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IMPROVING STUDENT COMPREHENSION IN CHEMISTRY
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TRACY LYNN HAROFF

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IMPROVING STUDENT COMPREHENSION IN CHEMSTRY LABORATORIES

By

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ABSTRACT

IMPROVING STUDENT COMPREHENSION IN CHEMSTRY LABORATORIES

By

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This study incorporated the use of activities and inquiry based labs in a high school chemistry curriculum to determine the effectiveness of their use in increasing student knowledge of the subject. The objectives of the unit were to increase student comprehension of stoichiometry concepts and to increase students' critical thinking skills. The unit was evaluated for its effectiveness of increasing comprehension and critical thinking through the use of a two pre and post test assessments contained within the unit, as well as a pre survey and a post survey of students' attitudes of labs and learning science. The study revealed that the students' overall conceptual knowledge of stoichiometry increased as the result of the unit as evidenced by the post test scores.

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I would like to thank my 2005-2006 chemistry students for being my "guinea pigs" to try my newly developed unit. I would like to thank my husband, Tom, for all of his support and encouragement as well as my family for their editing help, as well as their endless encouragement. To Melyssa Lenon, thank you for being there to talk to about chemistry and teaching. It is nice to be able to bounce new ideas off of another teacher. And finally, I would like to thank Dr. Merle Heidemann, for all of her guidance and help in developing new activities and Dr. Joyce Parker and Dr. Paul Hunter for reading my thesis and providing excellent ideas for me to further my work.

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INTRODUCTION

Statement of Problem and Rationale

For the past six years, I have had the privilege of teaching chemistry classes at Marshall High School. Every year, I look forward to the stoichiometry unit that I teach in the second semester. This unit is a culmination of many topics students have learned previously. In order to be successful in the stoichiometry unit, students must be able to understand how to write and balance chemical equations and have a basic knowledge of algebra. This unit is taught directly after we learn chemical reactions and basic mole problems. I see stoichiometry in my general chemistry class as the first "practical" chemistry to which my students are exposed. Every year, I teach the unit starting with a lecture that addresses the method of solving problems (checklist format), then move to guided practice for a few days and then the unit finishes out with a few traditional labs, where students are given the procedure, to solidify the concepts.

The past few years, I have observed my students doing well on unit tests in stoichiometry. However, students had difficulty verbally explaining the concepts of stoichiometry. In laboratory situations, students only follow directions in a rush to be the first group to finish. If asked conceptual questions about the lab, the students again fail to adequately answer. I knew that I was teaching my students the method of solving stoichiometry problems, but I was not sufficiently teaching the underlying concepts. My students were going through the motions of solving stoichiometry problems, but had no real knowledge of stoichiometry. I wanted to address this problem and see if I could affect a change in my students. I wanted to increase my students' critical thinking skills and improve comprehension in the stoichiometry unit.

In the summer of 2005, I began the development of a stoichiometry unit that incorporated inquiry laboratory activities. Keeping lecture information the same, I developed various inquiry activities that would force the students to think critically about the stoichiometric concepts being studied. I wanted the activities to be interesting to the students and to be based on real problems that needed to be solved. As a teacher, I wanted the students to understand that stoichiometry is an invaluable tool to the chemist, used to predict and evaluate laboratory situations. I first developed some activities that would strengthen previous conceptual ideas about balancing equations and drawing visual models of equations. I felt this was important as I moved on to stoichiometry so I could use the same conceptual models to enhance the stoichiometry unit. I then focused on the laboratory component of the stoichiometry unit. The labs were to be inquiry based, so that the students were responsible for the bulk of the lab procedure and conclusions. By implementing these labs and activities, I predicted that students would gain more insight into stoichiometric principles and how they relate to everyday situations. These activities should also improve my students' critical thinking skills. By making the inquiry labs partner-based, students have the chance to interact with each other and help each other comprehend the material.

THEORETICAL FRAMEWORK

When I meet someone new and they ask me, "What do you do?" and I reply that I teach high school chemistry, most people respond with the standard "I never really understood chemistry!" Unfortunately, I believe that this is too often a repeated phrase for most high school science students. Students come to class, take notes, participate in traditional lab activities, and then take tests to assess their knowledge. Do those tests accurately assess the students' knowledge on a particular topic? Or are students simply just going through the motions of the problems of chemistry without truly understanding the underlying chemical concepts? Inquiry learning forces students to think critically and develop problem solving skills. The National Science Standards (1996) report that "more and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems." If, as educators, we are not teaching our students these skills of tomorrow's work force, then who will?

The Standards also state that science is "something that students do, not something that is done to them (1996)." Therefore, I propose that students should be required to actively participate in laboratory activities that mimic problems adults might encounter and solve. Through problem solving and interacting with other people, students gain valuable knowledge and resources for the future. Therefore, it is the objective of the following unit to develop a series of activities and laboratories that will engage students in inquiry learning.

Inquiry Learning

Inquiry learning is defined by Hammer as a process in which students are presented with various tasks, problems, or questions that enables them to ascertain for themselves the material being studied (1997). In *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (2000), the authors state that there are essential features of classroom inquiry. Learners must be engaged by scientifically oriented questions; they must give priority to evidence, formulate explanations from evidence, evaluate explorations in light of alternative explanations and communicate and justify their findings. There are different levels to these essential features in inquiry learning. That is, instructors choose how much or how little information to give to students during an inquiry investigation. Instructors can choose from what the *Guide for Teaching and Learning* refers to as a Level One Inquiry to a Level Four Inquiry. Level One Inquiries would be all teacher directed activities. The amount of learner self-direction is minimal. A Level Four Inquiry would be almost no teacher direction while the amount of self-direction of the learner is high. Traditional science labs have been at the level one inquiry level. Furtak (2006) asserts that most science instruction takes place in between the extremes stated in the Standards in a process she refers to as "guided scientific inquiry". This method essentially combines scientific laws and accepted facts with a constructivist view of learning.

In inquiry learning, the students must be actively engaged in the scientific problem that they are trying to solve. Often, this requires solving problems to which the students may or may not know the answer. Students must then turn to other students or the teacher for information. Van Zee et al. (2001) refer to small group student interactions where the teacher is not present as being the time when "students construct knowledge by asking one another questions, explaining their understandings and doing tasks that provide a context for their asking and explaining." If other students cannot adequately answer the questions, students then turn to the teacher. This brings up an interesting challenge for the teacher. If the activity is a guided inquiry lab, as Furtak (2006) proposes, then the teacher knows the answer to the problem. As students ask the teacher questions, it is up to the teacher to not give the answer. Students know that the teachers ultimately know the answer to the problem, and will go along with the inquiry task for a while, but will then start asking for answers. Teachers must then ask better questions of the students to guide them through the inquiry stages. As Van Zee et al. (2001) propose, teacher-student discussion about inquiries may produce questions that help shape the next steps of instruction. Often, with high school age students, this can be difficult. Edwards (1997) asserts that older children have learned to memorize answers and prefer not to ask questions, instead letting teachers ask the questions. Heppert et al. (2002) state that "the laboratory instructor must be prepared to face frustration when students receive guidance rather that direct answers." One of the other requirements for inquiry learning is that the student be actively engaged in the process. Many older children have the tendency to be passive in their learning (Edwards, 1997) making it difficult for the student to glean any useful information through the inquiry process.

Inquiry learning also requires special treatment of lesson planning and implementation by the teacher. Teaching an inquiry-type activity is a very interactive process and the activity cannot stand by itself (Clark et al. 2000). Teachers often report that inquiry labs take more time to complete, take more time to grade and involve more student frustration (Deters, 2005). Often, teachers lack the training necessary to produce good quality inquiry type activities. Windschitl (2001) contemplates several studies that examine the reasons why teachers may have difficulties with inquiry type activities. He explains the difficulties of the teachers by the possibility that teachers are "confused about what constitutes inquiry".

For science labs, Deters recommends the best way for teachers to begin using inquiry in their classroom is to "take a fairly straightforward lab and simply delete the procedure, data recording, and analysis sections." Students are required to come up with their own ideas for those sections. She also suggests giving students some instruction on the conceptual framework of the activity ahead of time. (2004) This idea agrees with a statement by Finley and Pocovi (2000) that without content knowledge, a good question could not be posed.

CLASSROOM DEMOGRAPHICS

This inquiry stoichiometry unit was implemented at Marshall High School located in the small, rural, historic community of Marshall, Michigan. Marshall is located at the intersection of I-69 and I-94. The community of Marshall has approximately 8,000 residents. Student count at the high school is around 900 students, from both the city of Marshall and surrounding areas. The high school is on an eight-block instructional system with each class lasting eighty minutes. Students attend two sets of four eighty minute blocks Monday-Thursday and attend all eight classes on Friday for forty minutes.

General chemistry is an elective class offered to sophomores, juniors and seniors upon the completion of the prerequisite college preparatory biology. A few of the sophomore and junior students are dual-enrolled in anatomy/physiology or physics in addition to general chemistry. Almost all of the students enrolled in the general chemistry course will pursue a four-year post-secondary degree.

In the 2005-2006 school year, five sections of general chemistry were offered. One section was taught by another teacher and is not included in this study. The first section consisted of 23 students, the second section 18 students, the third section 18 students and the last consisted of 24 students. Of the 83 students, 4 were seniors, 32 were juniors, and 47 were sophomores. Forty of the 83 students were male and 43 were female. Four students did not participate in the study.

STOICHIOMETRY SCIENTIFIC BACKGROUND

Students participating in the stoichiometry unit were presented with lecture notes explaining the process of solving stoichiometry problems. Most presentations were given with the student taking notes or filling out guided note sets. Students also were encouraged to refer to the book for additional sample problems and reading. Guided practice was given during class time to help students learn the problem solving methods. After that, laboratory experiences were used to help strengthen the stoichiometry concepts they were applying in the problem sets.

Stoichiometry is the branch of chemistry that deals with estimating and predicting mass and amount relationships between reactants and products in a chemical reaction. Stoichiometry is from the Greek word *stoicheion*, which means "to measure the elements".

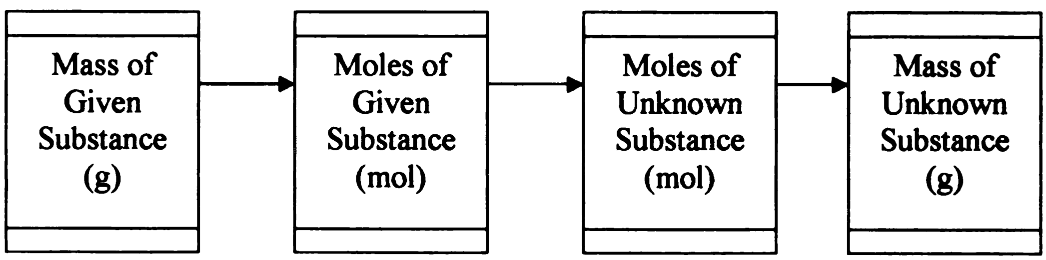
Mole ratios are the first concept to be learned in stoichiometry. Mole ratios are expressed as the coefficients in a balanced chemical equation because these coefficients represent the relative numbers of moles of substances involved in the reaction. These mole ratios can then be used as conversion factors to enable scientists to compare one compound or element to another compound or element in a chemical equation. For example, take the equation $4Al + 3O_2 \rightarrow 2Al_2O_3$. If Al is compared to aluminum oxide the mole ratio is 4:2. That means if a reaction uses 4 moles of Al, that reaction will produce 2 moles of aluminum oxide assuming all 4 moles reacts completely. If one number is changed in the mole ratio, the other number changes by the same amount. For example, taking the 4 moles of Al: 2 moles Al_2O_3, if the number of moles of aluminum is changed to 12, then the other number must be multiplied by an equal factor to keep the ratio consistent. In this case, we would multiply the number of moles of aluminum oxide by 3 to produce 6 moles of aluminum oxide. This mole ratio expressed as a conversion factor would look like:

$$\frac{6\ \text{moles}\ Al_2O_3}{12\ \text{moles}\ Al} \qquad \text{or} \qquad \frac{12\ \text{moles}\ Al}{6\ \text{moles}\ Al_2O_3}$$

Mole ratios provide the very basic stoichiometric conversion between moles of one compound to moles of another compound.

After understanding the concept of mole ratios, the next topic to be addressed in stoichiometry involves mass relationships in stoichiometric calculations. If an amount is given in units of grams, that amount can be converted to moles by using the molar mass as a conversion factor. Once the answer is in units of moles, the mole ratio can be applied to convert to moles of another reactant or product. The molar mass conversion factor can then be applied to convert to units of grams if so needed. The basic steps for solving a mass-mass stoichiometry problem can be expressed in the following flowchart.

Figure 1 – Basic Stoichiometry Flowchart



Once this concept is mastered, stoichiometry problems using density as a conversion factor between mass and volume are next. This entails knowing how to set up density as a conversion factor to correctly solve for mass or volume. For example, if a substance is given in units of liters and needed in grams, use density as a conversion factor to find the number of grams.

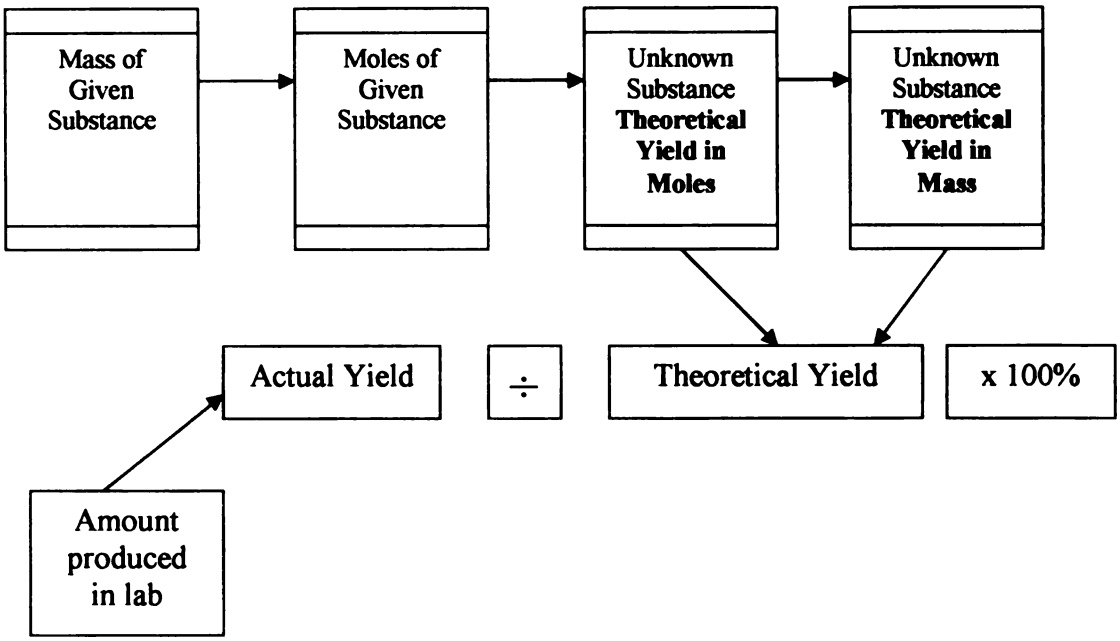
The next sequence in stoichiometry is limiting reactants. A limiting reactant is the reactant in a chemical equation that is used up first, thus limiting the amount of products made. The excess reactant is the reactant that is not used up, and has some amount left over. Finding the limiting reactant in a chemical equation enables the scientist to predict how much product he is able to produce. The steps to finding the limiting reactant are listed below:

1. Pick one reactant.
2. a. If given amount is in grams, calculate grams of the other reactant. If given amount is in moles, calculate moles of the other reactant.
   This is the amount that is needed to completely react with the entire reactant chosen.
3. Compare the needed amount with the amount that is given in the problem. Remember to compare the same compounds.
4. If the needed amount is larger than what is given in the problem, then that compound is the limiting reactant.
5. If your needed amount is smaller than what is given in the problem, then that compound is excess reactant and the other reactant is the limiting reactant.
6. Use only the given amount of the limiting reactant to find out how much product is produced.

Once the limiting reactant is identified, calculations can be done to identify how much of each product is produced, how much excess reactant is used, or how much excess reactant is left over. It is imperative to recognize that the limiting reactant stops the reaction. Once the limiting reactant is depleted, no more product can be made.

The last concept in stoichiometry is percent yield. Percent yield is a measure of how much reactant gets transformed into products. The percent yield is found by taking the actual yield and dividing by the theoretical yield and multiplying by 100%. Actual yield is how much product was produced in a laboratory setting. Theoretical yield is the amount of product that could have been produced if 100% of the reactants were converted into products. Theoretical yield is usually found by solving a stoichiometry problem.

Figure 2 – Percent Yield Flowchart



Theoretical yield can be in units of moles or grams depending on the unit of the actual yield. Because percent yield is a three-variable equation, if two variables are known, the third can be calculated. For example, to determine the percent yield of a reaction, first the actual yield would need to be found. Then, the theoretical yield can be calculated from a given reactant amount in grams or moles. The percent yield can then be calculated by dividing the actual yield by the theoretical yield and multiplying by 100%. Manipulations of this equation can be used to solve practical problems. For example, if given the percent yield for a particular reaction, one can predict how much product can be produced in a laboratory setting by solving for the actual yield. Scientists can then determine how many reactants to add together to produce a certain amount of product.

IMPLEMENTATION OF THE UNIT

The development of the inquiry based stoichiometry unit focused on replacing traditional labs with more inquiry based labs. Inquiry labs in this unit consist of labs where students are given a problem and are asked to write a procedure and find the answer to the problem. In the beginning, students are provided with more structure to the labs and as students become more familiar with the inquiry process, the structure is lessened. Examples of labs done in the past are mole ratio lab using magnesium and oxygen to form magnesium oxide and testing reaction combinations of oxygen and hydrogen to make the best rocket fuel. All of these labs had complete procedures that the students followed, made observations, performed calculations, and answered a few conclusion questions. I replaced these labs with six inquiry based labs that I developed. The lecture notes were the same as I used in the past. I also developed a few conceptual activities to enhance my stoichiometry unit. Table 1 shows the order of implementation of the unit.

Table 1 - Overview of Unit and Activities
*Developed summer of 2005

Objectives	Activities to complete objectives
Pre-Unit	Consent Form Completion – Appendix A Pre-survey – Appendix BI Stoichiometry and Density Pre-Test – Appendix CI
Week #1 The student will calculate basic stoichiometry problems using mole ratios and molar mass conversion factors.	Mole Ratio Activity* - Appendix DI Lecture – Mass-Mass Stoichiometry with flowchart Stoichiometry practice problems
Week #2 The student will apply stoichiometry calculations to solve real world problems.	Aqueous Solutions Lab* - Appendix DII Hard Water Testing Lab* - Appendix DIII
Week #3 The student will calculate stoichiometry problems using density as a conversion factor.	Lecture – Stoichiometry using density conversion factors It's a Gas, Gas, Gas Lab* - Appendix DIV Chemistry of Baking Lab* - Appendix DV

The student will apply the density stoichiometry calculations to solve real world problems.	
Week #4 & 5 The student will determine which reactant is limiting in a chemical reaction and calculate how much product is produced. The student will calculate percent yield for various reactions.	Finish Chemistry of Baking Lab Stoichiometry and Density Post Test – Appendix CII Limiting Reactant and Percent Yield Pre-Test – Appendix CIV Limiting Reactant Conceptual Activity* - Appendix DVI Lecture – Limiting Reactant Guided Notes Limiting reactant practice problems Lecture – Percent Yield Percent yield practice problems
Week #6 The student will use percent yield to predict how much actual product will be produced in lab.	Limiting Reactants and Percent Yield Lab* Appendix DVII Salt Lab Activity* - Appendix DVIII Oh, My Stomach Lab – Appendix DIX (not completed due to time constraints)
Week #7	Limiting Reactant and Percent Yield Post Test – Appendix CV Post Unit Survey – Appendix BII

I was anticipating this unit to only take four to six weeks, however, it took a total of seven weeks to complete.

Description of Activities

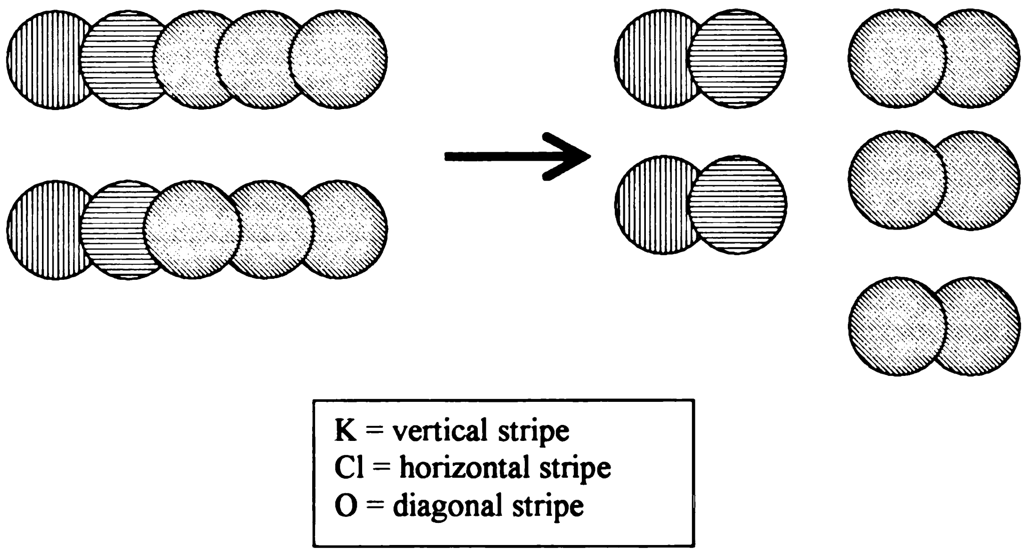
In general, the lab reports were graded for completion and correctness of statements given by students. In the beginning, student scores were low, but by the end of the unit, scores for the lab reports improved.

1) Mole Ratio Activity

When I teach my unit on chemical reactions, which precedes the stoichiometry unit, I show my students how to represent compounds in a chemical equation using visual equations. Teaching that unit, I have observed that students have a difficult time distinguishing between the coefficients in a chemical equation and the subscripts in each formula. Each student was given an unbalanced chemical equation. Each atom in a compound is assigned a certain color circle. Overlapping circles signify a bond. See Figure 3 for an example.

Figure 3 – Visual Representation of Equations

$$2KClO_3 \rightarrow 2KCl + 3O_2$$



Students make the compounds in each equation using this method. Then I ask if the equation is balanced. By looking at the number of each colored circle on each side, the students quickly see how to balance the equation.

Using this same method, I developed the mole ratio activity. The objective was that the students can recognize mole ratios and their relationships. Students are first asked to model what an equation would look like using the circles. Then, the coefficient of one compound is changed. The students are challenged to work with their group to identify what happens to the other compounds in the formula and present a relationship using the colored circles.

After repeating this same activity using different coefficients, the students recognize that when you change one coefficient, the other coefficients must change by the same factor. The students are then introduced to using the mole ratios as conversion factors. Because students have previously used conversion factors to solve basic mole problems, this task was not difficult for the students. This activity was completed by having students successfully identify and write mole ratios as conversion factors for various chemical equations.

This activity was assessed by looking for correct answers to each section during class time. If students have incorrect answers, they are asked to try again until the correct answer is reached.

2) Stoichiometry in Aqueous Solutions

This lab was developed to be more structured than the other inquiry labs that follow, due to the fact that this was the first time I was asking my students to develop procedures. The objective of this laboratory was that students use stoichiometric calculations to solve a problem or question. Students were told that the purpose of the lab was to determine how much iron (III) chloride was in a sample. After that, the lab was organized into a series of tasks that the students needed to complete before moving to the next task. Students worked in groups of two or three to accomplish these tasks. The first task involved using a solubility table to identify what would produce a precipitate when reacted with iron (III) ions. Because the students had not previously used a solubility table, I explained how to utilize the table. After that, students answered the questions and moved on to task two. Task two was to write a balanced chemical equation for the reaction between iron (III) chloride and sodium hydroxide (hydroxide was found to be an ion that would produce a precipitate when reacted with the iron (III) ion). For ease in lab, I chose hydroxide as the ion to react with the iron (III) ion. The third task involved having the students develop reactant amounts to use in lab. The fourth and fifth tasks were doing the procedure and weighing the precipitate. I gave students the procedure for these tasks because at this point in the unit they were not skilled enough to come up with a procedure for filtering a precipitate. The sixth task was to calculate the mass of iron present in milligrams. The seventh task was to write a lab report and report the findings. This lab was assessed by grading the students' lab reports for completeness.

3) Hard Water Testing

In this laboratory, students use stoichiometric calculations to solve a problem or question. The *Hard Water Testing* lab put the students in a position of being an employee for a company that makes soda water. They were given the task of finding out how much calcium is in the water supply. Limited information was given to the students to start the lab. Students were told that they had standard lab equipment available to them to complete the lab and could choose from three reagents: sodium nitrate, sodium carbonate or sodium hypochlorite. The students worked on preliminary lab reports so I could check them before they started the procedure. After the students finished the procedure, they were asked to write a business letter to the company president to explain the findings. They were told to include the method used, the reaction and any calculations, the calcium content in mg/L, and to suggest a way to correct the calcium content to 100 mg/L. The business letter was assessed similarly to the lab.

4) It's a Gas, Gas, Gas Lab

After lecturing about density as a conversion factor, the students completed practice problems. The next lab activity was the Gas, Gas, Gas lab. The students were expected to use stoichiometric calculations involving density to solve a problem or question. This lab was based on a traditional lab that is used in many gas law units: the reaction between magnesium and hydrochloric acid where one measures how much gas is created, then standardizes it to standard temperature and pressure. I took that same reaction and used it for a stoichiometry lab. The problem presented to the students was that they needed to make 20 milliliters of gas using magnesium and hydrochloric acid. I gave them the equation and the procedure because the students had never collected gas using a eudiometer tube, but I did not specify the amounts of the reactants. This lab was assessed by students completing a lab report.

5) Chemistry of Baking

This was designed to be an informal assessment of the inquiry process thus far in the unit. I had one objective in mind when I developed this activity. I wanted to observe the students while working and determine how many students would use stoichiometry methods to solve the problem instead of the "guess and check" method. I did not tell the students that this was an assessment; I simply told them that they had to solve the problem in their group with minimal help from me.

The problem involved the students taking on the role of an employee at a cookie corporation. The students were in charge of developing a substitute for baking powder. Students were given background information on baking powder such as the main ingredients and a word equation for the reaction that happens between the baking soda and cream of tartar in baking powder to produce the carbon dioxide. The students were to develop a recipe for the substitute baking soda that will ensure the proper amount of carbon dioxide gas was produced to make a batch of cookies. The students were also told that the proper amount of gas produced would fill a small gas container (sandwich baggy). This lab was assessed by my observations and by students completing a summary of their experimentation.

6) Limiting Reactants Conceptual Exercise

I developed this activity as a companion to the previous activity involving mole ratios. This activity was implemented before any formal lecture about limiting reactants. The *Limiting Reactants Conceptual Exercise* involves students using visual models to diagram chemical reactions. The students were to determine the limiting and excess reactants and justify their choices. The difference between this activity and the mole ratio activity is that students were given starting amounts, were asked to show the products using the colored circles, and determine the limiting and excess reactants. In addition, the students were asked various questions such as: "What happens to the bonds when reactants form products?' "What is the relationship between the number of molecules used in the reaction to the mole ratio in the equation?" Students completed this activity either independently or in small groups and the activity was assessed based on the students' responses to questions included in the activity.

7) Limiting Reactants and Percent Yield

In this lab students used limiting reactant calculations and percent yield calculations in a lab setting. Students had been practicing textbook problems involving limiting reactants and percent yield for about a week. Because this lab is the first the students used limiting reactants and percent yield, it was designed to be more structured. The problem posed to students is that they need to make half a gram of sodium acetate. Students are given the word equation of the reaction and the density of vinegar. They also were provided with a basic procedure, but the starting amounts of the reactants were omitted. Students were expected to pick one reactant to be limiting and add excess of the other reactant. Then the students determine the balanced equation, and the limiting reactant, actual yield, theoretical yield and the percent yield of the reaction. The students were assessed by observations in lab and correct determination of each of the required calculations.

8) Salt Lab Activity

After completing the limiting reactant and percent yield lab, the students began work on the *Salt Lab*. The objective of the *Salt Lab* was for students to take information provided about a reaction, determine the percent yield and apply that information to make a certain amount of product. This is an inquiry-based activity where students are given information gleaned in the laboratory and use that to figure out the calculations. Students are told that they have been hired by a company to produce salt. Their job is to develop a procedure to make one ton of salt in the factory, accounting for the percent yield. The students are given information completed by a previous colleague from the factory that gives the equation, how many reactants were used, and the procedure used. The information, however, is only for a small batch of sodium chloride. The students are asked to analyze that information and use it to determine the protocol for making one ton of sodium chloride. This activity is assessed by grading the students' work for correct answers to the problem.

Description of Assessments

The students' understanding of stoichiometry topics was evaluated throughout the unit with a variety of questions and lab reports. Written observations were noted for each activity and laboratory. Additionally, students' overall knowledge was assessed by comparing pre-test scores (Appendices CI & CIV) with post test scores (Appendices CII & CV). The first assessment covered stoichiometry and density problems, while the second assessment focused on limiting reactants and percent yield. Two assessment tools were used to shorten the test time for students. Most of the questions were written as constructed response or problems, so as to give the students the opportunity to demonstrate their knowledge on the topic. Most questions were worth multiple points (Rubric in Appendices CIII & CVI) and students could earn partial credit on each question based on completeness of answers. The students also participated in an anonymous pre-unit survey (Appendix BI) and an anonymous post unit survey (Appendix BII) that asked students questions about science and how they learn science best which students answered on a scale from 1 to 5. Included in the post unit survey (Appendix BII) was an evaluation of the laboratory component of the unit that students completed, again rating from 1 to 5.

RESULTS

The results of the unit will be presented in two parts. First, a subjective analysis of the labs from my observations will be presented and second, an objective analysis of the assessment tools.

ACTIVITY ANALYSIS

Mole Ratio Activity

This activity went relatively well in all my sections. The error I had to correct the most often was the difference between the coefficients and the subscripts. An example of that error would be showing six oxygen atoms all touching each other, indicating bonds, for $3O_2$. I showed most students the correct representation during this activity for the first question. Then the students could use that concept to complete the rest of the problems. The last problem I gave to the students on this visual mole ratio activity was challenging for them. Previously, I had not introduced fractional coefficients to the students. I changed the equation in such a way that one coefficient had to be a fraction. I encouraged the students to use the visual models to figure out the answer instead of giving them the answer. After a while of working with partners and talking through it, most students came up with the idea of using a fractional coefficient. When asked how that related to the other problems, most students understood that we were dividing by two in our equation and that is why we needed the fractional coefficient. Some students were shy to speak up about their idea of a fraction used as a coefficient because they thought they were wrong. After completing the visual equation part of the activity, the students worked independently to come up with mole ratios for example equations I had given them.

Observing the students while they were on task enabled me to guide the students and ensure all students were ultimately identifying correct relationships for the mole ratio activity. I feel this activity reinforced previous content knowledge and also provided an opportunity to learn new material in a familiar context.

Aqueous Solutions in Stoichiometry

This lab was broken down into tasks for students to complete because it was the first lab of the marking period. Tasks one and two were assigned for homework. These tasks were fairly easy for almost all of the students as observed by the completeness of the homework. The third task presented somewhat of a challenge for students. This task required the students to start with 5 milliliters of the sample containing iron (III) chloride and decide how much of the other reactant to use. The instructions stated that "To ensure proper results, we must make sure that all of the iron (III) chloride is used up." The students were unclear what that meant. I had to interact with almost all of the groups to help students figure out how much of each reactant to use. In the sixth task the instructions gave some hints, but it was left to the student to figure out the calculations. Most students did a great job with this task. Within 15 minutes of working, almost all of the students had set up a stoichiometry problem starting with the grams of precipitate and working to milligrams of iron. The most challenging part of this task was for the students to discern the compound that formed the precipitate. I referred students back to the balanced equation and asked them two questions: "What is a precipitate?" and "What compound in the reaction is a precipitate?" Once students figured that out, the rest of the task went smoothly.

Because this was the first lab we did where students generated parts of the procedure, most thought this was difficult from my observations during class time. I also had to keep going around the room and asking students to stay focused. Once the students were frustrated, they stopped trying to figure out an answer and wanted me to tell them the answer. When I answered their questions with questions, some were even more frustrated. While I anticipated this happening, I think the students benefited from this lab.

Hard Water Testing

This lab was very similar to the *Stoichiometry in Aqueous Solutions* lab, in that the students were not given the procedure and had to figure that out for themselves. I was curious to see if students would recognize the similarities between the labs and use similar procedure steps. Based on my observations in class, most students did not clearly make the connection between these two labs. Most students wanted to filter the water and collect the calcium ions on a piece of filter paper and weigh it. I had to explain to them that the calcium was dissolved in the water and would go through the filter paper with the water. I asked them "How can the calcium be removed from the water? or I asked them to think about what state of matter the compound was that did not go through the filter paper. After that question most students still needed a little prodding. I had to remind the students how to use the solubility table. From there, they realized the similarities of the previous lab and could then formulate a procedure.

Students knew how to take the mass of the calcium carbonate precipitate and use stoichiometry to find milligrams of calcium. However, when asked to determine the milligrams of calcium per liter, they struggled quite a bit. To assist them, I asked "What does miles per hour mean?" All of the students indicated that it meant taking the miles driven and dividing it by the hours. I then asked them to make the connection to mg Ca/L. They had difficulty getting the solution volume in liters, that is, in making the correct conversion. Some students went about the conversion in a different way. They had milligrams of calcium on the top of the fraction and they had milliliters of solution on the bottom. They knew the bottom unit needed to be in liters, so they multiplied both the top and bottom by 1000.

It's a Gas, Gas, Gas

At this point in the unit, we had been working on stoichiometry for three weeks. This lab was written with most of the procedure provided. However, the students had to write the equation and determine starting amounts of reactants. From my observations, I was surprised at the number of students who were still having a difficult time knowing where to start with the lab. Because this was the third inquiry lab we had completed, I wanted the students to come to me and ask questions on their own or rely on their partner for help. Almost all students could write the equation correctly. However, they were still having difficulty with figuring out the reactant amounts. I tried to guide them by asking, "What is the purpose of this lab?" I wanted them to answer that the purpose was to make 20 milliliters of hydrogen gas. If they answered in this way, I then asked the students, "What information do you need to know to complete this lab?" Most answered that they needed to know the reactant amounts. That answer usually came with the realization that they could then use the stoichiometry with density conversions to find out how much magnesium was needed.

Most of the students made informal comments to me during the lab period that this was their favorite lab. When I asked them why, they told me they thought the bubbles going up through the water were "cool". They also liked watching the acid falling down through the water as the eudiometer tube is inverted.

Chemistry of Baking

This lab was the least guided compared to the previous labs. I wanted to observe how the students would react and what they would do when given so little information. Out of my four sections, three sections took time to read over the given information again, try to brainstorm ideas, and write the balanced equation. It took most of the students about ten to fifteen minutes before they entered the lab area and began work. In one section, the students went right into lab and started measuring out chemicals. When I asked a few groups how they came up with the amounts they were using, most responded that they picked equal amounts and that they would try to use the "guess and check" method. That tells me those students still did not understand the concept of stoichiometry applied to lab situations. I observed out of all four sections, that five groups out of thirty-eight persisted with the "guess and check" method. I want to note here that labs, particularly inquiry labs, have a distinct disadvantage. Students are not conducting these experiments in a vacuum. Once one group decided to try stoichiometry, word spread and then everyone realized it was probably the "right answer" on how to solve this problem. It is very hard to individually assess each student on his thinking when working in a large setting.

Many students told me during the initial minutes of this lab that they felt "lost". They were not sure I had given them enough information. I encouraged them to talk to their partner and try to brainstorm ideas. I had one group tell me that they didn't like brainstorming and wanted me to tell them the answer because "I don't want it to be wrong." The second problem the students struggled with in this lab was determining the volume of the container. Most students were not sure that if they measured the container with water and determined the volume, it would equate to gas volumes. Some students tried to look at the sandwich baggies and measure the baggy to determine volume that way. They quickly realized that the baggy was not a definite shape and mathematical formulas for volume would be tricky to apply. After that, most students did stoichiometry problems to find the amount of reactants and then tested those amounts. An interesting challenge came when the students put the reactants in the bag. I had several groups bring the solid potassium hydrogen tartrate and sodium hydrogen carbonate mixed in the bag to me and ask why it wasn't producing gas. I tried to relate this to the problem they were solving. I asked them if they made cookies, what types of ingredients did they use to make the dough. Most responded the usual ingredients, flour, eggs, milk, etc. They quickly realized that the baking powder needed to be dissolved in water for the molecules to be able to react with each other to produce a gas.

This was an interesting lab for me to observe. I had the impression that some of the students disliked this lab. That was confirmed when the students responded on the post-survey.

Limiting Reactants Activity

This activity used visual models to help students determine the difference between the limiting reactant and the excess reactant. Students correctly modeled the given reactant molecules and product molecules, but were unsure what to do with the excess reactants. Most students wanted the equations to stay balanced and to not deviate from the mole ratio. From my observations, I am not sure they understood that we were still using the balanced equation to regulate how much product was being produced, but we could start with any given amount of reactants. Unfortunately, this activity did not address that issue and I think the students left the activity unsure about the starting amounts in a reaction. I think if I would have stated the given amounts more clearly, that misunderstanding could have been avoided.

This activity did not work well as an independent group activity. I believe that the way I wrote the questions and set up the activity hampered the students' ability to process the information. I spent most of my time during this activity helping groups get started. This activity would better be used as a teacher led activity with the students working in small groups.

As far as students understanding limiting and excess reactants, the activity initially performed well. Assessment of the written responses directly after the activity showed that they understood that the limiting reactant runs out first and that is why the reaction stops producing product. They also understood that the excess reactant is the reactant that is left over. On the post unit test, however, students seemed to regress. On a question that asked students to visually model the reaction, the average score was only 42%. That indicates the students still have problems identifying what equations represent on a molecular level. A question that followed asked students to identify the limiting and excess reactants from that diagram. The average student score on that question was 61%. Although I think this activity helped the students to conceptually understand what the limiting and excess reactants represent in an equation, these data support that students still have a difficult time conceptualizing this idea when presented with a molecular view of an equation.

Limiting Reactants and Percent Yield

This lab was more guided than previous labs in this unit so that the students could focus on the limiting reactants and percent yield concepts and not the procedure. Students were asked to conduct the experiment and write the equation, list the amount of reactants used, the limiting reactant, the actual yield, the theoretical yield and the percent yield. Even with those requirements being given on the lab sheet, in two of my sections students went right into lab and started drying the evaporating dish to start the lab. It was only after I started asking the different groups how they would know how many grams or milliliters of reactants to use that they started to realize that they needed more information. I had developed this lab with the idea that the students would pick one reactant to be the limiting reactant and add only a certain amount and have the other reactant be the excess reactant. What happened when students completed this lab is that they used the amount of product that was to be produced and calculated both amount of reactants. In essence, they had calculated both reactants to run out at the same time. I decided not to interfere and see if the students recognized that when they had to identify the limiting reactant. From assessing the lab reports, roughly half of the students did not recognize that they had in fact used both reactants as the limiting reagent.

The students did do all percent yield calculations correctly. One problem with this lab is that a majority of my students had a percent yield above 100% . I asked groups why they thought they had a percent yield over 100%. Some groups claimed that they made more product. I referred them to the law of conservation of mass. After that, some groups stated that maybe the excess reactant was adding mass but the most common response was that the water did not evaporate completely.

Salt Lab

Students used information from a lab situation to extrapolate new information about the same reaction. I read the given information to the students and then I just walked around the room and observed. I observed students talking to each other about what they should do first to figure out the answer. I also observed students starting to calculate some stoichiometry problems. Observing all my sections, all of the students started right away on the task and were working with their partners. I attribute that to the fact that this was the sixth inquiry lab that the students had done and the students were feeling comfortable with each other and the process. After observing the students and seeing that they had correctly calculated the percent yield for the smaller batch of salt, I decided to give them some more information. I gave the classes the information that if a reaction is done with a certain procedure, we can assume the percent yield will be the same if it is done in a small batch or a large batch. With that information, most students recognized that they needed to use the percent yield that was calculated with the actual yield that was given to find the theoretical amount of product. From the theoretical, the students could then solve the problem.

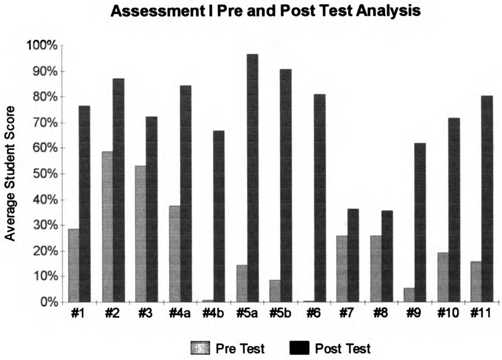
PRE AND POST TEST ANALYSES

The null hypothesis for this thesis project is that there is no difference between the first and second pre test and post test scores for each student. Appendices EI and EII show each students results from the two pre test and post test assessments. Using the paired t test, the pre test and post test scores were compared. The result of this test showed that there is a significant difference between the paired mean scores of the pre tests to the mean scores of the post tests. The t value for the first paired t test was -28.2 and the second value was -26.8. The probability of these results, assuming the null hypothesis is 0.000 and I reject the null hypothesis. Therefore, there is a significant difference between the pre test scores and the post test scores for the students. The students' average score on the pre tests were 18% and 18%. The scores for the post tests, respectively, were 75% and 67%. These data suggest that there was significant growth in knowledge concerning stoichiometry concepts.

Both the first and second pre test and post test assessments (Appendices CI, CII, CIV and CV) consisted of the same questions with only numbers changed in problems. Therefore, the same reasoning process is used in all questions, pre and post assessment. This makes it convenient to compare each student's pre and post test scores. The post test assessments contained additional problems and questions that the students were required to answer, but they are not evaluated in this study. The following analyses are for the same question asked on the pre tests and post tests. Refer to Appendices EIII-EVI for a complete breakdown of points earned by each student on each question for the pre and post test assessments.

Analysis of Pre and Post Assessment I

Figure 4 – Diagram of Pre and Post Test Analysis for Assessment I



On the first assessment (Appendices CI & CII), the first three questions dealt with the concept of mole ratios. The first question gave the students an analogy of a bridge to the mole ratio and asked students to identify how the mole ratio was related to the products and reactants. The average student score for this question was a 77% which shows moderate understanding of the concept, while the pre test score was a 29%. The next question gave students an equation and asked to list the mole ratios. Students scored a 58% on the pre test question, showing that they had some previous knowledge on that topic. In fact, the textbook that is used in my classes briefly discusses mole ratios in the chapter on mole problems and it is probable that the students gleaned the knowledge from that source. On the post test, the students showed significant improvement by increasing the average score to 87%. The last question on mole ratios changes some of the numbers in the mole ratios and asks the students what happens to the other parts of the equation. The students scored a 72% on that question on the post test and a 53% on the pre test. Again, the students showed some previous knowledge of that topic. These series of questions and data show that although students can easily identify the mole ratios in an equation, manipulating the mole ratio is still a challenge for some students.

The next question on the first assessment is a stoichiometry problem in which the reactants and products are given by name and starting amounts are given; however, the balanced equation is not provided. The question has two parts: first, what would be the first step in solving this problem and second, solve the problem. On the pre test assessment, 38% was the students' average score for correctly identifying the first step in solving the problem. On the post test assessment, this number increased to 84%. This shows that the students understand the basic concept that the mole ratio from the equation is needed to solve the problem. For the second part of this question, on the post test assessment, the average student score was a 67% while on the pre test assessment it was a 0.78%. I expected the students to score poorly on the pre test assessment of this question because they had no prior knowledge of this concept. I did expect the students to score better than an average of 67% on the post test assessment. However, in examining closely the students' data, the difficulty in the question was in properly writing and balancing the equation in order to obtain the correct mole ratio.

The next two questions on the first assessment dealt with basic stoichiometry calculations. The balanced equations were given to the students and both problems were mass to mole calculations. On the pre test assessment, the average student score for the problems were 15% and 9%. The scores on the post assessment test were 96% and 91%, respectively, showing clear student achievement in that concept.

Using density in stoichiometry calculations was the subject of the next question. Students were given the balanced equations and given relevant densities and starting with a volume amount, calculate the volume produced of a different compound. The students' initial average score on this question was a 0.22%. The average score for the post test question was an 81%. These data suggest that students understand calculations necessary for stoichiometry density problems.

The next question was a conceptual question that I put on the pre and post test assessments to identify whether the students' conceptual understanding of stoichiometry was increasing. The underlying idea of this question was not addressed directly in any of the labs or activities. The question told students that oxygen and water combine with iron to form rust. The students were then asked to predict how much the rust should weigh in relation to the nail if the iron nail were allowed to rust completely. On the pre test question, the average score was 26% showing a small portion of students understood the law of conservation of matter and how it applied to stoichiometry. On the post test question, there was only a slight increase of the average score, to 37%. These data show that even after all the lab activities, students are still confused about the idea of how much the reactants and products of a reaction should weigh in relation to each other after a reaction.

The next topic involved relating masses of compounds to the mole ratios of an equation. Students were told that aluminum atoms weigh about ½ of nickel atoms. They were then asked for a complete reaction to occur, (they were given the equation) what mass ratio of aluminum to nickel should be used. Responses to this question were the lowest student average of any other question on this assessment. Students' pre test average score was a 26% while the post test average score showed very little improvement to a 36%. This question was not addressed at all in class, because I wanted to see if the students' conceptual understanding increased. These data show that the students' understanding increased slightly, but that most students still do not understand the connection between molar masses and mole ratios.

The next question on the assessment dealt with a laboratory concept. The question asked the students to describe a procedure you might use to determine the amount of nitrate ions in a water sample. On the pre test assessment, the average student score was 6%. After completing the labs, the score on the post test was a 62%. This shows great improvement in the average score; however, this score is still quite low to show student mastery of this concept. This question's concept was very similar to two lab concepts that the students completed. These data support the fact that students were still having a difficult time relating knowledge from one situation to another.

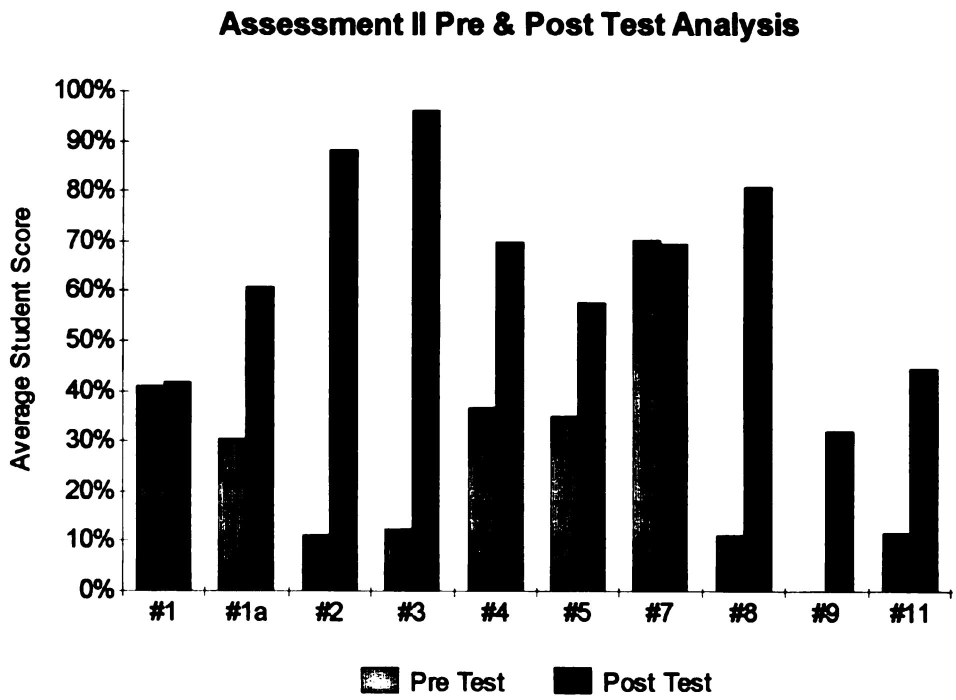
Another lab question was asked of the students, this time involving density stoichiometry calculations. Students were asked to describe a procedure that could be used to determine the amount of reactants needed to fill an airbag with gas. The students scored an 80% on the post test question compared to a 19% on the pre test. Students completed two labs on a related topic involving density stoichiometry calculations. Students understood the process involved in determining that procedure as evidenced by the significant increase in scores from the pre test question to the post test question.

The last question on the first assessment dealt with mole ratios. The question asked students to identify what they needed to know about moles to determine the outcome of chemical reactions. On the pre test question, the average student score was a 16% while the average student score for the post test question was a 81%. These data suggest that students understand that the mole ratio is needed to complete a stoichiometry problem.

Overall, the students' average scores on the pre test versus post test increased from an 18% to a 74% showing a significant increase in student knowledge and comprehension.

Analysis of Pre and Post Assessment II

Figure 5 – Diagram of Pre and Post Test Analysis for Assessment II



The first two questions on the second assessment (CIV, CV, #1 & #1a) included a visual diagram of molecules, gave the students a balanced equation and asked students to draw a diagram that shows the results after the mixture reacts as completely as possible. The average student score on that question for the pre test question was a 41%, while the average student score on the same question on the post test was a 42%. There was no improvement on student achievement. The second part to that question asked students to identify the limiting and excess reactants. On the post test question, the average student score was a 61% while the pre test question score was a 31%. In this aspect, students did show growth in correctly identifying the limiting and excess reactants.

The next question (#2) was a limiting reactant stoichiometry problem in which the students were not provided the chemical equation. Students were given two starting amounts and asked what mass of product would be produced. On the pre test question, the average student score was 11%, while on the post test score it was an 88%. These data suggests that students understand how to organize and calculate a limiting reactant stoichiometry problem.

The concept of the next question (#3) was also limiting reactants. This time, students were given two starting amounts and a balanced equation and asked to identify the limiting and excess reactants. The average student score on the pre test question was 13%, while the post test question average student score was a 96%, indicating mastery of this idea.

Question 4 presented three graphs with an explanation that two particular solutions added together form a precipitate. Students were asked if one solution was fixed and the other solution added indefinitely, what graph would correctly model the amount of precipitate. This is a conceptual question that indicates whether or not students understand the concept of limiting and excess reactants. On the pre test question, 37% was the average student score, while on the post test question, the average student score was 70%. This is a definite growth in understanding of the concept as evidenced by the data.

Students were given amounts of molecules and atoms that react and the amounts that are produced in question 5 and asked to correctly identify the limiting reactant and explain why. The average pre test score was a 35% and the average post test score was a 58%. This is not a large gain. These data indicate that students continue to have difficulty with representing equations at the level of atoms and molecules.

Question 7 asked the students whether or not the products of a reaction could ever have more mass than the reactants. On the pre test question, the average student score was a 70%, while the post test score stayed the same at 70%, showing no improvement.

Percent yield was the focus of question 8. The average score on the post test question was an 81%, while on the pre test question the average student score was a 12%. These data showed that the students were better able to calculate percent yield.

Percent yield and limiting reactants together were the focus of question 9. Students were given two starting amounts and asked how much product would be produced given a certain percent yield, but were not given the balanced chemical equation. The average student pre test score was a 0.2% while the average post test score was a 32%. These data support the fact that students have not mastered the ability to solve both a limiting reactant and percent yield problem.

The last question (#11) asked students about the concept of percent yield and the amount of reactants. The average student score for the pre test question was 12%, while the average student score for the post test was a 44%. Again this result suggests that the students have not mastered the concept of percent yield.

PRE AND POST SURVEY ANALYSES

The students participated in a pre survey and post survey (Appendix BI & BII) about labs conducted in science classes and the way in which they learn science the best. The students responded to the questions with a 5 for always, a 4 for often, 3 for sometimes, 2 for seldom and 1 for never. The same questions were asked in the pre and post surveys. Each survey statement is given below followed by analyses.

"My group or class always chooses what questions to answer in lab." In the pre survey, almost 50% of the students chose the response of never. This reflects the previous traditional style of the classroom. However, in the post survey, 54% percent of the students chose always, often or sometimes.

"I would like my group or class to choose the questions to answer in lab for every lab." In the pre survey, about 57% of the students responded that they would like to always, often or sometimes choose the questions to answer. In the post survey, however, the 72% of the students reported that they would always, often or sometimes choose the questions to answer. This is a clear increase of students who would like to choose the questions to answer in each lab.

"I would like the teacher to choose the questions to answer for each lab." I was curious to see how many students would prefer this step done for them. Eighty-four percent of the students chose either always, often or sometimes as having the teacher choose the questions to answer. After implementing the labs where students had some choices as to the direction of the lab, the post survey showed that this number, at 87%, hadn't really changed. This means that most students would like the teacher to choose the question to answer. Based on my observations, I believe this is from the sense of frustration about creating procedures that the students felt during many of the labs.

"When I complete a lab, it is very clear how it connects to what I am learning in class." Before the implementation of the unit, only 3% reported seldom or never. That leaves 97% of the students choosing always, often or sometimes. After the implementation of the unit, however, that percentage choosing always, often or sometimes went down to 93%. I believe that is due again to the frustration observed during the labs. Many students reported to me that they felt lost or confused by the inquiry labs.

"I am capable of explaining chemical concepts covered in labs to another student." The pre survey revealed that 88% of the students felt that they could always, often or sometimes explain chemical concepts to another student. The post survey revealed that 82% of the students reported always, often or sometimes being able to explain chemical concepts to another student.

The next three questions in the post survey dealt with lab situations. "Doing lab work helps me to learn the concepts covered in class." In the pre survey, 24 % of the students reported always, 49% reported often and 21% reported sometimes. In the post survey, 19% of the student reported always, 55% reported often and 19% reported sometimes. "Completing the lab report helps me learn the concepts." In the post survey, the students 82% of the students reported always, often or sometimes to that statement. In the pre survey, 86% of the students responded as always, often or sometimes. This is a slight decrease from the pre to post survey. "After completing a lab, I find it easy to write the lab report." In the pre survey, 85% of the students responded that it was easy always, often or sometimes. In the post survey, 81% of the students responded in the same way.

The next series of questions aims to reveal how the students prefer to learn concepts in class. "Taking notes in class helps me learn the concepts." A resounding majority of 99% felt taking notes helps to learn concepts always, often or sometimes. In the post survey, this was still confirmed; however, it decreased slightly to 97% responding as always, often or sometimes. "I feel discussing my lab work with other classmates helps me learn the chemical concepts." Ninety-two percent of the students reported in the pre survey that discussing lab work with other students helped always, often or sometimes. In the post test, that increased to 98% responding to always, often or sometimes. This shows an increase toward discussing lab work with other students. "I feel reading about the concept in the textbook after doing the lab helps me learn the chemical concepts." In the pre survey, 56% of the students responded as always, often or sometimes to that statement. In the post survey, 51% responded in the same way. This shows no real difference toward using the book to help learn the concepts. I believe that is attributed to the fact that students know the answer to an inquiry lab will not usually be found in the book. "I feel talking to the teacher about the concept after doing the lab helps me learn the chemical concept." In the pre survey, 97% of the students felt that talking with the teacher after lab always, often or sometimes helps to learn the concepts. In the post survey, only 89% reported that talking to the teacher helps always, often or sometimes. I attribute that decrease to the fact that during this unit I often asked students other questions and did not give the students direct answers to their questions. "I feel writing the lab report helps me learn chemical concepts." In the pre survey, 78% of the students said that completing the lab report helps always, often or sometimes. In the post survey, 82% of the students reported that writing the lab report helps always, often or sometimes.

"I like doing labs where the procedure is up to me to figure out." In the pre survey, 54% responded as always, often or sometimes to figuring out the procedure. In the post survey, 62% reported that they like to figure out the procedure always, often or sometimes. This is an increase toward inquiry type labs.

"I am more involved in the work of labs when an everyday problem must be answered." Students responded in the post survey that 91% felt that they were more involved always, often or sometimes when an everyday problem must be solved. In the pre survey, students responded that only 89% felt they were more involved always, often or sometimes when an everyday problem must be solved, indicating no real change.

"I find it easier to remember concepts that we have covered with lab activities." In the pre survey, 82% responded that is was always, often or sometimes easier to remember the concepts. In the post survey, that increased to 92% responding that it is easier to remember concepts that have been covered with lab activities always, often or sometimes.

Post Survey Lab Ratings

Eighty percent of the students reported on the post-unit survey that *Aqueous Solutions in Stoichiometry* was somewhere between very helpful and somewhat helpful in making sense of stoichiometry concepts. Only 6% rated it as least helpful.

According to student responses on the post-unit survey, 79% of the students rated *Hard Water Testing* as very helpful to somewhat helpful in making sense of stoichiometry concepts. Six percent rated this lab as least helpful in making sense of stoichiometry concepts. A question on the post unit test asked students a similar lab question that was posed in this lab and the previous lab. Students scored an average of 62% for that question on the post test. Looking at these data, I feel the students still cannot translate this knowledge to other situations.

The post-unit survey indicated that 21% of the students rated *It's a Gas, Gas, Gas* lab as very helpful in making sense of the stoichiometry concepts. Thirty one percent rated it fairly helpful and 28% rated it as somewhat helpful.

The *Chemistry of Baking* lab had the second highest percentage of students, rating it as least helpful to a little helpful, which was 25%.

Seventy-three percent of the students rated the *Limiting Reactant and Percent Yield* lab as very helpful to somewhat helpful. This lab had the highest number of students rating it as least helpful, 13%. From my observations, I think the students were overwhelmed by all of the calculations needed from this lab and I think they had a hard time sorting out the limiting reactant information from the percent yield information.

Based on my observations, students felt the *Salt Lab* was the hardest lab of all that we had completed thus far. However, 76% of the students rated this lab as very helpful to somewhat helpful in making sense of the stoichiometry concepts. At the end of the lab period, I asked students if they felt this lab helped them make sense of stoichiometry concepts. Some replies given anonymously were: "Yes, because we had to think much harder and when we go through a longer process to figure a problem then it makes us understand it better because it makes us think" and "It made me understand percent yield because we actually went backwards using it to find out theoretical." When asked how the students felt after solving the problem, some responses were: "I was pumped when we figured it out. It felt great because we had no assistance, we just thought for ourselves" and "Solving this problem made me feel like I had actually learned something worthwhile that actually can be used outside of school." With these responses coupled with the post survey data, I believe this lab was effective in helping students make sense of stoichiometry concepts.

CONCLUSION

My objectives in designing this unit were to improve comprehension in the stoichiometry unit and improve students' critical thinking skills by using inquiry labs. I feel I have met my objectives in this unit by analyzing the students' pre and post test scores which shows growth in overall knowledge of stoichiometric concepts. In the pre and post surveys, students reported growths in areas of learning science by completing lab reports (Questions 7& 13), preferring to do labs where the procedure is unknown (Question 14), being more involved when solving an everyday problem (Question 15) and remembering concepts better that they have covered with a lab activity (Question 16). Additionally, a majority of the labs were rated by 73% of the students as very helpful to somewhat helpful in making sense of stoichiometry concepts.

In previous years of teaching, I have felt that my students were simply going through the motions when it came to stoichiometry problems. This unit was designed to encourage critical thinking and stimulate questions from the students about the concepts by incorporating more inquiry based labs into my curriculum. The unit design included a series of 6 labs and 2 activities to be used in a stoichiometry unit that I developed in 2005. I expected that the labs and activities would foster critical thinking skills and develop more comprehension of stoichiometric concepts.

The biggest challenge in implementing this unit was for me as a teacher not to give answers in lab as students were conducting inquiry activities. The students often were frustrated as I asked them more questions. This is corroborated by the students' response on question 12 of the survey. After the unit was implemented, fewer students responded that talking to the teacher helped learn the concepts always, often or sometimes. Another question in the survey that supports the idea that students were frustrated by inquiry learning was the decrease of students responding always, often or sometimes to the statement that it is clear how lab connects to what we were covering in class.

Another challenge in this unit was the time that the labs required to implement. To make sure that I had enough time to teach this unit, I had to omit two other units that I previously taught. Each lab took at least two to three lab periods. My observations of students, showed that at the beginning of the unit, they were excited about doing lab work. By the end of the unit, they were asking me "Another lab?" Six inquiry based labs over the course of four to six weeks is too many with lecture and practice problems for homework. My students were overwhelmed with doing one to two labs every week.

I would make a few changes in the labs and activities. I would develop the *Mole Ratio Activity* as a teacher led exercise. Most students were not yet comfortable with the visual modeling of equations, thus, it would be better suited as a group activity led by the teacher. That would also alleviate the stress of reaching each group and correcting the same mistakes during the course of the activity. The *Aqueous Solutions in Stoichiometry* lab works well as it is. My observations indicated that the students were guided by each task they needed to complete and they stayed on task during the lab period. I would change the *Hard Water Testing* lab slightly to help students understand the calculation between milligrams of calcium and milligrams of calcium per liter, which was often questioned by students. I think I would leave the *It's a Gas, Gas, Gas* lab unchanged. Students were intrigued by the reaction and the bubbling, which generated interest in the lab, but only 21% rated it as very helpful in understanding stoichiometry. The *Chemistry* *of Baking* lab is beneficial for me to assess the student's abilities to use stoichiometry in the lab. However, I might have the class generate the procedure as a whole group. In this way, students are actively engaged in brainstorming and not just looking at what someone else did. The major problem of this lab was that students not on task could simply look at another group and figure out the procedure. I would change the *Limiting Reactants Activity* to a teacher led group activity and change the structure of the worksheet. Students were still apprehensive about visually modeling the equations, and making it a teacher led activity would ensure students were producing correct visual models. The *Limiting Reactants and Percent Yield* lab needs to be changed. Unfortunately, the reaction I chose did not yield accurate results, and most of the students calculated a percent yield greater than 100%. Performance of this lab may have been responsible for no student growth on assessment II question number seven. Students scored a 70% on both the pre and post test assessment concerning a question about the law of conservation of mass. The last lab in this unit, the *Salt Lab*, will not be changed. From my observations, the lab was challenging for the students, but I think it presented percent yield in a way that textbook problems cannot. I believe that by doing the lab, students had a better understanding of the percent yield concept. This is evidenced by 76% of the students on the post survey stating that the salt lab very helpful to somewhat helpful.

It is harder to determine whether implementing inquiry labs increased students' critical thinking skills. Several questions on both assessments were designed to reveal the students conceptual ideas of a topic. In assessment I, (Appendix CIV), question seven and eight were posed to assess conceptual knowledge about basic stoichiometric relationships. The relevant information required to answer these questions was never directly referenced in class, so increased performance on them would show that the students' conceptual knowledge was increasing. There was a slight increase in the average student score from the pre test to the post test, with question seven increasing from 26% to 37% and question eight increasing from 26% to 36%. This suggests that there is a slight increase in the students' conceptual knowledge. In assessment II, (Appendix CIII), questions four and five were posed to try to assess conceptual knowledge about limiting reactants. Again, relevant content was not directly referenced in class. Performance increased for each question, with question four going from a 37% to a 70%, clearly showing that students have a good grasp on the conceptual knowledge concerning limiting reactants. In question five, which asked students to visually model equations and determine the limiting reactant, the average student score showed an increase from 35% on the pre test to a 58% on the post test. These data show that students are still struggling with visual representations of equations.

When I have taught the stoichiometry unit in the past, using labs with the procedure given, the students have not been able to answer basic questions about labs. For instance, the students could not name precipitates being formed and because the procedure was given, there was no reason for the students to ponder that question. While I was teaching the inquiry unit, I realized that the students were gaining much more in depth knowledge about each process. Because they had to generate the procedure, the students had to critically think about the process of each reaction and had to plan for a specific result. The students also reinforced previous concepts of balancing equations and types of reactions. In the past, students have not been able to identify why one reactant is limiting in a lab situation. When inquiry labs were involved, my students were able to correctly identify the limiting reactant and justify their reasoning. Percent yield calculations were easier for students to understand after doing the inquiry labs. In the past, students completed one lab that involved simple percent yield calculations and were often confused by the concept. By doing in depth inquiry labs using percent yield, the students were forced to critically think about the concept. Overall, in comparing previous years to this year, I feel the students' critical thinking skills in lab have improved.

Based on all the data presented in the pre and post test assessments and the pre and post surveys, I believe that by implementing the unit using inquiry labs, students' comprehension in stoichiometry and students' critical thinking skills improved. Therefore, developing and implementing this unit was a worthwhile endeavor. I believe there is still room for improvement of the unit, as noted above, but that my objective in creating this unit was achieved.

APPENDIX A
CONSENT-ASSENT FORM

Improving Student Comprehension in Chemistry Laboratories

Parental Consent and Student Assent Document
Collection of Data for Thesis Work

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education (DSME). I have chosen to do my thesis work on increasing student comprehension in chemistry through inquiry learning. Students will generate their own questions to study in lab about a particular topic, actively participate in that study on that topic, and formulate conclusions with evidence to support with their peers. My study will focus on a unit that I have developed dealing with stoichiometry. Stoichiometry is the branch of chemistry that deals with the mass relationships of elements in compounds and the mass relationships between reactants and products in chemical reactions.

In order to complete the thesis work, I need to examine information that is generated by the students, such as pre and post-tests, quizzes, lab questions and surveys concerning the effectiveness of the unit. The data that are generated shall remain confidential. Privacy for your child will be a foremost concern. Your child's identity will not be attached to the data used in my thesis paper, nor will they be identified in any images that are used in the thesis presentation. Your child's privacy will be protected to the maximum extent allowable by the law.

Participation in this study is voluntary. Beyond your child's normal classroom activities, approximately 5 – 10 minutes per class period is needed to complete his/her study participation. Your student will receive no penalty in regard to his/her grade should you deny permission for the use of his/her data. Your student will still be expected to participate in the classroom activities and complete assignments. However, your student's data will not be used in my thesis work. At any time during the unit, you may request that your student's information not be included, and your request will be honored.

If you are willing to have your student participate in this study, please complete the attached form and return it to me by October 1st, 2005. If you have any questions about the study, please feel free to contact me by email at tharoff@marshall.k12.mi.us or by phone at (269) 781-1252. Questions about the thesis project can also be directed to Dr. Merle Heidemann at DSME, 118 N. Kedzie, Michigan State University, East Lansing, MI, 48824, by phone at (517) 432-2152, ext 107, or by email at heidema2@msu.edu.

If you have nay questions or concerns regarding your rights as a study participant, you may contact Peter Vasilenko, Ph.D., Chair of the University Committee on Research Involving Human Subjects (UCHRIS) by phone, (517) 355-2180; fax, (517) 432-4503; email, uchris@msu.edu or mail, 202 Olds Hall, East Lansing, MI, 48824.

Thank you,

Tracy Haroff
Chemistry Teacher
Marshall High School
tharoff@marshall.k12.mi.us
(269) 781-1252

I voluntarily agree to have ____________________________________ participate in this study.
(Print student name)

Please check all that apply:

Data:

_______ I give Mrs. Haroff permission to use data generated from my student's work in this class. All data from my child shall remain confidential.

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

Image:

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

_______ I do not wish to have m student's image used at any time during this thesis project.

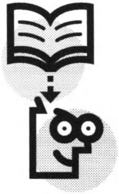
____ ________________
(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ ________________
(Student Signature) (Date)

APPENDIX BI

PRE SURVEY



Pre-Survey

Please answer honestly about your experiences in this classroom. Please respond to each question thinking about the last month of class.

Always is defined as 100% of the labs.
Often is defined as 75% of the labs.
Sometimes is defined as 50% of the labs.
Seldom is defined as 25% of the labs.
Never is defined as 0% of the labs.

1. My group or class chooses what questions to answer in lab.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

2. I would like my group or class to choose the questions to answer in lab for every lab.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

3. I would like the teacher to choose the questions to answer for every lab.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

4. When I complete a lab, it is very clear how it connects to what I am learning in class.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

5. I am capable of explaining chemical concepts covered in labs to another student.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

6. Doing lab work helps me to learn the concepts covered in class.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

7. Completing the lab report helps me learn the concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

8. After completing a lab, I find it easy to write the lab report.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

9. Taking notes in class helps me learn the concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

10. I feel discussing my lab work with other classmates helps me learn the chemical concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

11. I feel reading about the concept in the textbook after doing the lab helps me learn the chemical concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

12. I feel talking to the teacher about the concept after doing the lab helps me learn the chemical concept.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

13. I feel writing the lab report helps me learn chemical concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

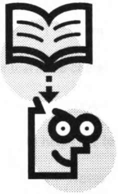
14. I like doing labs where the procedure is up to me to figure out.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

15. I am more involved in the work of labs when an everyday problem must be solved.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

16. I find it easier to remember concepts that we have covered with lab activities.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

APPENDIX BII

POST SURVEY



Post-Survey

Please answer honestly about your experiences in this classroom. Please respond to each question thinking about the last month of class.

Always is defined as 100% of the labs.
Often is defined as 75% of the labs.
Sometimes is defined as 50% of the labs.
Seldom is defined as 25% of the labs.
Never is defined as 0% of the labs.

1. My group or class chooses what questions to answer in lab.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

2. I would like my group or class to choose the questions to answer in lab for every lab.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

3. I would like the teacher to choose the questions to answer for every lab.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

4. When I complete a lab, it is very clear how it connects to what I am learning in class.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

5. I am capable of explaining chemical concepts covered in labs to another student.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

6. Doing lab work helps me to learn the concepts covered in class.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

7. Completing the lab report helps me learn the concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

8. After completing a lab, I find it easy to write the lab report.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

9. Taking notes in class helps me learn the concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

10. I feel discussing my lab work with other classmates helps me learn the chemical concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

11. I feel reading about the concept in the textbook after doing the lab helps me learn the chemical concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

12. I feel talking to the teacher about the concept after doing the lab helps me learn the chemical concept.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

13. I feel writing the lab report helps me learn chemical concepts.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

14. I like doing labs where the procedure is up to me to figure out.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

15. I am more involved in the work of labs when an everyday problem must be solved.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

16. I find it easier to remember concepts that we have covered with lab activities.
5 – Always 4 – Often 3 – Sometimes 2 – Seldom 1 – Never

17. Please rate each lab below:
Rank these labs 1-5, 1 being the most helpful and 5 being the least helpful, on how well each lab helped you make sense of the concepts of stoichiometry. Please feel free to look through your lab book if you do not remember what each lab was about.

Stoichiometry of Aqueous Solutions	1	2	3	4	5
Hard Water Testing	1	2	3	4	5
It's a gas, gas, gas!	1	2	3	4	5
Chemistry of Baking	1	2	3	4	5
Limiting Reactants and Percent Yield	1	2	3	4	5

Salt Lab	1	2	3	4	5

19. Please give me your honest opinion on how you like the structure (designing procedure, working with the whole class and partners, etc) of the labs in this unit.

Appendix CI
Stoichiometry and Density Pre Test

Knowledge Survey

Name: ______________________________________ Block:_________

Directions: Answer all questions to the best of your ability. Remember to show all work and include units where appropriate.

1. A mole ratio is to reactants and products as a bridge is to two islands. Therefore, how are the mole ratios and the reactants and products related? Explain your answer.

2. What are all the mole ratios for the following reaction?

$$H_2 + Cl_2 \rightarrow 2HCl$$

3. If I change the amount of hydrogen to 4.5 moles in the above reaction, how would the moles of chlorine and hydrogen chloride change?

4. Consider the following problem:
   If a reaction between 10 grams of magnesium and excess hydrogen phosphate occurs, how much hydrogen will be produced?
   a. What would be your first step in solving this problem?

   b. Solve the problem.

5. Consider the following reaction:

$$CaSO_4 + 2LiOH \rightarrow Ca(OH)_2 + Li_2SO_4$$

a. If 25 grams of calcium sulfate is reacted, how many moles of lithium sulfate are produced?

Chemical	Molar Mass
$CaSO_4$	136.2 g
LiOH	23.9 g
$Ca(OH)_2$	74.1 g
Li_2SO_4	109.9 g

b. If 43.2 moles of lithium hydroxide are used, how many grams of calcium sulfate are needed?

6. Consider this equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

What is the volume of carbon dioxide produced when we react 16 mL of oxygen? (The density of oxygen is 1.429 g/L and the density of carbon dioxide is 1.997 g/L.)

Chemical	Molar Mass
$C_6H_{12}O_6$	180.0 g
O_2	32.0 g
CO_2	44.0 g
H_2O	18.0 g

7. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that in relation to the nail, the rust weighs____.
(Fill in the blank with a phrase.) Explain your answer.

8. Al atoms weigh about one-half of Ni atoms:
For a complete reaction (Ni + Al ---> NiAl), roughly what mass ratio of Al to Ni should be used? Explain your answer.

9. Explain how you could determine the amount of nitrate ions in a water sample.

10. Describe the procedure you might use to determine the amount of reactants that are needed to be used to produce enough gas to fill an airbag.

11. What do you need to know about moles to determine the outcome of chemical reactions?

Appendix CII
Stoichiometry and Density Post Test

Knowledge Survey

Name: ____________________________________ Block:_________

Directions: Answer all questions to the best of your ability. Remember to show all work and include units where appropriate.

1. A mole ratio is to reactants and products as a bridge is to two islands. Therefore, how are the mole ratios and the reactants and products related? Explain your answer.

2. What are all the mole ratios for the following reaction?

$$H_2 + Cl_2 \rightarrow 2HCl$$

3. If I change the amount of hydrogen to 10.5 moles in the above reaction, how would the moles of chlorine and hydrogen chloride change?

4. Consider the following problem:
   If a reaction between 24.3 grams of magnesium and excess hydrogen phosphate occurs, how much hydrogen will be produced?
   a. What would be your first step in solving this problem?

   b. Solve the problem.

5. Consider the following reaction:

$$CaSO_4 + 2LiOH \rightarrow Ca(OH)_2 + Li_2SO_4$$

a. If 25 grams of calcium sulfate is reacted, how many moles of lithium sulfate are produced?

b. If 24.2 moles of lithium hydroxide are used, how many grams of calcium sulfate are needed?

6. Consider this equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

What is the volume of carbon dioxide produced when we react 2.5 L of oxygen? (The density of oxygen is 1.429 g/L and the density of carbon dioxide is 1.997 g/L.)

7. How many grams of oxygen are needed to produce 3.4 liter of water? (The density of water is 1.00g/mL)

8. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that in relation to the nail, the rust weighs____.
(Fill in the blank with a phrase.) Explain your answer.

9. Al atoms weigh about one-half of Ni atoms:
For a complete reaction (Ni + Al ---> NiAl), roughly what mass ratio of Al to Ni should be used? Explain your answer.

10. Explain how you could determine the amount of nitrate ions in a water sample.

11. Describe the procedure you might use to determine the amount of reactants that are needed to be used to produce enough gas to fill an airbag.

12. What do you need to know about moles to determine the outcome of chemical reactions?

13. What do you need to solve any stoichiometry problem?

14. Consider the following equation:

Potassium iodide + silver (I) bromide → silver (I) iodide + potassium bromide

a. If 54.8 moles of potassium iodide react with excess silver (I) bromide, how much silver (I) iodide in grams is produced?

b. If 35.4 grams of potassium bromide are produced, how many grams of silver (I) bromide reacted?

15. Consider the following equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

(The density of oxygen is 1.429 g/L and the density of hydrogen is 0.0899 g/L)

a. How many liters of oxygen gas are needed to make 97 grams of water?

b. How many grams of water will be produced if 3.5 liters of hydrogen gas is used?

APPENDIX CIII
STOICHIOMETRY AND DENSITY RUBRIC

Knowledge Survey

Name: ____ Block:_________

Directions: Answer all questions to the best of your ability. Remember to show all work and include units where appropriate.

1. A mole ratio is to reactants and products as a bridge is to two islands. Therefore, how are the mole ratios and the reactants and products related? Explain your answer.
   One point - mole ratio links reactants and products
   Two points – mole ratio links reactants and products and concept that mole ratio compares reactant/product
   Three points - mole ratio links reactants and products and concept that mole ratio compares reactant/product and from there gram amounts, atom amounts, etc can be figured out
2. What are all the mole ratios for the following reaction?
   $$H_2 + Cl_2 \rightarrow 2HCl$$
   One point – one correct mole ratio
   Two points – two correct mole ratios
   Three points – three correct mole ratios

3. If I change the amount of hydrogen to 4.5 moles in the above reaction, how would the moles of chlorine and hydrogen chloride change?
   One point – one correct answer
   Two points – two correct answers

4. Consider the following problem:
   If a reaction between 10 grams of magnesium and excess hydrogen phosphate occurs, how much hydrogen will be produced in grams?
   a. What would be your first step in solving this problem?
   One point – writing balanced equation

   b. Solve this problem.
   One point - each step - 5 points total

5. Consider the following reaction:

$$CaSO_4 + 2LiOH \rightarrow Ca(OH)_2 + Li_2SO_4$$

a. If 25 grams of calcium sulfate is reacted, how many moles of lithium sulfate are produced?

Chemical	Molar Mass
$CaSO_4$	136.2 g
LiOH	23.9 g
$Ca(OH)_2$	74.1 g
Li_2SO_4	109.9 g

One point for each conversion factor – 4 points total

b. If 43.2 moles of lithium hydroxide are used, how many grams of calcium sulfate are needed?

One point for each conversion factor – 4 points total

6. Consider this equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

What is the volume of carbon dioxide produced when we react 16 mL of oxygen? (The density of oxygen is 1.429 g/L and the density of carbon dioxide is 1.997 g/L.)

Chemical	Molar Mass
$C_6H_{12}O_6$	180.0 g
O_2	32.0 g
CO_2	44.0 g
H_2O	18.0 g

One point for each conversion factor – 6 points total

7. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that in relation to the nail, the rust weighs____.
   (Fill in the blank with a phrase.) Explain your answer.
   0 – incorrect or no answer
   1 – correct fill in the blank answer with beginning explanation
   2 – correct fill in the blank answer with full explanation

8. Al atoms weigh about one-half of Ni atoms:
   For a complete reaction (Ni + Al ---> NiAl), roughly what mass ratio of Al to Ni should be used? Explain your answer.
   0 – incorrect or no answer
   1 – correct answer with beginning explanation
   2 – correct answer with full explanation

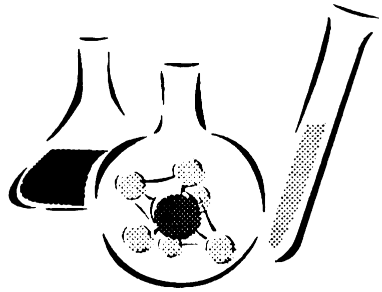
9. Explain how you could determine the amount of nitrate ions in a water sample.
   0 – no explanation or mostly incorrect
   1 – beginning explanation, some incorrect ideas
   2 – good explanation, with some correct lab ideas
   3 – full explanation, all correct lab ideas

10. Describe the procedure you might use to determine the amount of reactants that are needed to be used to produce enough gas to fill an airbag.
   0 – no explanation or mostly incorrect
   1 – beginning explanation, some incorrect ideas
   2 – good explanation, with some correct lab ideas
   3 – full explanation, all correct lab ideas

11. What do you need to know about moles to determine the outcome of chemical reactions?

   0 – no explanation or mostly incorrect
   1 – beginning explanation, some incorrect ideas
   2 – good explanation, with some correct lab ideas
   3 – full explanation, all correct lab ideas

APPENDIX CIV
LIMITING REACTANTS & PERCENT YIELD PRE TEST

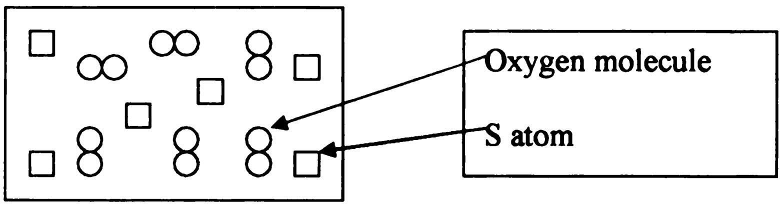


Knowledge Survey

Name: ______________________________ Block:________

Directions: Answer all questions to the best of your ability. Remember to show all work and include units where appropriate.

1. The diagram represents a mixture of S atoms and O_2 molecules in a closed container.



Draw a diagram that shows the results after the mixture reacts as completely as possible according to the equation:

$$2S + 3O_2 \rightarrow 2SO_3$$

Identify the limiting and excess reactants.

2. If 4.1 grams of Cr is heated with 9.3 grams of Cl_2, what mass $CrCl_3$ will be produced?

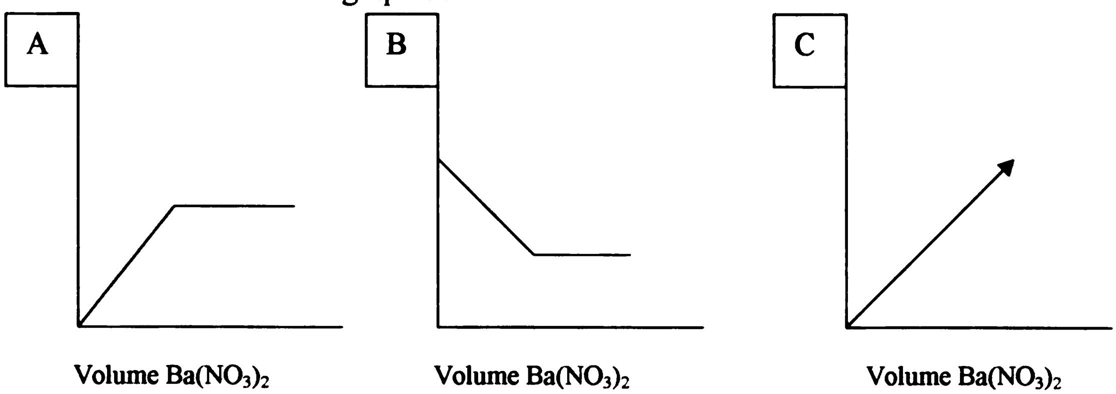
Chemical	Molar Mass
Cr	52.0 g
Cl_2	72 g
$CrCl_3$	158.5 g

3. If 3.5 grams of zinc and 3.5 grams of sulfur are mixed together, what is the limiting reactant and what is the excess reactant?

$Zn + S \rightarrow ZnS$

Chemical	Molar Mass
Zn	65.4 g
S	32.1 g
ZnS	97.5 g

4. A solution of $Ba(NO_3)_2$ is added to a solution of Na_2SO_4 to make a precipitate, barium sulfate and aqueous sodium nitrate. The amount of precipitate collected from the fixed amount of Na_2SO_4 solution as the $Ba(NO_3)_2$ is added indefinitely will look like which graph below?



Explain what graph you chose and why.

5. Which is the limiting reactant when 9 Ca atoms and 8 H_3PO_4 molecules react and produce 3 molecules of $Ca_3(PO_4)_2$ and 9 molecules of H_2? Explain your answer.

6. For the following reaction, $Mg + 2AgCl \rightarrow MgCl_2 + 2Ag$, 25 grams of silver chloride was used with an excess of magnesium. If silver chloride is 75% silver, what is the most silver that could be produced?

Chemical	Molar Mass
Mg	24.3 g
AgCl	143.35 g
$MgCl_2$	95.3 g
Ag	107.9 g

7. In a reaction, will the products ever have more mass than the reactants? Explain.

8. A piece of copper with a mass of 5.00 grams is placed in a solution of silver (I) nitrate. The percent yield of silver was 89.4%. How much silver metal was produced?

$$Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$$

Chemical	Molar Mass
Cu	63.5 g
$AgNO_3$	169.9 g
$Cu(NO_3)_2$	187.5 g
Ag	107.9 g

9. If 20 grams of sodium metal and 40 grams of oxygen react, how many total grams of product would you expect if you had 80% yield for the reaction? Explain.

10. In determining a limiting reactant for a specific reaction, what beginning questions should be answered?

11. Is percent yield of a reaction affected by the amount of reactants? Explain.

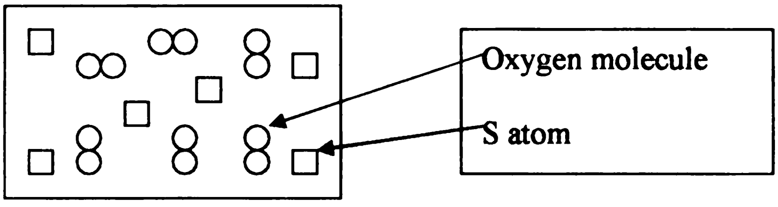
APPENDIX CV
LIMITING REACTANTS & PERCENT YIELD POST TEST

Knowledge Survey

Name: ______________________________ Block:________

Directions: Answer all questions to the best of your ability. Remember to show all work and include units where appropriate.

1. The diagram represents a mixture of S atoms and O_2 molecules in a closed container.



Draw a diagram that shows the results after the mixture reacts as completely as possible according to the equation:

$$2S + 3O_2 \rightarrow 2SO_3$$

Identify the limiting and excess reactants.

2. If 4.1 grams of Cr is heated with 9.3 grams of Cl_2, what mass $CrCl_3$ will be produced?

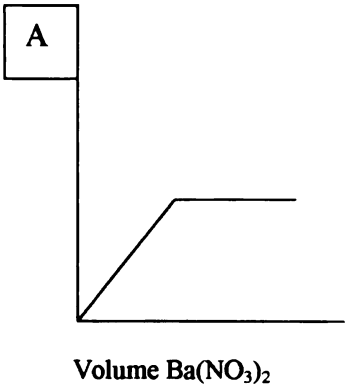
Chemical	Molar Mass
Cr	52.0 g
Cl_2	72 g
$CrCl_3$	158.5 g

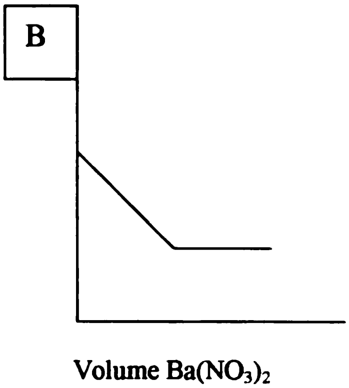
3. If 3.5 grams of zinc and 3.5 grams of sulfur are mixed together, what is the limiting reactant and what is the excess reactant?

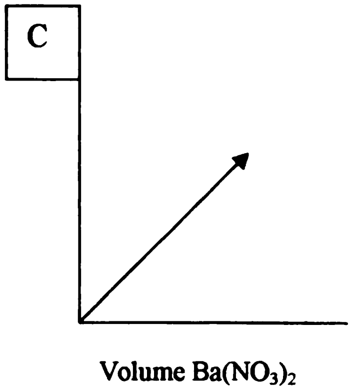
$Zn + S \rightarrow ZnS$

Chemical	Molar Mass
Zn	65.4 g
S	32.1 g
ZnS	97.5 g

4. A solution of $Ba(NO_3)_2$ is added to a solution of Na_2SO_4 to make a precipitate, barium sulfate and aqueous sodium nitrate. The amount of precipitate collected from the fixed amount of Na_2SO_4 solution as the $Ba(NO_3)_2$ is added indefinitely will look like which graph below?







Explain what graph you chose and why.

5. Which is the limiting reactant when 9 Ca atoms and 8 H_3PO_4 molecules react and produce 3 molecules of $Ca_3(PO_4)_2$ and 9 molecules of H_2? Explain your answer.

6. For the following reaction, $Mg + 2AgCl \rightarrow MgCl_2 + 2Ag$, 25 grams of silver chloride was used with an excess of magnesium. If silver chloride is 75% silver, what is the most silver that could be produced?

Chemical	Molar Mass
Mg	24.3 g
AgCl	143.35 g
$MgCl_2$	95.3 g
Ag	107.9 g

7. In a reaction, will the products ever have more mass than the reactants? Explain.

8. A piece of copper with a mass of 5.00 grams is placed in a solution of silver (I) nitrate. The percent yield of silver was 89.4%. How much silver metal was produced?

$$Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$$

Chemical	Molar Mass
Cu	63.5 g
$AgNO_3$	169.9 g
$Cu(NO_3)_2$	187.5 g
Ag	107.9 g

9. If 20 grams of sodium metal and 40 grams of oxygen react, how many total grams of product would you expect if you had 80% yield for the reaction? Explain.

10. In determining a limiting reactant for a specific reaction, what beginning questions should be answered?

11. Is percent yield of a reaction affected by the amount of reactants? Explain.

APPENDIX CVI
LIMITING REACTANTS & PERCENT YIELD RUBRIC

Knowledge Survey

Name: ________________________________ Block:_________

Directions: Answer all questions to the best of your ability. Remember to show all work and include units where appropriate.

1. The diagram represents a mixture of S atoms and O_2 molecules in a closed container.

Draw a diagram that shows the results after the mixture reacts as completely as possible according to the equation:

$$2S + 3O_2 \rightarrow 2SO_3$$

Identify the limiting and excess reactants.

2 points for correct picture
2 points for correct answers for limiting and excess

2. If 4.1 grams of Cr is heated with 9.3 grams of Cl_2, what mass $CrCl_3$ will be produced?

Chemical	Molar Mass
Cr	52.0 g
Cl_2	72 g
$CrCl_3$	158.5 g

1 point – balanced equation; 1 point for each conversion factor – 6 points total

3. If 3.5 grams of zinc and 3.5 grams of sulfur are mixed together, what is the limiting reactant and what is the excess reactant?

$Zn + S \rightarrow ZnS$

Chemical	Molar Mass
Zn	65.4 g
S	32.1 g
ZnS	97.5 g

1 point – each conversion; 2 points for correct limiting and excess reactant – 7 total

4. A solution of $Ba(NO_3)_2$ is added to a solution of Na_2SO_4 to make a precipitate, barium sulfate and aqueous sodium nitrate. The amount of precipitate collected from the fixed amount of Na_2SO_4 solution as the $Ba(NO_3)_2$ is added indefinitely will look like which graph below?

Explain what graph you chose and why.

1 point for identifying limiting reactant; 2 points for correct explanantion

5. Which is the limiting reactant when 9 Ca atoms and 8 H_3PO_4 molecules react and produce 3 molecules of $Ca_3(PO_4)_2$ and 9 molecules of H_2? Explain your answer.

1 point for balanced equation and 2 points for limiting reactant

6. For the following reaction, $Mg + 2AgCl \rightarrow MgCl_2 + 2Ag$, 25 grams of silver chloride was used with an excess of magnesium. If silver chloride is 75% silver, what is the most silver that could be produced?

Chemical	Molar Mass
Mg	24.3 g
AgCl	143.35 g
$MgCl_2$	95.3 g
Ag	107.9 g

2 points – correct % Ag; 1 point – correct answer

7. In a reaction, will the products ever have more mass than the reactants? Explain.

2 points – correct explanation

8. A piece of copper with a mass of 5.00 grams is placed in a solution of silver (I) nitrate. The percent yield of silver was 89.4%. How much silver metal was produced?

$$Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$$

Chemical	Molar Mass
Cu	63.5 g
$AgNO_3$	169.9 g
$Cu(NO_3)_2$	187.5 g
Ag	107.9 g

1 point for each conversion factor; 1 point for correct % error calculation – 6 points total

9. If 20 grams of sodium metal and 40 grams of oxygen react, how many total grams of product would you expect if you had 80% yield for the reaction? Explain.

1 point – balanced equation
1 point for each conversion factor – 8 total

10. In determining a limiting reactant for a specific reaction, what beginning questions should be answered?

1 point – balanced equation

11. Is percent yield of a reaction affected by the amount of reactants? Explain.
2 points – correct explanation

APPENDIX DI
MOLE RATIO ACTIVITY

Mole Ratios

Mole ratios are found using the coefficients of the compounds in a formula.
For example:

$$\underline{2}KClO_3(s) \rightarrow \underline{2}KCl(s) + \underline{3}O_2(g)$$

Using the colored circles, model what this equation represents. Sketch what you have on your desk below:

Now, let's change the number of $KClO_3$ to 4 and model and sketch that equation. Remember to observe the Law of Conservation of Mass! What happens to the number of KCl and O_2? Do you see a relationship? After deciding with your group, explain below.

Change the number of KCl to 1 and model and sketch that equation. What happens to the other numbers of reactants and products? What is the relationship here? Explain.

You have just discovered the basis of mole ratios. From the formula we are using:

$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

For every 2 moles of potassium chlorate used; we will produce 2 moles of potassium chloride and 3 moles of oxygen. If we change one of the numbers, the other numbers in the mole ratio change by that same amount.

We can relate any two reactants or products using mole ratios. For example, we could represent the mole ratio between oxygen and potassium chloride as

$$\frac{2 \text{ moles } KCl}{3 \text{ moles } O_2} \quad \text{or} \quad \frac{3 \text{ moles } O_2}{2 \text{ moles } KCl}$$

Remember, we choose which mole ratio to use by looking at what unit we want canceled.

What are the other mole ratios from this equation?

Identifying mole ratios is the first step in successful solving of stoichiometry problems.

Balance each reaction and identify all the possible mole ratios in the following equations:

$$CH_4 + Cl_2 \rightarrow CCl_4 + HCl$$

$$Fe_2O_3 + Mg \rightarrow MgO + Fe$$

$$AgNO_3 + KI \rightarrow AgI + KNO_3$$

APPENDIX DII
STOICHIOMETRY IN AQUEOUS REACTIONS

Stoichiometry in Aqueous Reactions

You will be given a solution that contains an unknown amount of iron (III) chloride. Through this lab, you will learn how to react the iron (III) chloride with another chemical to produce a precipitate and how to measure the amount of precipitate produced. A solubility table will be utilized to help us identify what compounds will be insoluble in water.

First Task:
Use the given solubility table to answer the following questions in your lab notebook:

1. What does s and i on the table indicate?
2. How do you read the table?
3. Is silver sulfate soluble in water?
4. Is sodium chloride soluble in water?
5. Based on this table, what ions could you react iron (III) chloride with that would produce a precipitate?

Bring your lab notebook to the instructor for a check.

Second Task:
Write the balanced chemical equation between iron (III) chloride and the instructor approved compound from above. Be sure to include states of matter for every compound in the reaction.

Third task:
Start with 5 mL of the unknown sample. To ensure proper results, we must make sure that all of the iron (III) chloride is used up. Mix the two solutions together in a beaker and write down observations in your lab notebook.

Fourth task:
The next step is to filter the precipitate and dry the filter paper. You must always remember to mass the filter paper before starting this step. Be sure to record in your lab notebook. Using the buchner funnel set-up explained by your instructor, carefully filter the solution containing the precipitate. Wash your precipitate with alcohol. Take your

filter paper out of the funnel, label a paper towel and set the filter paper on your labeled paper towel to dry over night.

Fifth task:
Weigh the dry filter paper and determine the mass of the precipitate.

Answer the following questions:

1. What is the formula for the compound on the filter paper?
2. From what compound did the iron (III) ion originate?
3. What ion did it combine with?
4. What is the ratio of iron ions to the compound?

Sixth task:
Now you need to calculate the mass of iron present (in milligrams) in the sample using stoichiometry. You will need to use the ratio of iron ions to the compound in part of your problem. For example, in the formula Na_3PO_4, the ratio of sodium ions to the compound is 3 to 1 because we need 3 sodium ions to cancel the charge of the 1 phosphate ion. We use this ratio just like we use mole ratios. Record all information in your lab notebook like equation used, calculations, etc.

Seventh task:
Write your lab report by making claims and supporting those claims with evidence from the lab. Be sure that you answer your beginning questions thoroughly. Don't forget to consult at least three sources about the lab and what you have learned. Cite these sources at the end of the lab report.

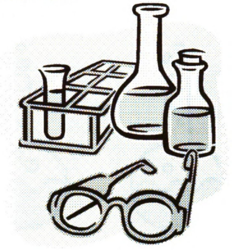
Post Lab Questions (include in your summary):

1. Include how much iron was contained in your unknown sample.
2. What was the ion that reacted with the iron (III) ion?
3. How did you calculate the amount of iron ion in the water?
4. How did you use the solubility table to help you with this lab?
5. Why do you need to be able to write and balance double replacement reactions correctly in this lab?

When you are finished with your lab, be sure to clean up your area and put all equipment and chemicals away.

Begin working on your lab report!

APPENDIX DIII
HARD WATER TESTING



Hard Water Testing

You are working for a company that makes soda water. They need water for the beginning part of the process that has approximately 100 mg of Ca per Liter. Currently, the company is using city water. At this point, they are not sure of the level of calcium in the water.

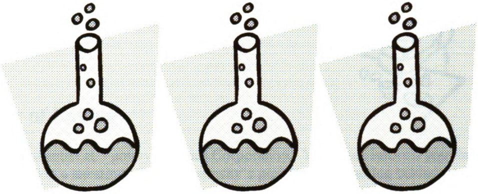
Here is some information to get you started on your project. You can use any one of the following chemicals: sodium nitrate, sodium carbonate or sodium hypochlorite. Standard lab equipment is available to you.

Before completing the lab, you will be required to complete a preliminary lab report that will use the method we have learned. This will help you organize your thoughts before you do the next task. This will be included in your lab notebook just as normal.

After writing your preliminary lab report and finishing the lab, you need to write a letter to the company president that explains your method, any relevant information (reactions, calculations, etc.), the sample's original calcium content and how you might suggest to the company how to correct the calcium content to 100 mg/L. Be sure your data is included in a succinct data table. Be sure to use a correct business letter format and be sure you are writing to the intended audience.

APPENDIX DIV
IT'S A GAS, GAS, GAS

It's a gas, gas, gas!



Some reactions produce gases. We know that it is not very convenient to mass gases (even though all gases have mass). Instead, we use volume most often to quantify gases. In a chemistry lab, gases are usually measured in liters or milliliters. We have learned that we can change from grams to liters and vice versa by using the density. (Density values for common gases are listed in the back of your book.)

In this lab, we will use the reaction between solid magnesium and aqueous hydrochloric acid (hydrogen chloride). It will produce hydrogen gas and aqueous magnesium chloride.

To prepare to collect gas, have the instructor pour the HCl into your tube. Completely fill the tube with water by carefully pouring the water down the side of the tube. Then suspend the magnesium from a string and place the stopper in the tube holding the string so that the magnesium is immersed in the water, but the string hangs over the side of the tube. Cover the hole in the stopper with your finger and invert the tube into the beaker filled with water. Be sure the stopper does not touch the bottom of the beaker, but it should be covered by water. Clamp the tube to the ring stand.

After we have collected the gas, we must read the volume when it is at the same pressure as the atmosphere. To do this, we must carefully transfer the gas collection tube to the large beaker and immerse it until the water level inside the tube is the same as the large beaker. Then you can read the volume.

Your job is to make 10 mL of hydrogen gas.

Post Lab Questions:

1. What are some facts that you must know to complete this lab?
2. Will changing the amount of magnesium change the amount of gas produced? Explain.
3. Could you figure out the answer to this problem without completing the lab? Explain.

APPENDIX DV
CHEMISTRY OF BAKING

Chemistry of Baking

You are a food scientist at Yummy Cookies Corporation. Your boss informs you that you need to develop a substitute for the company's popular single acting baking powder. The supplier of the single acting baking powder has a transportation problem and the baking powder can't be delivered until next month. Unfortunately, the baking powder is to be used in a new cookie recipe that has just started production. The CEO of Yummy Cookies is putting all of her faith in you to develop a substitute for the single acting baking powder. Preliminary data shows that the amount of gas needed for one batch of the new cookie recipe needs to fill a small gas container completely, but without bursting.

Here are the materials that are available to you:
Cream of tartar (potassium hydrogen tartrate, $KHC_4H_4O_6$)
Baking Soda (sodium hydrogen carbonate)
Cornstarch
gas containers (sandwich baggies)
various lab equipment

Technical Data:
Most baking powders are composed of three elements: an acid, a base and filler. The filler is usually cornstarch. The cornstarch keeps the powders dry and it also promotes the flow of the baking powder, however, cornstarch is not included in the overall reaction. Here is the formula that indicates the chemistry of baking powder.

sodium hydrogen carbonate + potassium hydrogen tartrate → potassium sodium tartrate + water + carbon dioxide

Problem:
Develop a recipe for the substitute baking soda that will ensure the proper amount of gas is produced for one batch of cookies.

When you are finished with your lab report, write a memo to the CEO explaining the development and calculations that led you to your recipe. Be sure to include the recipe for the substitute as well.

APPENDIX DVI
LIMITING REACTANTS CONCEPTUAL ACTIVITY

Limiting Reactants Conceptual Activity

You are familiar with using visual models. Now we will use visual models to help us understand the concepts of limiting reactants, excess reactants and the products formed from these reactions.

Each group will get a set of colored circles. Each color will represent a different type of atom in each problem. For each problem:

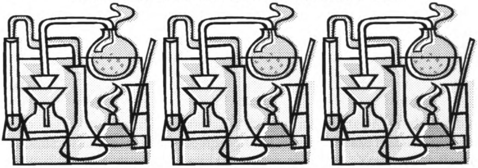
1. Write out the balanced formula equation.
2. Construct the correct number of molecules for the reactants given using the colored circles. Remember, if the reactant has more than one atom in it, the circles should overlap slightly to indicate a bond.
3. Sketch what you have before going to the next step. Be sure to indicate type of molecule.
4. Using only the given number of molecules, construct the product molecules.
5. Sketch the product molecules.
6. Answer the following questions for each problem:
    a. What happens to the bonds when reactants form products?
    b. What is the limiting reactant?
    c. What is the excess reactant? How much do you have left over?
    d. How many product molecules did you produce?
    e. What is the relationship between the number of molecules used in the reaction to the mole ratios in the equation?

Problem #1
Hydrogen plus oxygen yields water.
5 molecules of hydrogen react with 2 molecules of oxygen.

Problem #2
Aluminum plus chlorine yields aluminum chloride.
6 atoms of aluminum react with 10 molecules of chlorine.

Problem #3
Magnesium + iodine yields magnesium iodide.
1 atom of magnesium reacts with 1 molecule of iodine.

APPENDIX DVII
LIMITING REACTANTS & PERCENT YIELD



Limiting Reactants and Percent Yield

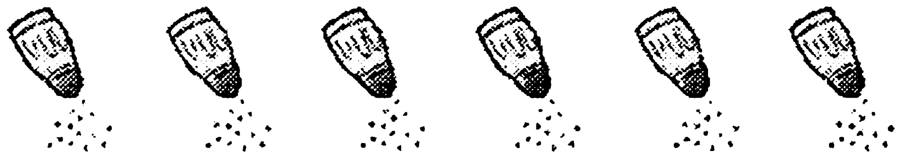
Our chemicals that we are using today are aqueous hydrogen acetate (1mL = .05 g) and solid sodium hydrogen carbonate. When reacted together, they form carbon dioxide gas, aqueous sodium acetate and water. You must make 0.5 grams of sodium acetate.

Protocol:

1. Obtain an evaporating dish and wash it. With the Bunsen burner, dry the evaporating dish for 5 minutes in the strongest part of the flame. This ensures all the water has evaporated before massing the dish.
2. Allow the dish to cool for 3 minutes and mass the dish. Record.
3. Add the sodium hydrogen carbonate to the evaporating dish and mass. Record.
4. Obtain the hydrogen acetate. Slowly add this to the dish. Do not let the solution bubble over. Stir to ensure proper mixing.
5. After the bubbling has stopped, heat the evaporating dish gently, not allowing the liquid to splash out of the dish. You should continue heating until all water has been evaporated.
6. Cool the dish for 5 minutes.
7. Mass the dish. Record. Save the product for instructor's approval.

In a paragraph, explain your results. You must include the reaction, how much of each reactant used, the limiting reactant, the theoretical yield, the actual yield and the percent yield in your summary. Include all calculations used to find all information.

APPENDIX DVIII
SALT LAB



Salt Lab

Recently, you have been hired by a company that has just started to produce table salt, sodium chloride. The process your company uses is an acid-base reaction that combines sodium hydroxide and hydrochloric acid (hydrogen chloride). You need to figure out the protocol for making 1 ton (907,185 grams) of sodium chloride accounting for percent error and provide this to the technicians.

Your first task has been done for you by a colleague. She has the equation, the amounts of reactants, and the protocol. She has given you a copy of her data.

Be sure to keep your calculations and notes neat and accurate, because our manager wants to look at your results before approving large scale operation. Your manager would also like a memo explaining the process and the results of your investigation.

8-24-05
K. Fondren

Experiment 1:

$$NaOH + HCl \rightarrow H_2O + NaCl$$

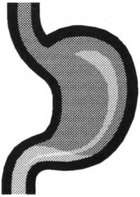
Preliminary calculations:

0.1 grams sodium hydroxide
4 mL of hydrochloric acid (each milliliter contains 0.03645 g)

I obtained a watchglass and wrote my name on the edge of the watchglass with the grease pencil. I made sure it was clean and completely dry. I massed the watchglass and recorded. I placed 0.1 grams of sodium hydroxide on the watchglass (approximately 1 small pellet). Using a pipette, I dropped exactly 3 mL of the hydrochloric acid onto the pellet. I made sure all of the sodium hydroxide dissolved by stirring with a toothpick. I carefully carried the watchglass to the hood to evaporate overnight.

Data
Trial 1 – 0.113 grams
Trial 2 – 0.105 grams
Trial 3 – 0.100 grams

APPENDIX DIX
OH, MY STOMACH!



Oh, my stomach!

What happens when you take an Alka-Seltzer® tablet?

You will receive the following as materials:
- Balloon
- String
- Alka-Seltzer® tablet
- Water
- Beakers
- Balances
- Rulers

Here is the equation:

$$3NaHCO_3\ (s) + H_3C_6H_5O_7\ (s) \rightarrow Na_3C_6H_5O_7\ (aq) + 3H_2O\ (l) + 3CO_2\ (g)$$

You need to determine amount of gas that is produced, find the limiting reactant, calculate the theoretical value of carbon dioxide gas and compare it to the experimental value using percent yield.

You may complete more than one trial if you time permits. See me for more tablets. Good Luck!

APPENDIX EI

STUDENTS' STOICHIOMETRY DENSITY PRE AND POST TEST SCORES

Student #	Pre Unit Score	Post Unit Score	Student #	Pre Unit Score	Post Unit Score
1	10%	93%	36	27%	95%
2	20%	88%	37	22%	85%
3	0%	71%	38	7%	71%
4	0%		39	17%	85%
5	12%	76%	40	24%	80%
6	24%	68%	41	12%	24%
7	34%	85%	42	22%	61%
8	22%	68%	43	22%	63%
9	37%	88%	44	2%	56%
10	20%	66%	45	5%	39%
11	37%	66%	46	24%	76%
12	20%	73%	47	22%	100%
13	27%	95%	48	17%	68%
14	2%	68%	49	20%	88%
15	5%	61%	50	22%	88%
16	29%	76%	51	12%	63%
17	2%	44%	52	32%	59%
18	20%	83%	53	7%	90%
19	20%	88%	54	10%	66%
20	22%	93%	55	5%	80%
21	10%	80%	56	27%	93%
22	12%	37%	57	24%	90%
23	37%	90%	58	2%	71%
24		51%	59	22%	88%
25	17%	90%	60	32%	90%
26	15%	95%	61	20%	80%
27	17%	78%	62	10%	85%
28	20%	88%	63	7%	85%
29	24%	66%	64	12%	78%
30	17%	88%	65	10%	32%
31	27%	73%	66	17%	90%
32	12%	80%	67	10%	56%
33	17%	59%	68	12%	71%
34	10%	61%	69	15%	85%
35	15%	78%	70	12%	66%

APPENDIX EI

STUDENTS' STOICHIOMETRY DENSITY PRE AND POST TEST SCORES

Student #	Pre Unit Score	Post Unit Score
71	49%	76%
72	24%	93%
73		46%
74	32%	85%
75	22%	95%
76	20%	61%
77	37%	88%
78	10%	59%
79	2%	

APPENDIX EII

STUDENTS' LIMITING REACTANT PERCENT YIELD PRE TEST AND POST TEST SCORES

Student #	Pre Unit Score	Post Unit Score	Student #	Pre Unit Score	Post Unit Score
1	20%	90%	36	29%	93%
2	37%	78%	37	24%	100%
3	27%	71%	38	15%	49%
4	0%		39	17%	73%
5	15%	88%	40	22%	98%
6	17%	80%	41	0%	61%
7	20%	61%	42	15%	61%
8	0%	34%	43	29%	56%
9	29%	78%	44		49%
10	20%	66%	45	2%	56%
11	17%	49%	46	32%	78%
12	2%	49%	47	2%	83%
13	34%	78%	48	12%	66%
14	0%	73%	49	7%	61%
15	10%	90%	50	32%	71%
16	10%	54%	51	10%	68%
17	10%		52	29%	88%
18	17%	61%	53	2%	56%
19	5%	68%	54	27%	68%
20	29%	68%	55	22%	71%
21	0%	56%	56	34%	80%
22	5%	20%	57	24%	59%
23	46%	80%	58	5%	73%
24	24%	27%	59	17%	78%
25	20%		60	46%	80%
26	29%		61	20%	59%
27	7%	73%	62	20%	76%
28	27%	59%	63	10%	63%
29	2%	54%	64	22%	73%
30	22%	98%	65	12%	49%
31	12%	85%	66	22%	78%
32	10%	66%	67	17%	51%
33	10%	56%	68	12%	73%
34	10%	41%	69	73%	88%
35	17%	73%	70	24%	46%

APPENDIX EII

STUDENTS' LIMITING REACTANT PERCENT YIELD PRE TEST AND POST TEST SCORES

Student #	Pre Unit Score	Post Unit Score
71	7%	51%
72	51%	100%
73	2%	46%
74	10%	61%
75	22%	78%
76	20%	73%
77	20%	71%
78	24%	46%
79		

APPENDIX EIII
INDIVIDUAL STUDENTS' STOICHIOMETRY DENSITY PRE TEST SCORES FOR EACH QUESTION

Student #	#1	#2	#3	#4a	#4b	#5a	#5b	#6	#7	#8	#9	#10	#11	Score
	3	3	2	1	5	4	4	6	2	2	3	3	3	41
1	2	0	2	0	0	0	0	0	0	0	0	0	0	4
2	1	1	0	1	0	0	0	0	0	2	1	1	1	8
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	2	0	0	0	0	0	0	2	0	0	0	1	5
6	1	3	2	1	0	0	0	0	2	0	0	1	0	10
7	2	3	2	0	2	2	0	0	0	0	0	0	3	14
8	1	1	2	0	0	2	1	0	0	2	0	0	0	9
9	1	2	0	0	0	2	0	0	0	2	2	3	3	15
10	0	2	0	1	0	2	1	0	2	0	0	0	0	8
11	2	3	2	0	1	2	4	1	0	0	0	0	0	15
12	0	3	2	0	0	1	0	0	0	0	0	1	1	8
13	0	3	2	1	0	0	0	0	2	2	0	1	0	11
14	1	0	0	0	0	0	0	0	0	0	0	0	0	1
15	1	1	0	0	0	0	0	0	0	0	0	0	0	2
16	1	2	2	1	0	2	1	0	2	0	0	1	0	12
17	0	0	0	0	0	0	0	0	0	0	1	0	0	1
18	1	3	2	1	0	1	0	0	0	0	0	0	0	8
19	1	3	2	1	0	0	1	0	0	0	0	0	0	8
20	1	3	2	1	0	0	0	0	2	0	0	0	0	9
21	1	0	0	1	0	0	0	0	2	0	0	0	0	4
22	1	0	0	0	0	0	0	0	1	2	1	0	0	5
23	1	3	2	1	0	2	0	0	2	2	0	1	1	15
24														
25	1	3	0	1	0	2	0	0	0	0	0	0	0	7
26	1	3	2	0	0	0	0	0	0	0	0	0	0	6
27	0	3	0	1	0	1	1	0	1	0	0	0	0	7
28	1	0	2	1	0	0	0	0	2	0	1	0	1	8
29	1	3	2	0	0	1	1	0	2	0	0	0	0	10

APPENDIX EIII

INDIVIDUAL STUDENTS' STOICHIOMETRY DENSITY PRE TEST SCORES FOR EACH QUESTION

30	1	3	2	0	0	0	0	0	0	0	0	1	0	7
31	1	3	2	0	0	2	1	0	0	2	0	0	0	11
32	1	2	0	0	0	0	0	0	0	1	0	1	0	5
33	1	0	1	1	0	0	1	0	0	0	0	0	3	7
34	0	2	0	0	0	1	1	0	0	0	0	0	0	4
35	0	3	2	0	0	0	0	0	0	0	0	1	0	6
36	2	3	2	0	0	0	0	0	0	0	0	3	1	11
37	1	3	2	1	0	0	0	0	2	0	0	0	0	9
38	1	2	0	0	0	0	0	0	0	0	0	0	0	3
39	2	0	0	0	0	0	0	0	2	1	1	1	0	7
40	0	3	2	1	0	2	1	0	0	1	0	0	0	10
41	2	1	0	0	0	0	0	0	0	1	1	0	0	5
42	0	3	2	0	0	0	0	0	2	2	0	0	0	9
43	2	3	2	1	0	0	0	0	0	0	0	1	0	9
44	0	0	0	0	0	0	0	0	0	1	0	0	0	1
45	0	0	0	0	0	0	0	0	0	2	0	0	0	2
46	2	3	2	0	0	0	0	0	0	0	0	2	1	10
47	2	3	2	1	0	0	0	0	1	0	0	0	0	9
48	2	0	2	0	0	0	0	0	0	2	0	1	0	7
49	0	3	0	0	0	0	0	0	0	2	0	0	3	8
50	2	3	2	1	0	0	0	0	0	0	0	1	0	9
51	0	3	2	0	0	0	0	0	0	0	0	0	0	5
52	1	3	1	0	0	2	0	0	2	2	1	1	0	13
53	0	1	0	0	0	0	0	0	1	0	1	0	0	3
54	1	0	2	0	0	0	1	0	0	0	0	0	0	4
55	0	0	0	1	0	0	0	0	1	0	0	0	0	2
56	1	3	2	0	0	2	0	0	0	0	0	1	2	11
57	1	3	2	0	0	2	1	0	0	0	0	1	0	10
58	1	0	0	0	0	0	0	0	0	0	0	0	0	1
59	1	2	0	1	0	0	0	0	1	2	0	1	1	9
60	1	2	2	0	0	2	1	0	0	0	1	1	3	13

APPENDIX EIII

INDIVIDUAL STUDENTS' STOICHIOMETRY DENSITY PRE TEST SCORES FOR EACH QUESTION

61	1	1	0	1	0	0	0	0	0	2	0	1	2	8
62	1	1	0	1	0	0	0	0	0	0	0	1	0	4
63	1	0	0	0	0	0	0	0	2	0	0	0	0	3
64	2	0	2	1	0	0	0	0	0	0	0	0	0	5
65	1	1	0	0	0	0	0	0	0	0	1	1	0	4
66	2	2	0	0	0	1	1	0	0	0	0	1	0	7
67	1	0	0	0	0	0	0	0	0	0	0	3	0	4
68	0	3	2	0	0	0	0	0	0	0	0	0	0	5
69	0	1	1	1	0	0	0	0	0	0	0	3	0	6
70	0	3	2	0	0	0	0	0	0	0	0	0	0	5
71	1	3	0	1	0	4	4	0	2	2	0	0	3	20
72	1	1	1	1	0	2	1	0	0	0	0	3	0	10
73														
74	0	0	2	0	0	2	2	0	0	2	0	2	3	13
75	1	3	2	0	0	1	0	0	0	0	0	2	0	9
76	1	0	2	1	0	1	1	0	0	2	0	0	0	8
77	1	3	2	0	0	1	1	0	2	1	1	0	3	15
78	0	3	0	1	0	0	0	0	0	0	0	0	0	4
79	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Average Score	0.86	1.75	1.06	0.38	0.04	0.58	0.35	0.01	0.52	0.52	0.17	0.57	0.47	7.29
Average Percent	29%	58%	53%	38%	1%	15%	9%	0%	26%	26%	6%	19%	16%	18%

APPENDIX EIV
INDIVIDUAL STUDENTS' STOICHIOMETRY DENSITY POST TEST SCORES FOR EACH QUESTION

Student #	#1	#2	#3	#4a	#4b	#5a	5b	#6	#7	#8	#9	#10	#11	Score
	3	3	2	1	5	4	4	6	2	2	3	3	3	41
1	3	3	2	1	5	4	4	6	0	2	2	3	3	38
2	1	3	0	0	5	4	4	6	2	2	3	3	3	36
3	1	3	2	1	5	4	2	4	0	2	1	1	3	29
4														
5	2	3	1	1	3	4	4	6	0	0	1	3	3	31
6	3	3	2	1	3	4	2	6	0	0	1	0	3	28
7	3	3	2	1	5	4	4	5	0	0	2	3	3	35
8	1	1	2	1	3	4	4	6	0	2	0	1	3	28
9	3	2	2	1	3	4	4	6	0	2	3	3	3	36
10	3	3	2	0	3	3	3	5	0	0	2	0	3	27
11	3	3	0	1	1	4	4	4	0	2	2	3	0	27
12	3	0	1	1	2	4	4	6	0	0	3	3	3	30
13	3	3	2	1	5	4	4	6	2	0	3	3	3	39
14	3	2	0	0	3	4	4	6	0	0	0	3	3	28
15	1	0	0	1	2	4	4	4	0	0	3	3	3	25
16	3	3	2	1	3	4	4	6	2	0	3	0	0	31
17	1	3	0	1	3	4	3	0	0	0	0	3	0	18
18	1	3	2	1	5	4	4	6	2	0	3	3	0	34
19	3	3	2	1	4	4	4	6	1	2	3	3	0	36
20	3	3	2	1	5	4	4	6	2	2	3	3	0	38
21	3	2	0	1	3	4	4	6	0	2	2	3	3	33
22	1	0	0	1	2	3	2	2	1	2	1	0	0	15
23	3	3	2	1	3	4	4	6	2	2	1	3	3	37
24	0	0	1	1	2	4	4	2	2	0	1	1	3	21
25	3	3	2	1	3	4	4	6	0	2	3	3	3	37
26	3	3	2	1	5	4	4	6	2	0	3	3	3	39
27	1	3	2	1	5	4	4	6	0	2	0	1	3	32
28	3	3	2	1	5	4	4	3	2	0	3	3	3	36
29	3	3	2	1	2	4	2	1	2	0	1	3	3	27

APPENDIX EIV
INDIVIDUAL STUDENTS' STOICHIOMETRY DENSITY POST TEST SCORES FOR EACH QUESTION

30	3	3	2	1	5	4	4	6	0	0	2	3	3	36
31	3	3	2	1	2	4	4	4	0	0	3	1	3	30
32	3	3	2	1	2	4	4	6	2	2	1	0	3	33
33	2	3	0	0	2	4	4	1	2	1	0	2	3	24
34	1	3	1	0	3	4	4	2	0	0	1	3	3	25
35	1	3	2	1	5	4	4	4	0	0	2	3	3	32
36	3	3	2	1	5	4	4	6	0	2	3	3	3	39
37	3	3	2	1	4	4	4	5	0	0	3	3	3	35
38	1	3	0	1	4	4	4	6	0	0	0	3	3	29
39	3	3	2	1	2	4	4	6	2	0	2	3	3	35
40	3	3	2	1	5	4	4	6	0	0	2	0	3	33
41	1	0	0	0	2	2	3	0	2	0	0	0	0	10
42	1	3	2	1	3	3	4	6	0	0	1	1	0	25
43	3	3	2	1	2	4	4	2	0	0	2	0	3	26
44	2	1	0	0	2	4	4	6	0	0	1	0	3	23
45	0	0	2	1	2	3	0	6	0	0	2	0	0	16
46	1	3	2	1	4	4	3	6	0	0	1	3	3	31
47	3	3	2	1	5	4	4	6	2	2	3	3	3	41
48	3	3	2	0	2	4	2	4	0	0	2	3	3	28
49	3	3	1	1	5	4	4	6	0	0	3	3	3	36
50	3	3	1	1	3	4	4	6	0	2	3	3	3	36
51	1	3	2	1	3	4	4	4	0	0	1	3	0	26
52	3	3	2	1	3	4	4	4	0	0	0	0	0	24
53	3	3	2	1	3	4	4	4	2	2	3	3	3	37
54	3	3	2	0	2	4	4	1	0	2	3	0	3	27
55	3	3	2	1	3	4	4	6	0	0	1	3	3	33
56	3	3	2	1	5	4	4	6	2	2	2	3	1	38
57	3	3	2	1	4	4	4	6	2	0	2	3	3	37
58	1	3	0	1	3	4	4	6	2	0	2	0	3	29
59	3	3	2	0	2	4	4	5	2	2	3	3	3	36
60	3	3	2	1	5	4	4	6	0	0	3	3	3	37

APPENDIX EIV
INDIVIDUAL STUDENTS' STOICHIOMETRY DENSITY POST TEST SCORES FOR EACH QUESTION

61	3	3	2	1	3	4	4	4	0	2	1	3	3	33
62	3	2	2	1	4	4	4	6	0	0	3	3	3	35
63	3	3	1	1	3	4	4	6	2	0	2	3	3	35
64	3	3	0	1	3	4	4	6	2	0	0	3	3	32
65	3	3	2	0	1	0	1	0	0	2	0	0	1	13
66	3	3	2	1	4	4	4	6	0	2	2	3	3	37
67	3	3	0	1	3	4	2	6	0	0	1	0	0	23
68	0	3	0	0	3	4	4	6	2	0	3	1	3	29
69	3	3	2	1	3	4	4	6	0	0	3	3	3	35
70	0	3	1	1	3	4	2	6	0	0	1	3	3	27
71	3	3	2	1	2	4	3	4	2	0	2	3	2	31
72	3	3	2	1	5	4	4	6	0	1	3	3	3	38
73	1	2	0	1	1	3	2	1	2	2	1	0	3	19
74	3	3	2	1	3	4	4	4	2	1	2	3	3	35
75	3	3	2	1	5	4	4	6	2	0	3	3	3	39
76	1	0	1	1	5	4	4	6	0	0	2	0	1	25
77	3	3	2	1	4	4	4	6	0	0	3	3	3	36
78	0	3	0	1	2	4	3	2	0	2	1	3	3	24
79														
Average Score	2.30	2.61	1.44	0.84	3.34	3.86	3.62	4.84	0.73	0.71	1.86	2.14	2.40	30.70
Average Percent	77%	87%	72%	84%	67%	96%	91%	81%	36%	36%	62%	71%	80%	75%

APPENDIX EV

INDIVIDUAL STUDENTS' LIMITING REACTANTS PERCENT YIELD PRE TEST SCORES FOR EACH QUESTION

Student #	#1	#1a	#2	#3	#4	#5	#7	#8	#9	#11	Score
	2	2	6	7	3	3	2	6	8	2	41
1	1	0	0	2	3	0	2	0	0	0	8
2	2	1	1	2	3	2	2	0	0	2	15
3	1	0	1	7	0	0	2	0	0	0	11
4	0	0	0	0	0	0	0	0	0	0	0
5	1	0	3	0	0	2	0	0	0	0	6
6	0	0	1	0	0	0	2	4	0	0	7
7	0	0	1	0	3	2	2	0	0	0	8
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	3	3	2	4	0	0	12
10	1	0	0	0	3	2	2	0	0	0	8
11	0	0	0	0	1	0	2	4	0	0	7
12	0	0	1	0	0	0	0	0	0	0	1
13	2	2	0	2	3	3	2	0	0	0	14
14	0	0	0	0	0	0	0	0	0	0	0
15	1	0	1	0	0	0	2	0	0	0	4
16	0	0	0	0	0	2	2	0	0	0	4
17	1	0	0	0	0	3	0	0	0	0	4
18	1	0	0	2	0	0	2	0	0	2	7
19	1	0	0	0	0	1	0	0	0	0	2
20	2	2	2	2	3	0	1	0	0	0	12
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	2	0	0	0	0	0	0	2
23	1	0	1	5	3	3	2	4	0	0	19
24	0	0	1	7	0	0	0	2	0	0	10
25	0	0	0	0	3	3	2	0	0	0	8
26	0	0	0	7	0	3	2	0	0	0	12
27	0	0	1	2	0	0	0	0	0	0	3
28	1	0	3	0	0	3	2	0	0	2	11
29	1	0	0	0	0	0	0	0	0	0	1

APPENDIX EV
INDIVIDUAL STUDENTS' LIMITING REACTANTS PERCENT YIELD PRE TEST SCORES FOR EACH QUESTION

30	1	2	0	0	3	1	2	0	0	0	9
31	0	0	0	0	3	0	0	2	0	0	5
32	0	0	0	2	0	0	2	0	0	0	4
33	1	0	0	0	3	0	0	0	0	0	4
34	0	0	0	0	0	1	1	2	0	0	4
35	1	0	0	0	3	1	2	0	0	0	7
36	1	0	3	0	3	3	2	0	0	0	12
37	1	2	0	2	3	0	2	0	0	0	10
38	2	2	0	0	0	0	2	0	0	0	6
39	0	2	0	0	0	3	2	0	0	0	7
40	2	2	1	0	0	0	2	2	0	0	9
41	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	2	2	0	2	0	0	0	6
43	0	0	0	0	3	3	2	4	0	0	12
44											
45	1	0	0	0	0	0	0	0	0	0	1
46	2	2	1	0	3	3	2	0	0	0	13
47	1	0	0	0	0	0	0	0	0	0	1
48	0	0	0	0	1	2	2	0	0	0	5
49	1	0	0	0	0	0	2	0	0	0	3
50	1	0	1	0	0	1	2	6	0	2	13
51	2	0	0	0	0	0	2	0	0	0	4
52	2	2	3	2	0	1	2	0	0	0	12
53	0	0	0	0	0	1	0	0	0	0	1
54	2	2	0	0	3	2	2	0	0	0	11
55	1	2	2	2	0	0	2	0	0	0	9
56	2	2	3	2	3	0	2	0	0	0	14
57	1	0	2	0	0	1	2	4	0	0	10
58	0	0	0	0	0	0	2	0	0	0	2
59	1	0	0	0	0	0	2	4	0	0	7
60	2	2	0	7	3	3	2	0	0	0	19

APPENDIX EV

INDIVIDUAL STUDENTS' LIMITING REACTANTS PERCENT YIELD PRE TEST SCORES FOR EACH QUESTION

61	1	0	3	2	0	0	2	0	0	0	8
62	1	2	0	0	3	0	2	0	0	0	8
63	0	0	0	0	0	0	2	0	0	2	4
64	0	0	1	0	3	3	2	0	0	0	9
65	0	2	0	0	3	0	0	0	0	0	5
66	1	2	3	0	0	0	2	0	1	0	9
67	2	2	0	0	0	1	2	0	0	0	7
68	0	0	0	0	0	3	2	0	0	0	5
69	2	2	3	7	3	3	2	6	0	2	30
70	2	2	0	0	3	1	2	0	0	0	10
71	0	0	0	0	0	1	2	0	0	0	3
72	2	2	3	0	3	3	2	4	0	2	21
73	1	0	0	0	0	0	0	0	0	0	1
74	1	0	3	0	0	0	0	0	0	0	4
75	2	2	0	0	0	3	2	0	0	0	9
76	1	0	3	0	0	3	0	0	0	1	8
77	1	2	0	0	0	1	2	0	0	2	8
78	1	2	0	0	3	1	2	0	0	1	10
79											
Average Score	0.82	0.61	0.68	0.88	1.10	1.05	1.40	0.68	0.01	0.23	7.47
Average Percent	41%	31%	11%	13%	37%	35%	70%	11%	0%	12%	18%

APPENDIX EVI

INDIVIDUAL STUDENTS' LIMITING REACTANT PERCENT YIELD POST TEST SCORES FOR EACH QUESTION

Student #	#1	#1a	#2	#3	#4	#5	#7	#8	#9	#11	Score
	2	2	6	7	3	3	2	6	8	2	41
1	0	0	6	7	3	3	2	6	8	2	37
2	2	2	6	6	3	3	2	6	0	2	32
3	1	0	6	7	3	1	2	6	1	2	29
4											
5	2	2	6	7	3	3	0	6	5	2	36
6	1	2	6	7	1	0	2	6	8	0	33
7	0	0	6	7	3	1	2	6	0	0	25
8	1	2	4	6	1	0	0	0	0	0	14
9	1	0	6	7	3	1	2	6	4	2	32
10	1	0	2	5	3	3	2	3	8	0	27
11	0	0	6	7	3	2	0	2	0	0	20
12	0	0	6	7	1	1	0	1	4	0	20
13	0	2	5	7	3	3	2	6	4	0	32
14	0	2	6	7	3	1	0	4	7	0	30
15	2	2	6	7	3	3	2	6	4	2	37
16	2	2	3	7	0	3	2	3	0	0	22
17											
18	0	2	6	7	0	3	2	5	0	0	25
19	2	2	6	7	3	3	2	3	0	0	28
20	2	2	6	5	3	2	2	6	0	0	28
21	1	2	6	7	0	1	0	4	0	2	23
22	0	0	2	6	0	0	0	0	0	0	8
23	2	2	6	7	3	3	0	6	4	0	33
24	1	0	2	2	0	0	0	6	0	0	11
25											
26											
27	0	2	6	7	3	0	2	6	4	0	30
28	0	0	6	5	0	3	2	6	2	0	24
29	2	2	4	5	0	1	0	6	0	2	22

APPENDIX EVI
INDIVIDUAL STUDENTS' LIMITING REACTANT PERCENT YIELD POST TEST SCORES FOR EACH QUESTION

30	1	2	6	7	3	3	2	6	8	2	40
31	1	2	6	7	3	0	2	6	8	0	35
32	1	2	6	7	0	1	2	6	0	2	27
33	0	2	6	7	1	2	2	3	0	0	23
34	0	0	6	5	0	1	1	4	0	0	17
35	0	0	6	7	3	1	2	6	3	2	30
36	1	2	6	7	3	3	2	6	8	0	38
37	2	2	6	7	3	3	2	6	8	2	41
38	0	0	6	7	0	1	2	4	0	0	20
39	2	2	6	7	3	0	2	6	0	2	30
40	2	2	6	7	3	3	1	6	8	2	40
41	0	0	4	7	0	1	1	4	8	0	25
42	0	0	5	5	3	2	2	6	0	2	25
43	0	0	6	7	3	1	0	4	0	2	23
44	1	0	3	7	1	0	0	6	0	2	20
45	0	0	6	7	3	1	0	4	0	2	23
46	1	2	6	7	3	3	2	6	0	2	32
47	1	0	6	7	3	1	2	6	8	0	34
48	0	0	6	7	3	3	2	3	1	2	27
49	0	0	6	7	3	3	0	6	0	0	25
50	0	2	6	7	3	3	2	6	0	0	29
51	2	2	6	7	0	3	2	6	0	0	28
52	0	2	6	7	3	0	2	6	8	2	36
53	0	0	6	7	2	0	0	3	3	2	23
54	2	2	6	7	0	3	2	6	0	0	28
55	1	2	6	7	3	0	2	2	4	2	29
56	2	2	6	7	3	3	2	6	0	2	33
57	2	2	5	7	0	0	2	6	0	0	24
58	1	2	3	7	3	2	0	4	6	2	30
59	0	2	6	7	3	0	2	6	6	0	32
60	2	2	6	7	3	3	2	6	0	2	33

APPENDIX EVI

INDIVIDUAL STUDENTS' LIMITING REACTANT PERCENT YIELD POST TEST SCORES FOR EACH QUESTION

61	0	2	6	7	0	1	2	2	4	0	24
62	0	2	6	7	3	3	2	6	0	2	31
63	0	0	6	7	3	1	2	5	0	2	26
64	1	0	6	7	3	3	2	6	0	2	30
65	0	2	2	7	3	3	0	1	2	0	20
66	2	2	6	7	3	3	2	6	1	0	32
67	0	0	6	7	3	0	2	1	0	2	21
68	1	0	6	7	3	3	2	6	2	0	30
69	2	2	6	7	3	3	2	6	5	0	36
70	1	2	1	7	3	0	2	2	1	0	19
71	0	2	3	7	3	0	2	4	0	0	21
72	2	2	6	7	3	3	2	6	8	2	41
73	0	2	0	7	3	0	0	4	3	0	19
74	0	0	6	7	1	1	2	6	0	2	25
75	2	2	6	7	3	3	2	6	1	0	32
76	1	2	4	7	0	3	0	6	5	2	30
77	1	0	6	7	0	1	0	6	8	0	29
78	1	0	4	7	0	3	0	4	0	0	19
79											
Average Score	0.84	1.22	5.30	6.73	2.09	1.73	1.39	4.85	2.57	0.89	27.61
Average Percent	42%	61%	88%	96%	70%	58%	70%	81%	32%	45%	67%

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