disposed of by rinsing down the drain with city water or they may be saved for future use by running a continuous strip of clear tape over the top of a row of wells. Run your finger over the top of the wells to seal the tape over the liquid.

Name: ______________________ Hr. _____

Partners: ____________________ Due Date: _____

Data and observations:

1. On the grid provided label the approximate pH of each column. Label each row with the indicator used. Note and record the significant color changes in each row with the use of a grid.

2. What does the seventh well of each row represent? All the pH values below that well are considered to be...? above that?

3. At what pH does each indicator change? Make a list of the indicators and the pH range of each indicator.

4. Which of the indicators tested is a good acid pH range indicator? Why?

5. Which of the indicators tested is a good base pH range indicator? Why?

6. Phenolphthalein is not a good indicator to use when testing the pH of aquarium water. Suggest a reason why.

7. Which would be a good indicator for an HCl / NaOH titration and why?

APPENDIX C-5

Acid-base Titrations

Objectives

- To prepare and standardize a base solution using a solid acid as a primary standard
- To determine the mass percentage of acetic acid in a vinegar sample

Introduction and Discussion

One of the important tools in a chemist's arsenal for finding quantitative data (how much is in there) is the technique of titration. In a titration, a solution of known concentration or pH is added gradually to a solution of unknown concentration. In most cases the known substance is a base. When the unknown solution is exactly neutralized, the number of moles of hydronium ions is equal to the number of moles of hydroxide ions.

$$\text{number of moles } H_3O^+ = \text{number of moles of } OH^-$$

This endpoint is shown by the color change of an acid-base indicator or by the reading on a pH meter.

In a titration, the solutions are dispensed from burets. The volume of the solution used is calculated by subtracting the initial volume (before the titration begins) from the final reading (when the titration is complete). The volume in a buret can be read accurately to ± 0.01 mL. This makes it possible to determine the concentration of the unknown solution with a great degree of accuracy provided the known solution is also accurately prepared. A solution whose concentration is known to a high degree of accuracy is a standard solution.

In the first part the experiment you will standardize a sodium hydroxide solution by a titration against a primary standard. A primary standard is a chemical substance of such purity that it can be used as a reference for standardizing other reagents. In this case the primary standard is potassium hydrogen phthalate, an organic acid whose formula is $KHC_8H_4O_4$, referred to as KHP for short. In water it ionizes to form $K^+ + HC_8H_4O_4^-$ The latter ion then reacts with the OH^- from the base solution:

$$HC_8H_4O_4^- (aq) + OH^- (aq) \text{ --> } H_2O + C_8H_4O_4^{-2} (aq)$$

The moles ratio of $HC_8H_4O_4^-$: OH^- is clearly 1:1, therefore at the endpoint the no. moles $HC_8H_4O_4^-$ = no. moles OH^-. So, the mass KHP / molar mass KHP = $M_{base} \times V_{base}$ and you can find the molarity of the base. You will be massing your acid samples by difference using a weighing vial. You will mass the vial containing the acid, dispense a portion of the acid, then remass the vial. The difference between the final and the initial masses is the mass of acid used.

Finally you will use your standardized base solution to determine the mass percent of acetic acid in a vinegar sample supplied.

This experiment when done properly is probably the most accurate of all the labs you have performed. You may be using your determinations from this lab in your acid-base exploration. To get good results you must be careful with all your measurements and use proper technique. With great care, you will have enough solution and good data to use on the second day. As you read over the procedure try to recognize those steps which must be done exactly right, since that will help you when you actually do the experiment.

Prelab

• Problems

1. Two hundred milliliters of KOH solution were prepared. A 10.0 mL sample of the solution neutralized 2.40 g of $H_2C_4H_4O_6{\cdot}H_2O$ (s) according to the reaction: $H_2C_4H_4O_6{\cdot}H_2O$ (s) + 2 KOH (aq) --> $K_2C_4H_4O_6$ (aq) + 3 H_2O Determine the molarity of the potassium hydroxide solution.

2. A second 10.0 mL portion of the KOH solution neutralized a 15.0 mL sample of HNO_3 (aq). The density of the acid solution is 1.05 g/mL. Determine the mass percent of HNO_3 in 100. mL of the sample solution.

• Get with your partner and prepare a flow chart for each part. (You each need one.) Divide the duties to use your time efficiently.

• Prepare a data table that will allow you to record the readings on each of the burets, acid and base, for three separate trials in Part 2.

<u>Safety</u>

• Goggles and apron required

• Sodium hydroxide is very caustic especially in the concentrated solid pellets. It can damage skin, eyes, and clothing. If you spill any pellets, clean up your mess immediately. NaOH is deliquescent. A pellet left in the open may take on enough water to mistaken for water! If the solid comes in contact with you, rinse with plenty of water.

- Report all spills to your instructor.
- Wash your hands thoroughly before leaving the lab.

Procedure

General Directions for Buret Care and Usage

Prepare: If you are using a base solution, choose a "B" buret and an "A" one for an acid. The buret(s) needs to be cleaned with soap, water, and a buret brush. It should be rinsed thoroughly with a tap water then with two small portions (~ 5 mL) of deionized water. Careful, burets do not fit in the sink! Check the stopcock to make sure it twists smoothly. If not notify your instructor for assistance. The buret should then be rinsed with two small aliquots of the prepared solution used for the titration. These rinses should be disposed of in the sink with water. The final rinses will insure that the concentration of the solution will be the same throughout the buret.

Fill: Fill the buret by placing your solution in a small beaker from which you can pour slowly. Be sure to eliminate air bubbles including the tip.

Clean-up: When finished with your titration, any titrant left in the buret can be saved in your stock bottle for use in subsequent acid-base labs. The buret should be rinsed thoroughly with tap water and hung inverted, with the stopcock open, from the buret clamp.

Part 1 - Preparation of the Primary Standard

1. Wash and rinse both Erlenmeyer flasks.
2. Obtain a vial of KHP and mass out by difference about 1.3 g of KHP to the accuracy of the balance. Place the acid directly in one of the cleaned Erlenmeyer flasks. Record the masses. To the acid sample in the flask, add about 50 mL of deionized water and one or two drops of phenolphthalein indicator. Dissolve the acid by swirling for about two minutes. If the acid doesn't dissolve, don't worry, it will later in the titration.
3. Prepare a flask for a second trial in the same manner as above only massing about 1.6 g of KHP.

* If a third trial is required, mass about 1.5 g of KHP.

Preparing and Standardizing the Base Solution

1. Wash and rinse a bottle and cap. Final rinse with deionized water. It doesn't need to be dry inside. Label the bottle with your station and drawer number.
2. Prepare a sodium hydroxide solution that is about 0.5 M by dissolving about 5 g of solid reagent in enough deionized water to make about 250 mL. Because the substance is deliquescent you should work quickly. Be sure to close the stock reagent bottle immediately after you use it. If you spill any pellets, clean up your mess immediately.

Once the solid has dissolved, the solution can be stored in the prepared bottle.

* Only about one third of this solution should be used for Part 1. The remainder is required for Part 2 and your exploration. Follow the general directions for filling the buret.

3. Place the first flask prepared on a piece of white paper beneath the buret. Lower the buret so the tip is inside the neck of the flask. Record the initial buret reading, then dispense 10.0 mL of the base into the flask. Swirl to mix and dissolve any of the solid acid that wasn't dissolved previously. Rinse the inside walls of the flask with a small stream of deionized water. While constantly swirling the flask, add the base dropwise. As you approach the endpoint, the pink color will appear and then fade. Go slow. When the pale pink color remains for at least 30 seconds, record the final buret reading.

4. Refill the buret, and repeat the steps above with your second flask.

5. Do a quick check to determine if a third titration trial is necessary. Take the volume of base delivered and divide by the mass of acid delivered for each trial. Compare the quotient obtained for each. They should be within ± 00. of one another. If they are not check with your teacher before proceeding with a third titration.

6. Return the acid weighing vial containing any unused acid to the designated container. Clean up and store all equipment. Your standardized hydroxide solution can be stored in your lab station drawer for further use.

7. Complete the calculations and questions for Part 1. The report is due on the day you are scheduled to do Part 2. Record the concentration of the standardized base solution on the data table for Part 2.

<u>Part 2 - Determination of the Mass Percent of Acetic Acid in Vinegar</u>

1. Obtain approximately 60 mL of vinegar in a clean dry 150 mL beaker. Follow the general buret directions for cleaning and filling. Clean and rinse both Erlenmeyer flasks.

2. Record initial buret readings of both burets, and place one of the flask on a piece of white paper beneath the acid buret. Dispense about 10 mL of the vinegar solution into it, add about 50 mL of deionized water, and 1 or 2 drops of phenolphthalein. Titrate with the base using constant swirling until the pale pink endpoint is reached. Remember to periodic rinse the inside walls of the flask. Now add enough vinegar solution, dropwise, until the pink disappears, then add base dropwise until the pink color is back and remains. Repeating this back and forth method several times ensures the endpoint is clearly established. Record the final buret readings.

3. Top off both burets with their respective solutions and repeat the procedure with the second Erlenmeyer flask.

4. Clean and rinse the first flask and repeat the procedure again for the third trial in the set.

5. Follow clean-up procedures as indicated in Part 1.

Report - Part 1

Data Table 1	Trial 1	Trial 2	Trial 3*
Initial mass vial & acid sample			
Final mass vial & acid sample			
Mass of acid used			

* If needed. Cross out the trial not being used.

Data Table 2	Trial 1	Trial 2	Trial 3*
Initial buret reading			
Final buret reading			
Volume of base used			

Calculations

Show all set-ups in the space provided. Circle your answer. Use units and significant figures correctly.

1. Determine the number of moles of base used in each trial.

Trial 1	Trial 2

2. Determine the molarity of the base in each trial.

Trial 1	Trial 2

3. The average molarity of the base is _________ .
(Record this value on the report sheet for Part 2.)

Questions and Problems

1. Assume the acid to be in the solid state and write the correct net ionic equation for the neutralization in Part 1.

____

2. Explain why sodium hydroxide cannot be used as a primary standard by massing it out and dissolving it in water.

3. Standardized hydroxide solutions need to be capped tightly. State one physical and one chemical reason for needing to tightly cap these bottles.

Name: ______________________ Hr. _____

Partners: ______________________ Due Date: _____

Report - Part 2

__________ Molarity of base as determined in Part 1

Calculations

Show all set-ups in the space provided. Place your answers on the line provided. Use units and significant figures correctly.

1. The volume of vinegar and the base used for each trial have been calculated on the data table you produced. Determine the molarity of the vinegar in each trial. Determine the average molarity for the vinegar.

__________ Trial 1

__________ Trial 2

__________ Trial 3

__________ Average value

__________ 2. Using your average value, calculate the number of moles of acetic acid in 100. mL of the vinegar solution.

__________ 3. How many grams of acid are in this sample?

__________ 4. What is the mass percent of acetic acid in this sample, if the density is assumed to be 1.00 g/mL?

__________ 5. If the manufacturer's reported percentage is 5% acid content, calculate the percent error.

6. Write the correct net ionic equation for the reaction that occurred in Part 2.

____

7. The acetic acid present in a 45.0 g of an aqueous solution is completely neutralized by 28.0 mL of 1.00 M $Ca(OH)_2$ (aq). Determine the mass percent of acetic acid in the aqueous solution.

APPENDIX C-6

Salt Hydrolysis

Objectives

- To determine the pH's of several aqueous salt solutions
- To explain the results by means of net ionic equations for salt hydrolysis
- To predict whether additional solutions will be acidic, basic, or neutral in pH

Introduction

A salt formed in the neutralization reaction between a strong acid and a strong base will dissolve in water to give a solution that has a pH of approximately 7, neutral. Salts formed in neutralization reactions of other acid-base combinations may form solutions that are not neutral! The salt of a weak acid and a strong base gives a solution that has a basic pH. The salt of a strong acid and a weak base forms a solution that has a pH of less than 7. This phenomenon, the reaction of a salt with water to produce an acidic or basic solution, is called salt hydrolysis.

Amphoteric substances can act as either a Brønsted acid (proton donor) or a Brønsted base (proton acceptor). Water is amphoteric and can act as an acid or base depending on the substance it is combined with, creating salt hydrolysis. (Remember: stronger acid + stronger base —> weaker acid + weaker base) If the cation of the salt is a strong-enough Brønsted acid, such as NH_4^+, a proton is transferred to water, acting as a Brønsted base. The net ionic equation describing this reaction is:

$NH_4^+ + H_2O \longrightarrow H_3O^+ + NH_3$, where H_3O^+ is the conjugate acid and NH_3 is the conjugate base created after the proton transfer. The opposite is true if the ion in solution were a strong-enough Brønsted base.

In this experiment you will determine the pH of solutions of various salts. You will analyze your results to determine if one of the ions produced in solution is capable of reaction with water to produce hydronium or hydroxide ions.

Predemo Preparation

1. Prepare a data table to record your results. The table should include the name of the salt solution, the formula, the approximate pH obtained, and your conclusion as to whether the solution was acidic, basic, or neutral.

Materials

Solutions of:	sodium chloride	sodium acetate
sodium bicarbonate	ammonium chloride	sodium carbonate
sodium phosphate	zinc sulfate	universal indicator

Further Analysis and Conclusions

1. For each salt, write a balanced net ionic equation (NIE) to show how it dissociates in a water solution.
2. For those salts whose solutions are acidic, write an additional NIE to show the hydrolysis producing the hydronium ion.
3. For those salts whose solutions are basic, write an additional NIE to show the hydrolysis producing the hydroxide ion.

Application

1. Predict whether solutions of the following salts would be acid, basic, or neutral in pH.

a) $NaNO_3$ b) Na_2SO_4 c) $(NH_4)_2SO_4$ d) K_2SO_4 e) $KHCO_3$

Write balanced NIE to justify your answer for those predicted to be acidic or basic.

2. What is the role of water in the process of hydrolysis?

• Your lab report should consist of a title, the items prepared in the predemo, data collected, an analysis and conclusions section, an application section, and metacognition -- "The one thing I will remember five years from now about acid-base chemistry is..."

APPENDIX C-7

Demonstration of Amphoteric Hydroxides

Materials:

* 3 mL 0.1 M aluminum sulfate	3 large test tubes
* 3 mL 3 M ammonia solution	2 glass stirring rod
* 20 mL dilute hydrochloric acid	goggles
* 10 mL 2 M sodium hydroxide	apron or lab coat
* Volumes are approximate	test tube rack

Note: Goggles and apron or lab coat should be worn. All materials can be disposed by rinsing down the drain with running water.

Amphoteric hydroxides:

- are metallic hydroxides that can act as an acid or base depending on what they are combined with.

- include transition metals, heavy metals, and aluminum

Procedure:

1. Fill a large test tube (tt) 1/4 full of approximately 0.1 M aluminum sulfate $[Al_2(SO_4)_3]$
2. Add about equal volume of 3 M ammonia solution (NH_3 (aq)) and stir with a glass stir rod. A whitish gelatinous precipitate should be visible. Remember aqueous ammonia can also be written NH_4OH or $NH_3 \cdot H_2O$.
3. Students write the balanced chemical formula equation for the formation of the gelatinous precipitate (ppt).

$$Al_2\,(SO_4)_3\,(aq) + 6\,NH_4OH\,(aq) \rightarrow 2\,Al(OH)_3\,(s) + 3\,(NH_4)_2SO_4\,(aq)$$

4. Transfer 1/2 of the ppt to another tt. (You will also be transferring $(NH_4)_2SO_4$ (aq).
5. To one of the tt with the precipitate add approximately 20 mL dilute hydrochloric acid (6 M HCl) with stirring to react all. (The ppt will appear to dissolve. Some ammonium chloride gas may be produced as a side reaction but have students focus on the neutralization reaction.)
6. Students write a balanced chemical formula equation for the neutralization reaction that occurs.

$$Al(OH)_3\,(s) + 3\,HCl\,(aq) \rightarrow 3\,H_2O\,(l) + AlCl_3\,(aq)$$

6. Students should identify the Bronsted-Lowry acid, base, conjugate acid, and conjugate base. The hydrochloric acid is the acid and the aluminum hydroxide acts as the base as expected.
7. To the remaining tt add enough 2 M sodium hydroxide (NaOH) to dissolve the ppt with stirring.
8. Assist the students with writing the reaction that produces water and a salt that contains a complex ion. (Complex ions are beyond the scope of this course.)

$$Al(OH)_3\ (s) + NaOH\ (aq) \rightarrow H_2O\ (l) + \text{salt containing complex ion}$$

9. Bring to the students attention that in this case the aluminum hydroxide is acting as the acid to produce the characteristic products in a neutralization reaction.
10. Students should write a brief statement summarizing the reactions of an amphoteric hydroxide. (When amphoteric hydroxides are combined with a strong acid they act as a base. When they are combined with a strong base they act as an acid. Whether the amphoteric hydroxide acts as a proton donor or acceptor depends on what it is combined with.)

Acids, Bases, & Salts Review Worksheet

Name: ____________________________

Date: ________ Hour: _____

Acids, Bases & Salts Worksheet

Show your work in the space provided. Use the proper units and significant digits.

1. How would you prepare 300. mL of 3.0 M H_2SO_4 from 9.0 M H_2SO_4? (3 points)

_______ 2. a. If 12.0 mL of 0.70 M LiOH are neutralized with 0.40 M HNO_3, how many milliliters of acid are required? (2 points)

b. Sketch a titration curve representing the above reaction indicating the approximate pH at the beginning of the titration, at the equivalence point, and approximately 5 mL beyond the equivalence point. Label the axes properly. (3 points)

3. What range of pH values is associated with an aqueous solution of each of the following salts relative to pH 7 (< 7, > 7, approximately = 7)? Write the correct NIE if hydrolysis occurs. (1 point each part)

a. $LiC_2H_3O_2$ _____ ____

b. K_2SO_4 _____ ____

c. Na_2CO_3 _____ ____

_______ 4. a. What is the pH of a 3.0×10^{-3} M KOH solution?

_______ 4. b. What is the pOH of this solution?

5. Write a correctly balanced a) chemical formula equation, b) complete ionic equation, and c) net ionic equation for each of the following combinations.

a. Ca (s) + $HClO_2$ (aq) b. $BaCO_3$ (s) + HClO (aq) c. SO_2 (g) + KOH (aq)

APPENDIX D

EXPLORATION PROJECT DOCUMENTS

APPENDIX D-1

Acid-base Exploration Project

You will choose a possible acid-base exploration. All of the tasks involve the chemistry common of household items. In your home you use many commercial products which are acidic or basic in nature. Vinegar, fruit juices, ammonia, baking soda, lye, and toilet bowl cleaner are just a few examples. All of these products are regularly tested by their manufacturers as part of their quality control operations. Government agencies test such products for purity, uniformity of content, and agreement with advertising claims and label information. In many of the cases your exploration will mimic some of these tests.

Initial research for your acid-base exploration can be accomplished with your own text and the labs you have performed. In previous labs within this unit (and others) you have developed the techniques and materials. For examples: the standardized solution you created, the acetic acid solution concentration you determined, and the indicator grid you developed may be useful. In addition to your text there are reference materials in the science office and the media center. There are sites on the Internet which may be helpful.

You will be given a set of rubrics which will be used for grading your exploration. You will be given due dates. Don't wait to the last minute to submit your plan. The early you get started the sooner you will get on with other steps in the process. Divide up the duties among all small group members.

<u>All groups must</u>

1. prepare <u>before</u> you begin the exploration:
   - a detailed one page plan for the procedure
     - Give the necessary data tables
     - Give any chemical equations pertinent to your study
     - If you need to prepare solutions, your method for preparation should be given.
     - Give any calculation set-ups needed to complete the investigation
   - a detailed list of equipment and materials to include -
     - any chemicals needed, approximate mass or volume
       (Will you be doing multiple trials? How many? Have you allowed for that?)
     - the amount of reagent needed to prepare a solution
       - if you are using a solution you have already prepared (and you should whenever possible), indicate that and give with what

concentration you are working
- equipment requirements should be divided into
  what is available in your own bin
  what you require from general supplies that may be available

Once your plan is approved, you may begin your lab work.

- All group members must take part in the laboratory investigation.

2. submit a general plan for your oral presentation indicating the type of visual aid with which you plan to work (Hyperstudio, ClarisWorks Slide Show, PowerPoint, posterboard, video)
3. prepare a two page written report of your exploration which includes
   - a summary paragraph describing how the exploration was performed
   - detailed and organized data tables and where applicable graphs
   - detailed and organized analysis of data collected and error
     - What are the results? Did you prove or show what you attempted?
     - How could the method be improved?
     - How could the error be corrected?

4. present an oral report of your exploration using visual aids of your choosing. You will be the class expert, other need to learn from you! Creativity and color are good, just don't get caught up with "flashy-techy" and forget the purpose of your mission.

5. When you finish your lab work, borrowed equipment and unused supplies must be checked back to your teacher.

Exploration Opportunities

1. Antacid analysis & commercial
2. Hydrolysis, pH meter, and titration curve (3)
3. Safe acid-base indicator prepared from fruits or vegetables
4. Analysis of household ammonia cleaners
5. Analysis of toilet bowl cleaners
6. Analysis of vitamin C tablets
7. Analysis of calcium carbonate in eggshells
8. Comparison of the acidity of fruit juices
9. Determine the mass percent of copper in a post-1982 penny
10. Comparison of aspirin, Bufferin, and non-aspirin analgesics

APPENDIX D-2

Scenarios for the Acid-base Exploration

1. Antacid analysis & commercial

You have been selected to analyze a commercial antacid to create an advertisement for the product. For examples: does Rolaids consume "47 times its own weight of excess stomach acid"? Does a Tums tablet "neutralize 1/3 more acid than a Rolaids tablet"? If it's true how might the manufacturer counteract the claim? Is Tums-EX a better buy than regular strength Tums or a store brand antacid in terms of grams of acid neutralized per tablet (grams of acid/ penny)?

Commercial antacids contain one or more weak bases as their active ingredients. They are designed to neutralize "stomach acid". Stomach acid is secreted as approximately 0.1 M hydrochloric acid. Unlike determining the percent of acetic acid in vinegar, direct titration of the antacid tablet with hydrochloric acid is not feasible, since the antacid is relatively insoluble and the end point can't easily be distinguished. The procedure that is actually needed is called a back-titration. It involves adding a known, excess amount of HCl to known mass of the antacid tablet. This combination is titrated with a standardized NaOH solution. Expressing this in an equation:

total moles of H_3O^+ added = moles of base in antacid + moles of NaOH required.

Inspect the labels and determine the active ingredient. Using these pieces of information and the mass of antacid, you can determine the ability of the antacid to neutralize acid. Give the neutralization reaction. You will be provided a roll of antacid tablets from general chem. supply. If you want to use others or more, you must purchase your own.

2. Hydrolysis, pH meter, and titration curve (1 of 3)

From your study of acid-base chemistry thus far you know that a relationship exists between the hydronium ion concentration and the pH of the acid. You know that certain salts hydrolyze. You know you have your doubts about all this information, so your classmates must be in the same boat. Your team will become the teaching experts correlating the change in pH with the volume of acid or base added in a titration. You must develop a method to create a titration curve for a <u>weak acid titrated with a strong base</u> using indicators or a pH meter. Your report and visual aid must include this curve with clear indication of the endpoint, equivalence point, and what is controlling the pH along the way through the titration. Any areas of buffering should be indicated and explained. Give the balanced net ionic equation for the neutralization reaction.

3. Hydrolysis, pH meter, and titration curve (2 of 3)

From your study of acid-base chemistry thus far you know that a relationship exists between the hydronium ion concentration and the pH of the acid. You know that certain salts hydrolyze. You know you have your doubts about all this information, so your classmates must be in the same boat. Your team will become the teaching experts correlating the change in pH with the volume of acid or base added in a titration. You must develop a method to create a titration curve for a strong acid titrated with a strong base using indicators or a pH meter. Your report and visual aid must include this curve with clear indication of the endpoint, equivalence point, and what is controlling the pH along the way through the titration. Any areas of buffering should be indicated and explained. Give the balanced net ionic equation for the neutralization reaction.

4. Hydrolysis, pH meter, and titration curve (3 of 3)

From your study of acid-base chemistry thus far you know that a relationship exists between the hydronium ion concentration and the pH of the acid. You know that certain salts hydrolyze. You know you have your doubts about all this information, so your classmates must be in the same boat. Your team will become the teaching experts correlating the change in pH with the volume of acid or base added in a titration. You must develop a method to create a titration curve for a strong acid titrated with a weak base using indicators or a pH meter. Your report and visual aid must include this curve with clear indication of the endpoint, equivalence point, and what is controlling the pH along the way through the titration. Any areas of buffering should be indicated and explained. Give the balanced net ionic equation for the neutralization reaction.

5. Safe acid-base indicator prepared from fruits or vegetables

As you are aware there are many times in the home when it is necessary to determine the correct pH of different things in the home to assure safe usage or survival. For example there are test kits for swimming pool analysis, fish aquariums, and hair relaxers. You are research chemists for a small independent company who has been hired by a consumer advocate group to create a safe pH test kit for home use. Many fruits and vegetables contain complex substances that act as acid-base indicators. Red cabbage has been tested and found to be a good acid-base indicator. The preparation of red cabbage juice can be a stinky job. You may use red cabbage but choose some other fruits or vegetables and develop a method to determine the range of pH over which they change color. You may choose to use a pH meter or universal indicator to make the determinations of pH. Test the indicators that you create

with some common household items or acids and bases of known concentration. Decide which of the indicator substances tested is best suited and promote your indicator in an advertising campaign.

6. Analysis of household ammonia cleaners

In an effort to cut costs, the school district has decided to use your expertise in acid-base chemistry to find the best ammoniated window cleaner for use in all the buildings in the district. Window cleaners often contain ammonia to increase their effectiveness for cleaning grease and grime from glass. You must determine the percent of ammonia in window cleaner by finding out how many moles of NH_3 are in a given sample. Assume the density of household ammonia solutions to be 1.00 g/mL. Research how and why ammoniated cleaners work. Do a cost analysis: cents / mass of active ingredient and report your analysis and findings back to the district.

7. Analysis of toilet bowl cleaners

You are a chemist in an independent firm that has been contracted by the manufacturer of XXX. There are rumors in their plant that someone may have attempted to sabotage the quality of a batch of their product during a recent employee dispute. Your task is to determine the percent of hydrogen chloride in a given sample of toilet bowl cleaner and calculate the percent error from the amount indicated on the label. Assume the density of the solution to be 1.00 g/mL. Give the balanced equation for the neutralization reaction that occurs. Report back to the company on your findings. You will be provided with XXX grams of their product.

8. Analysis of vitamin C tablets

Vitamin C content may be determined in the same manner as with the vinegar titration. The percentage of acetic acid in vinegar depends on the brand of vinegar used. Often store brands have a smaller percentage than name brands of vinegar. Develop a method for analyzing the mass percent of ascorbic acid in the 10 vitamin C tablets provided. There are two different brands. If you need more or others, you must purchase them on your own.

Give a balanced equation for the neutralization reaction. Because ascorbic acid decomposes in water solution, the solution must be prepared fresh. Storing the solution in a refrigerator overnight may slow the decomposition. Aha! Another experiment - how much degradation goes on in a 24-hour period at room temperature?

9. Analysis of calcium carbonate in eggshells

You are a chemist working for the department of agriculture. A farmer in the area believes there is a contamination problem in the area linked to a landfill which is be investigated for illegal dumping. Because the dump is upstream from his chicken ranch he believes there is a connection between the possible contaminants and his hen's eggs becoming more and more fragile. This is causing him to lose money his egg marketing.

Birds produce calcium carbonate shells for their eggs which provides a strong protective coating. Research has shown that some chemicals such as PCB's can decrease the amount of $CaCO_3$ in eggshells creating ones that are thin and fragile.

You need to determine if the farmer's egg problems with breakage are due to a low percentage of $CaCO_3$. Research in another lab found normal eggshells to be approximately 95% $CaCO_3$. Use this value in your comparison. Are any differences you determine significant enough to link it with PCB-induced weaknesses? You will be provided two eggs. You are only evaluating the shell so remove and discard the membranes and other materials. You may want to use a drying oven to remove moisture. Your final report may be written in the form of letter reporting your data, technique and findings to the farmer.

10. Comparison of the acidity of fruit juices

You realize that fruit juices are an important component of a balanced diet. They are a quick and easy method for receiving needed nutrients. You want to choose a juice that has a low concentration of acid because you read that an excess of dietary acids can cause other problems. Your task is to predict what juice you believe is lowest in acid and determine the type of acid present and the acid content in percent. You will assume that all of the acidity comes from the major acid component and that the density of the acid solution is 1.00 g/mL. Your report must include an exploration of how acidic foods affect your blood's pH.

11. Determine the mass percent of copper in a post-1982 penny

The penny has undergone several changes in composition since it was first minted in the United States. Before 1982 pennies were made of a copper alloy. Pennies minted after 1982 have a zinc alloy core and a copper alloy exterior, kind of like a sandwich of zinc and copper.

Your task is determine the percent of copper in a post-1983 United States penny and report the information to the class. You should be able to determine the true value of the penny based on its components and the current market value of the metals involved.

12. Comparison of aspirin, Bufferin, and non-aspirin analgesics

You are part of a research team at a small drug company that wants to break into the lucrative market of analgesics. An analgesic is a compound that acts as a pain reliever. They contain different active ingredients that have other medicinal effects as well. In addition to the active components, they contain fillers which act to prevent the tablet from falling apart and breaking down with moisture in the air. Some have fillers which control pH. Although a few large companies control the market now, your company intends to create an improved product that will draw the consumers away from the brand-name products.

You need to analyze aspirin, Bufferin and an aspirin substitute to find out what percent of the product is insoluble filler and what percent is active ingredient. You also will also determine the pH and how easily they can be neutralized. You should research each product's claim to superiority and incorporate recommended usage for the three analgesics. Under what circumstances might one be better than another? What improvements might you suggest to your company for designing a better analgesic?

You will be provided twelve of each type of tablet. If you require more, you must purchase them for yourself. If you wish to do a faster filtration method than the gravitational method used in the past, instruction and equipment will be made available to you.

APPENDIX D-3

Rubrics for the Exploration Plan

4 Plan shows careful & thorough planning with excellent reasoning & logic.
3 Plan shows careful & thorough planning but logic behind is not clearly expressed.
2 Plan shows some logic but not enough to solve the problem.
1 Plan shows only a small amount of logic or understanding of the problem.
0 Plan is illogical and unacceptable.

4 Plan is complete, appropriate, and safe; will work efficiently.
3 Plan is appropriate and safe and mostly complete; will probably work.
2 Plan is safe but it includes inappropriate procedures; will probably work.
1 Plan may not be completely safe; many important steps necessary are missing.
0 Plan is unsafe; will definitely not work or address the investigation proposed.

4 Plan is expressed clearly and concisely.
2 Some parts of the plan could be expressed more clearly.
0 Plan is poorly written.

4 Proposed data tables are made properly & clearly indicate all measurements that must be made to solve the problems.
3 Minor errors in proposed data tables.
2 Proposed data tables include most of the necessary information, but errors have been made in preparing them.
1 Proposed data tables include some necessary information but there are some serious exclusions.
0 Proposed data tables omitted or entirely unsatisfactory.

4 Proposed list of equipment and supplies includes all materials necessary to carry out the proposed plan with no unnecessary materials requested.
3 Proposed list of equipment and supplies is nearly complete, minor omissions or includes a few unnecessary pieces.
2 Proposed list of equipment and supplies omits a few materials necessary for completion of the plan and/or may include several pieces of unnecessary supplies.
1 Proposed list of equipment and supplies has so many exclusions that it would be difficult to carry out the procedure for the plan. List includes many unneeded pieces.

0 Little or no thought given to the choice of equipment and/ or many unnecessary supplies.

4 Other requirements for the project are addressed clearly, concisely, and completely.
2 Other requirements for the project could be addressed more clearly, concisely, and completely. Some have not been met at all.
0 Many (or none) of the other requirements are not met.

APPENDIX D-4

Rubrics for the Final Report

Rubrics for the Final Report

2 Purpose or objective is clearly stated for the investigation.
1 Purpose or objective is stated.
0 No purpose or objective is given.

4 Data and observations were recorded accurately, descriptively, and with no serious errors. Graphs, if necessary, are drawn neatly and accurately.
3 Data and observations were recorded accurately, descriptively, and with some significant errors. Graphs, if necessary, are generally drawn neatly and accurately.
2 Data and observations were recorded but lacked accuracy and/or descriptions, and some significant errors were present. Graphs, if necessary, were present . This section may be lacking neatness in some cases.
1 Some data were present. In general useable observations for interpretation of the study were missing or inadequate. Lack of neatness causes problems for interpretation by the reader of data presented.
0 No data or observations were evident or if present were not interpretable to have significance to the study.

4 Calculations are performed neatly and correctly with use of correct significant figures and units. The section is easily found, and it is easy to follow the steps performed.
3 Calculations are performed correctly with use of correct significant figures and units for the most part. Neatness or ease of following the method of solutions are somewhat lacking.
2 Calculations are present but with several errors present or some key calculations are missing. Neatness may be lacking. The calculations were not in a clearly defined section.
1 Some calculations are present. Many important parts are missing or incorrect. Neatness is lacking to such a degree that it makes it difficult to follow the operations.
0 Any calculations present do not indicate an understanding of the process involved or no calculations are evident.

4 The conclusions and summary are clear, concise, and well-written to supporting lab data collected. Error analysis has been given thoughtful consideration with clear evidence as to how error might be decreased. Metacognition is present.
3 Conclusions and summary are present and are generally well-written to supporting data. Error analysis is less than adequate. Metacognition may be missing.
2 Conclusions and summary are present but generally lacking in key aspects given in 4 and 3.
1 Summary and conclusions can be found but lack any real substance valued in a study.
0 Section is totally missing from the paper.

4 Students expressed their recognition of the connection between their observations and the related chemistry concepts in an exemplary manner. Objectives of the exploration have been clearly reached.
3 Students expressed their recognition of the connection between their observations and the related chemistry concepts in a manner that was above average. Most of the stated objectives in the exploration have been met.
2 Students were able to make some connection between their observations and the related chemistry concepts. Not all of the objectives in the exploration have been completed.
1 Little evidence of connection between observations and related chemistry concepts. What was presented was merely a restatement of observations. . Few of the objectives in the exploration have been completed.
0 No evidence or attempt at interpreting data and observations. Objectives of the exploration have not been met.

4 Excellent reasoning and logic are evident throughout the report. The format allows for ease of reading and ability to find pertinent information.
3 Reasoning and logic are present in the report. The format of the report sometimes makes it difficult to find important information easily.
2 Reasoning and logic are present in the report but not as clearly evident as a 3 or 4. The format of the report makes it difficult to find important information easily.
1 Reasoning and logic are often lacking in the report. The format of the report makes it difficult to impossible to find important information easily.
0 No reasoning or logic are evident. The report is confusing.

2 Grammatical (sentence fragments) and/or spelling errors are minimal.
0 Errors in grammar and spelling make it difficult to read the paper.

APPENDIX D-5

Rubrics for the Oral Presentation

Each team's performance will be rated according to the following criteria. Scores will be assigned that best describe the oral presentation.

5 The team clearly described the study and new knowledge was effectively created and delivered to the audience. All the members of the team were enthusiastic and used apt tools of engagement. They were mindful of and responsive to the audience in preparation and delivery. The visual aid that was used, made the presentation more effective. Questions from the audience were answered with specific and appropriate information.

4 The team described the study and new knowledge was created and delivered to the audience. Most team members engaged the audience and were somewhat mindful of and responsive to the audience. There was evidence of preparation, enthusiasm, and organization. The visual aid was used somewhat effectively. Questions from the audience were answered clearly.

3 The team described the study but supporting information was not as strong as a 4 or 5. Some of the information contained small errors. Most team members engaged the audience and were somewhat mindful of and responsive to the audience. There was some indication of preparation and organization. A visual aid was used. Questions from the audience were answered. Some assistance may have been required to clarify the material presented.

2 The team stated the study but failed to clearly indicate the purpose of or knowledge gained from the work. There were significant errors presented that needed to be corrected for the audience to have clear understanding of the new knowledge presented. Few of the team members were mindful of and responsive to the audience. Evidence of preparation and/or organization were lacking. A visual aid was used but wasn't particularly helpful in creating new knowledge for the audience. At times the audience may have been more distracted by the aid than helped. Questions from the audience were answered with only the most basic response. Assistance may have been required to clarify answers given.

1 The team made a presentation without a clear indication of their study. The topic was unclear. The delivery lacked organization and/or the audience was

having trouble following. The presentation lacked preparation. Questions from the audience received only the most basic, or no, response. Considerable assistance was required for the audience to have the opportunity for new knowledge.

0 No oral presentation was attempted.

APPENDIX D-6

Scoring Report of the Oral Presentation

Team Members: ______________________________________

Date Presenting: ______________ Hour Presenting: _______

Title of Exploration: ______________________________________

Brief Abstract: ______________________________________

____

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5 4 3 2 1 The team clearly described the study and new knowledge was effectively created and delivered to the audience.

5 4 3 2 1 All the members of the team were enthusiastic and used apt tools of engagement. They were mindful of and responsive to the audience in preparation and delivery.

5 4 3 2 1 The visual aid that was used, made the presentation more effective.

5 4 3 2 1 Questions from the audience were answered with specific and appropriate information.

Overall Score: ______

Comments:

APPENDIX E

EXAMPLES OF STUDENTS' FINAL REPORTS

APPENDIX E

EXAMPLES OF STUDENTS' FINAL REPORTS

FRUITS AND VEGETABLES

AS

ACID-BASE INDICATORS

OBJECTIVE

In this experiment, the objective was to find fruits and vegetables whose juices change color with changes in pH. Juices which show such a change in color can be used as an effective and non-toxic acid-base indicator .

PROCEDURE

To begin with, fruits and vegetables were chosen by either a distinct color or a distinct flavor. The fruits and vegetables chosen for this experiment were: tomatoes, purple onions, red cabbage, strawberries, grapes, and carrots. The first step was to find standard substances with known pH's over a wide range to use for a basis of the test. The substances to be used as standards were: lemon juice, vinegar, baking soda, and ammonia (NH_3). The pH's of these are determined by using universal indicator and a color chart. To start with the experiment, testing grids must be washed with deionized water to prevent contamination by other ions that could be found in ordinary tap water. Once the grids are washed, put three drops of vinegar in to well A, row 1, three drops of vinegar into well A, row two, a pinch of baking soda into well A, row 3, and three drops of ammonia into row A, well 4. Once the standard substances are in the proper wells drop three drops of universal indicator into each well and compare the color change to the color chart to find the pH, record both color changes and the known pH. After the pH and colors have been recorded, re-wash the testing grid with deionized water.

Next the juices from the fruits and vegetables need to be prepared. To do this, cut out the stems, leaves, or other parts of the food that are not usually eaten.

Drop the fruit or vegetable into a blender and add deionized water. Set the blender on liquefy. Once the substance has been liquefied, strain through a strainer into a clean beaker. This can be done for each substance. Juices must be kept separate throughout experiment. Record initial color of each juice.

Put three drops of lemon juice into well A, three drops of vinegar in well B, a pinch of baking soda in well C, and three drops of ammonia in well D. Obtain a clean pipette for each new juice, and put three drops of one juice into well 1. Record the color change, if any. Dump the extra juice from the beaker down the drain and wash the beakers out with deionized water. Prepare two new juices and record their initial color. Repeat the process of putting three drops in each will of row 2 and record the results. Repeat these steps for each juice, dropping the different juices into wills 3-6.

DATA

Observations were recorded when instructed to do so in the procedure. From the observations the pH of the standardized substances (which were originally determined using color changes of the experimental indicators), could be determined by knowing the original color of each experimental indicator, and observing if a color change occurred. The data table is as follows.

Data Table for Standards

Substance	pH (known)	Color w/ universal indicator
Lemon Juice	4.5	orangish-pinky
Vinegar	5.0	orangish-red
Baking Soda	8.5	turquoise
Ammonia (NH3)	10.0	purple

Data Table for Experiment

Indicator	Substance Tried	Color Change (w/ juice indicator)
Red Cabbage	Lemon Juice	peach
	Vinegar	pink (baby)
	Baking Soda	light blue
	Ammonia (NH3)	minty green

Grape Juice	Lemon Juice	peachish-pink
	Vinegar	peachish-pink
	Baking Soda	gray-smoky
	Ammonia (NH3)	greenish-yellow
Coconut	*material not obtained*	
Tomatoes	Lemon Juice	peach (light)
	Vinegar	peach (light)
	Baking Soda	peach (light)
	Ammonia (NH3)	peach (light)
Mango	*material not obtained*	
Carrot Juice	Lemon Juice	peach/orange
	Vinegar	peach/orange
	Baking Soda	peach/orange
	Ammonia (NH3)	peach/orange
Onion	Lemon Juice	pinkish-peach
	Vinegar	pinkish-purple
	Baking Soda	light yellow
	Ammonia (NH3)	neon yellow (lime)
Avocado	*material not obtained*	
Strawberries	Lemon Juice	orangy-pink
	Vinegar	orangy-peach
	Baking Soda	reddish w/ purple tint
	Ammonia (NH3)	purple (dark)

CONCLUSION

Summary: We discovered that some fruits and vegetables contain juices that can be used as acid-base indicators because the juices have different colors at different pH's. Out of curiosity we found that the fruits and vegetables whose juices were able to indicate a pH change had pH's of 4.0-4.5. From this we found that we can not determine whether a substance will be a good indicator due to the fact that the juices of those which did not work had a pH of 5.0 and 6.0 and all these values are very close.

ERROR ANALYSIS

Throughout our experiment there were many chances for error. One chance where our experiment may have gone wrong was with the readings of the initial pH which may not have been completely accurate, which would affect our scale of color change in the experimental indicators. To be more accurate a pH meter may have been used. Another way there may have been error was with the condition of our fruits and vegetables. The freshness of the fruit or vegetable may have an effect on the pH of the fruit. We know that a ripe fruit is more acidic than an unripe fruit, based on the fact that the longer a substance oxidizes, the more opportunity for the fruit to lean toward acidity. To be more accurate with this we could be sure that the fruit and vegetable are fresh and be consistent with using the same freshness. Another error could be that we may not have fully cleaned out old juice from the blender before preparing a new juice to test. For reducing this error we could have washed each part of the blender, blades and the bottom ring that screws on by taking it apart and washing each part the juices that may have been trapped in the crevices could be cleaned out to ensure a more pure juice to be prepared. We did not allow for an actual range of our substances to be found. For a more accurate idea of the ranges we could have done a dilution process of those juice that worked. Another error possibility was the fact that we did not truly prove whether or not the color change in the juices were reversible, which is what true indicators are. To find out if the reaction was reversible one could add more acid or base to balance out the reaction and change the color back to its original.

METACOGNITION

This experiment is most memorable for the fact that there are different house-hold fruits and vegetables that are able to change color when added to acids or bases. Ten years from now the things we will remember and reflect upon are, the fruits and vegetables which we used that worked, the household products that we used with the fruits and vegetables to see if they were acidic or basic. We could even use our knowledge in the future to test out household products to be sure of their pH.

Lab Report in Toilet Bowl Sabotage

Purpose: To determine the percentage of HCl in the sample of Sno Bowl brand toilet bowl cleaner and to assess if the HCl concentration level was in accord with percentage given on product's bottle.

Data:

	Trial 1: Acid	Trial 1: Base
Initial buret reading	*3.10 mL*	*8.70 mL*
Final buret reading	*13.10 mL*	*30.25 mL*
Difference	*10.00 mL*	*21.55 mL*
	Trial 2: Acid	Trial 2: Base
Initial buret reading	*4.70 mL*	*18.65 mL*
Final buret reading	*15.55 mL*	*42.45 mL*
Difference	*10.85 mL*	*23.80 mL*
	Trial 3: Acid	Trial 3: Base
Initial buret reading	*6.00 mL*	*17.40 mL*
Final buret reading	*16.80 mL*	*40.65 mL*
Difference	*10.80 mL*	*23.25 mL*

Balanced chemical formula equation: $HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$

Observations:

Several observations were made during the experiments. It was observed that acid should be diluted in a volumetric flask instead of a graduated cylinder to facilitate mixing. By not using a volumetric flask, acid concentrations were not constant throughout the solution. It was noted that when pouring the acid solution bubbles were produced. This can be attributed to sudsing. Observations were made that it was necessary to use 2-3 drops of Hph (phenolphthalein) during the titration procedure because the acid solution was blue and masked color change. It was also observed that the endpoint was a pale purple, rather than pink, due to the color of the acid solution. All three titrations were similar in color, with the second titration slightly darker due to excess base.

Calculations:

Calculate the molarity of the acid in each titration

Trial 1

x(10.00 mL acid) = (0.479 M base)(21.55 mL base)

x = 1.03 M HCl = molarity of acid in diluted solution

4x = 4.13 M HCl = true molarity of acid in Trial 1

Trial 2

x(10.85 mL acid) = (0.479 M base)(23.80 mL base)

x = 1.05 M HCl = molarity of acid in diluted solution

4x = 4.20 M HCl = true molarity of acid in Trial 2

Trial 3

x(10.80 mL acid) = (0.479 M base)(23.25 mL base)

x = 1.03 M HCl = molarity of acid in diluted solution

4x = 4.12 M HCl = true molarity of acid Trial 3

Determine the average molarity of the acid

4.13 M HCl + 4.20 M HCl + 4.12 M HCl / 3 = 4.15 M HCl

Determine the mass percent of HCl in the solution

4.15 ~~mol HCl (aq)~~	36.508 g HCl	1 ~~L soln~~
1 ~~L soln~~	1 ~~mol HCl (aq)~~	1000 ~~mL soln~~

=0.152 g HCl

(.152 g HCl / 100 g soln) (100 %)

= 15.2 %

Determine % error

(| 15.2 % - 14.5 %| / 14.5 % HCl) (100 %) = 5 % error

Conclusion:

The percent of acid between the given and the experimental was 5%. This means that the Toilet Bowl Terrorist would have sabotaged the cleaner by adding excess acid. His motives can not be fully understood. However, we can not be certain whether or not this amount of error is due to the manufacturing process or whether this was an act of terror. More titrations using bases of different molarities would need to be performed to reach conclusive results.

There are mulitple, possible sources for error. Sudsing occurred which made it difficult to judge volume thus providing inaccurate measurements of amount of acid used. This could could have been averted by using a weaker concentration of acid solution. Another possible error source dealt with our base, which was old and could have lost water due to evaporation, thus changing the molarity. This could have been avoided by making a new base solution.

In future experiments we will try using two different base solutions to achieve more accurate results. One thing we will remember in the future is to always use a volumetric flask in dilutions.

APPENDIX F

EXCERPTS FROM STUDENTS' COMMENTS

APPENDIX F

EXCERPTS FROM STUDENTS' COMMENTS

(Second semester grades of students are in the parentheses following the entries.)

- fun but challenging...enjoyed doing it; learned a lot from actually doing; liked this unit more than other because we had more labs (A-)
- project was a lot of fun; topics were interesting; toughest unit of the year; endless amounts of information; needed objectives list (A)
- liked working in the lab; annoying because it took a long time; needed more lab time because of the length of time to setup; overall process good, fun, but maybe confusing; liked the amount of time spent on notes because that gets boring; (improved by) more choices on projects (C+)
- the project was a good way to apply the lab techniques and information we learned, a good way to build our problem solving skills as we searched for different ways to complete our project tasks; helped us learn how to solve problems that would apply to chemistry related fields which I am considering pursuing; useful for real life applications; unit was probably the most life-applicable unit that we have gone through all year, and I liked that; more time needed with note taking and our projects (A-)
- unit was tough, but I liked it a lot. I loved doing the long term project. I can see what is happening instead of just being told what is happening. This was my favorite unit. I looked forward to coming to chemistry to work on the project or go to the lab. I learned a lot even though my grade won't show it. The test kinda took me for a surprise.(C+)
- kind of a neat experience; I actually understood titration and how to find mass percent of a substance a lot better after the project. (Improved by) taking a few days during the project time to review material covered earlier in the unit. (A-)
- So much information to learn; project was a good idea, but perhaps not as effective of a teaching tool as other options could have been. The labs make the information easier to understand. I found it was necessary to go over material more outside of class in order to understand it. (B)
- Length of this unit was what made it hard; didn't really like having so many labs this marking period; big lab... I learned a lot from that. I think I concentrated more on procedures for the (smaller) labs than the actual concepts we were supposed to learn from it. It would have helped if we discussed the purposes of these labs more. (Improved by) more practice problems. (A)
- This unit has been the most difficult for me. I snowballed in the labs. Labs grew on one another, and I got lost on the first one. As we went on, I got more and more

confused. Normally, I like labs, and I think they are good. (Improved by) showing students an example of a previous project and final report would be helpful. (A-)

- I have a B this 6 weeks, a whole letter grade down from usual A's. I think we had too many labs. Labs are not my strong area because I always have to come in and get help for the questions at the end. The project was cool. We needed more discussion time in class or another week to write up our procedure. I didn't like having it due the day we got back from Spring Break. I felt like I had a lot of control over the project... cool to do something on my own. (A-)
- enjoyed going into lab... very challenging, being able to run experiments on my own was very helpful in my understanding of the material; its development took a lot of thinking and planning. I feel like I understood all the separate concepts but in tying them together I often got confused. Even though I struggled through this unit, I did learn a lot - not just new material but also about problem solving, work technique, and study habits. (B+)
- project was very interesting. When we first got our purpose I felt very unprepared and didn't think that we could solve the problem... I was pleasantly surprised that we were able to develop a successful method. I think that labs are always more difficult to learn from and are more confusing yet during the project I began to enjoy them more. It was rewarding to have a final product to show for the work we had done. (A)
- This unit was probably the most difficult because you didn't teach us quite as much. It was more of a teach yourself type of thing. I liked the labs... but thought they were kind of difficult, especially the project. I'm not sure that we answered the right question. (B)
- project was a good idea... time consuming, needed more time. (C)
- kind of hard; I never learned (material from previous unit) which affected my ability to do hydrolysis problems; projects were helpful in understanding pH levels because it was hands-on working and understanding; we could see what was physically there. (C+)
- I liked how we did all those labs. (Improved by) more time reviewing.(C-)
- I didn't like all the labs. I do a lab I understand it less, because I'll do the procedure and record the data, but I won't really understand what's happening. Also I think you should stress reading out of the book more. (B-)
- I enjoyed this unit. I thought it was interesting how Milk of Magnesia kept changing to clear then back to pink when we added acid. I would have liked a few more quizzes (non-lab grades). I had fun doing the exploration and would recommend that it be done again. (A)
- I think the project should have been a couple of days longer, but the continued lab time was helpful...helped me understand a lot of it better. Labs seemed to flow together and become muddled. Centered more on real uses. (C+)
- Acids and bases is one of my favorite subjects. It explains a lot of reactions that you see in your own life, however ...(this) did not suit my learning style. I am much more into the theory end chemistry than the labs, and theory is where I excel. I believe that lab should compliment the book, theoretical end, of a science in a first year chemistry

course, not vice versa. One thing I did enjoy is the independence that the labs gave you. (A)

- Labs were easy and understandable; (I liked) being able to choose an ending project which they were able to tackle and demonstrate proficiency. (C-)
- This project was worthwhile; gave break from notes; chance to figure some stuff out on our own. The lab helped us understand what we were doing. (Improved by) a few more worksheets for more practice. (B+)
- The project was the fun part; liked to hear other projects that have to deal with everyday things dealing with chemistry. For instance the project done on aspirin and Bufferin, Milk of Magnesia, which I've heard of but never knew what it was for and how it did it. I liked using the pH testers. (C)
- I liked the hands-on experience. I think an explanation on how it worked would have helped it to be more understandable. (Improved by) a list of objectives for the test and more worksheets. (A)
- very rigorous; required many after school hours; I liked the freedom the projects granted, but I disliked the fact that other groups got practical topics (painkiller, toilet cleaner) and I got one that was hard to express a real interest in. I liked choosing my own group and making our own plan. (Improved by) planning so presentations landed immediately after a weekend, so we would have the weekend to work. (I ended up pulling a lot of late-nighters.) (A)
- The projects we did worked well to make us think and work on our own. It is easier for me to understand something if I can see it. Overall, I enjoyed the unit. (A-)
- I liked the project. I got to meet new people, and it was a great way to show how life situation use what we learn in class. I liked... more things hands-on, things we learned got applied to real life. If we did this more often, everyone would a better time in school. I thought this unit was easier to understand than most of the other ones.(C+)
- The unit was pretty tough. The project was fun but a lot of work; challenging. (C+)
- unit was hard because it required a lot of independent learning and research. I enjoyed the project... hands-on (labs and demos) is very helpful to understand new materials. It was an appropriate challenge to research and come up with a procedure and finally to use an effective way to present (teach) the information. I liked the unit as a change and to have variety, but found it difficult to understand some ideas without as much organized teaching. I would have benefited more (gradewise) from more notes and lectures. (A-)
- very helpful. I think I will remember more from this lesson because it was very hands-on and very visual... being able to see the results makes it easier to understand. The projects were also helpful because my topic dealt with important parts of acid-base chemistry. The calculations are fairly simple and straight forward. I wouldn't change much of this unit because I like the idea of doing labs to learn the information. The project also showed us how acid-base chemistry relates to real life. (A)
- During test taking I was amazed about how much I actually learned from our project. Most of the questions on the test I could think back to our project and have some visual idea of what the questions was asking. Overall, this unit was fairly easy to

understand and every concept was put in such a way that the student could visually see what was going on. The project was a great idea... I learned a lot from it. (A)

- The project was great!! It was so hands-on. We designed the experiment and method. We weren't told how to do it. That was fun! ...remember as being a learning experience as well; loved having so much time to work on the project. I want to whine about a couple of labs that weren't graded... we got zero credit for doing it and answering the questions. (A)
- I loved doing our project... fun and interesting... helped me learn about pH through the hands-on experiment. I thought it was a good process to make rough drafts and plan things out ahead of time. Biggest problem is the way we became "specialized" in one area, but didn't know that much about... things that hadn't pertained to our experiment. That really concerned me when I was studying. (A-)
- I learned a lot during this unit. I enjoyed the labs... fun and allowed me to visualize reaction so that I can figure out what is going on with the calculations. I learned better by visual senses. The projects were fun, but took a lot of thinking and working. Some of the experiments did not work in our favor, but we got through them. (Note: They had to modify their method and try again when a side reaction occurred that they hadn't thought about in method development.) (B)
- The project was a good hands-on experience. I was very disappointed with amount of work some group member put in. This unit stretched out too long... by test time I had forgotten much of the stuff. Maybe you should have given us a mid-unit mini-test and a review worksheet. (A-)
- I enjoyed this unit more than most we have done in the past; more labs. Almost all note-taking was done early in the unit, and by the time of the test it was not all fresh in my mind because spring break cut into the middle of the unit. The group project was a very good experience to be able to design our own lab procedure and work out problems on our own. (C)
- I enjoy the more hands-on type stuff along with the lectures. The projects were a pretty effective way of teaching us. I liked the fact that we did a lot of self teaching. For people who learn better by doing it was really helpful. (Improved by) more lecture on some of the concepts or an outline of things we needed to know. (B+)
- The abundance of labs made this unit more enjoyable but also significantly harder. For my learning style, I think it's better to finish a unit faster without as many interruptions in the lab. The use of the project was a good idea, not so much for learning others' information, but for thoroughly understanding our own. I definitely prefer the method used over the rest of the year. The hardest thing about the unit was that it was spaced out over too long a period of time. (Note: good plug for block scheduling?!?) (A)
- The project presentations helped to learn about buffer systems and titrations although I did not understand the purpose of some of the projects. (C+)
- I really enjoyed this unit. Labs were fun and interesting... by doing the labs I felt like I got a better understanding of the unit. Doing the titrations and then figuring out how use it in your group project was a really good way to apply and learn. The project

made me feel more involved and challenged to use the things I had learned. I really enjoyed the hands-on experience. It was fun. (A-)

- The unit was harder the other units for me. I am not good with theory-like things. I am good with calculation and there were few in this unit. I did like the project even though ours was very frustrating at times. Working in a larger group was fun as was the problem solving we had to do in the group. (Note: This was another group whose original method didn't work and they had to revise it. They did a great job as a group in figuring out what to change to make it work.) I did like the unit. We also got to make a commercial which was very amusing. The unit was very good for me, but other group's projects didn't seem real like ours was. We actually felt like we discovered something! (A)
- The projects were a good idea and I learned a lot from them... I thought they could have been more challenging and more extensive possibly by including a research section. The process in learning this unit was helpful and seemed to follow a logical order. (B)
- Our group project went fairly well; we all worked well together. (A)
- I really liked the project part of this unit; disliked not having lecture or formal notes; having more labs throughout this unit made learning about hydrolysis, indicators and titrations easier. A combination of formal notes and hands-on experiments would make this unit better. (A)
- very interesting; I realized partly through my experiment that there is chemistry in almost everything we do. The projects were a great idea; had to know it well because then you had to teach it; unit overall was one that I understood better. (B-)
- interesting; learned a lot but not necessarily in the easiest possible way. I'm not the type of student who learns well through doing; hard to investigate; difficult to devise a method of testing. (A-)
- project was really good to do; helped to show the different applications of the chemistry. I didn't find myself asking "when am I ever going to use this?" I liked learning by doing. (B)
- I learned more in this unit than any other. The project and presentation were my favorite part. It was nice to have to apply the equations to the work. I felt we took a lot more time for this unit, and I liked that. (C+)
- I liked this unit. We had difficulty determining endpoints when doing our titrations. Maybe we picked a bad indicator for what we were doing. (NOTE: Good example of the problem solving that was still going on in some students minds. They weren't totally pleased with the results they achieved, ran out of time, and were still thinking of ways they could have made it better.) (A)
- extremely interesting; I enjoyed it very much; using the lab more consistently allowed students to gain a larger understanding of the process and information; helpful in imprinting information on my mind; easier than book work or taking notes; broaden our minds by setting up our own experiments, research, and using past knowledge to complete the project. I thought it was an excellent way to review... made this unit more enjoyable to me than any other done in the past; allowed students to process material. (C+)

- I thought the projects were a nice idea; fun way to learn about something; letting groups form themselves is a good idea, it makes the project more enjoyable. (A)
- I really enjoyed doing the project. My group really did well working together. I learn a lot better when doing hands-on projects. I also thought doing journals was a good idea; learned a lot from the other students' presentations. I am sure it will help me in future classes. (B-)
- increased number of labs was a good idea; a lot of people put a lot of time into their projects, and it showed. (B)
- I liked the project because it gave me a chance to use what I know and design a lab that works. (B)
- project was a really cool thing to do; fun and challenging; I learned much more in doing them (labs) then from taking notes. (Improved by) trying to do it before spring break or after. (Spring break was in the middle of the unit.) (C+)
- enjoyed doing this unit; I liked that we had more labs... I'm a hands-on person; like to work in groups; learned a lot from working with my group members; probably learned more that I would ever need to know about vitamin C. (B-)
- was fun to do, but stressful; made me think a lot, and brainstorm good ideas. My partner and I worked very well together. The lab work was stressful, but we learned to deal with the problems and felt confident when we were finished. I gained a lot of confidence in the lab... I was proud of how we worked; short deadlines kept us on track and moving. (A)

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