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A CONCRETE STOICHIOMETRY UNIT FOR HIGH SCHOOL CHEMISTRY

By

Jennifer Louise Pakkala

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ABSTRACT

A CONCRETE STOICHIOMETRY UNIT FOR HIGH SCHOOL CHEMISTRY

By

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Stoichiometry is the study of quantitative relationships that exist in reactions and is traditionally difficult for students to master. The main obstacle to a thorough understanding of stoichiometry is that the topic is abstract, being taught at the symbolic level. In addition, we suspect many of the students (roughly 50%) have not yet reached the final stage of cognitive development, formal operations. These students are unable to understand material taught at the abstract level. Therefore it is necessary to develop models and activities that allow these students to move from the concrete level to the abstract level.

Models were developed and implemented to assist concrete learners. The most effective activity involved a hamburger sandwich analogy built on the students' previous knowledge of fast food. Hamburger models were built and used in instruction so that students could rearrange the pieces and gain an understanding of molecular events by using a macroscopic model.

The incorporation of the concrete models into the instruction of stoichiometry proved to be successful with an average improvement of 70% between pre and post tests. The largest improvement for an individual student was 90%. High school students show improved understanding of chemical reactions and stoichiometry when taught with some concrete tools.

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INTRODUCTION

Rationale for Study

The chemistry topic covered within this study, reactions and stoichiometry, was chosen as a focus because it is one of the most important topics taught in general chemistry, yet is difficult for students to master. When asked to rank chemistry topics in terms of importance, a group of college professors ranked stoichiometry fourth out of twenty-two topics that should be taught to students in high school chemistry (Deters, 2003). Stoichiometry is the study of quantitative relationships that exist in chemical formulas and reactions. An understanding of reactions is necessary because a chemical equation must be properly balanced in order to be successful in solving stoichiometry problems. Stoichiometric calculations are important because they enable chemists to determine the exact amounts of reactants and products in a chemical reaction. Stoichiometry answers the question "how much of this reactant do I need?" or "how much product will I get?" Moreover, stoichiometry is important to the chemistry student because any career that relies on chemistry, from pharmacist to chemical engineer, will require a solid understanding of stoichiometry.

Stoichiometry is traditionally difficult for students to master. Steiner (1986) writes that one possible reason for this difficulty is, "We introduce the topic with the horrendous new word 'stoichiometry'." Realistically, the main obstacle to a thorough understanding of stoichiometry is that the topic is abstract. Furthermore stoichiometry is taught at the highest level of abstraction, the symbolic level (Gabel, 1999). In addition, about half of the students that attempt to learn stoichiometry do so before they have reached the stage of formal operational thought (Huddle, 1986 and Smith, 1978). According to Piaget's theory of cognitive development, learners should reach formal operations between the ages of 12 and 15. However, the majority of learners do not reach this stage by the age of 15, as many as 50 % of high school students have not reached formal operations (Smith, 1978). It is therefore necessary to incorporate a good deal of concrete examples and activities when stoichiometry is first introduced. The purpose of this study was to determine if the incorporation of some concrete learning tools coupled with purposeful, hands-on lab experiments would help general chemistry students understand the abstract topic of stoichiometry.

School Demographics

This study was conducted with students enrolled in General Chemistry, an introductory chemistry course, at Redford Union High School in Redford Township, Michigan. Redford Township is situated just west of the city of Detroit; the two municipalities share a border. The Redford Union District enrolls residents from Redford Township as well as a number of school-of-choice students who reside in Detroit. Redford Union High School is a public school with an enrollment of 1,235 students in grades 9-12. The student body is 79 % White, 19 % Black, 1% Hispanic, with Asian and American Indian students comprising the final 1%. The economic level of the community is middle-class with 24 % of high school students eligible for the free or reduced –price lunch program. The numbers for the Redford Union District as a whole are slightly different with 35% of students in the district eligible for free or reduced-price lunch, similar to the state average of 36%

(Michigan Department of Education, 2006). Students that participated in the study were eleventh and twelfth graders and ranged in age from 16 to 18 years old. Participating students were from two different class periods. The first class period only had a total of 10 students, and the other had a total of 21 students. Eighteen of the 31 students enrolled in General Chemistry elected to participate in the in the study by returning a signed consent form (Appendix D-IX).

Summary of Science Taught:

The focus of this study, reactions and stoichiometry, is traditionally difficult for students to master because much of the study is at the symbolic level, rendering the topic abstract and unreachable to some students. This study was conducted covering two chapters from the text Modern Chemistry (Davies et. al. 1999); *Chemical Equations and Reactions and Stoichiometry*.

In the first section, *Chemical Equations and Reactions*, the major sub-sections are describing chemical reactions, balancing chemical equations, classifying types of reactions and using the activity series. In a chemical reaction, atoms are rearranged to form new substances. Typical indicators that a chemical reaction has taken place are a change in color, the formation of a gas or precipitate, and the evolution or absorption of heat or light. When a chemical reaction occurs, mass is conserved. The total mass as well as the numbers and types of atoms are the same on both the reactant and product side of a reaction. Coefficients are used in front of formulas in order to balance a reaction. An important component of understanding chemical equations is to understand the symbols used therein. Symbols are used in chemical equations to identify the physical states of substances as well as the physical conditions during a reaction. For example, the symbol (aq) stands for aqueous, which means the substance had been dissolved in water. Chemical reactions are classified into five different types: synthesis, decomposition, single replacement, double replacement, and combustion. In a synthesis reaction two reactants form a single product. In a decomposition reaction, a single reactant forms two or more products. In a single replacement reaction, an element replaces an element from a compound. In a double replacement reaction, the ions of two compounds switch places, replacing each other and forming two new compounds. In a combustion reaction, a hydrocarbon reacts with oxygen to form carbon dioxide and water. The activity series is a list of elements arranged according to relative reactivity and is used to make predictions about the products of a replacement reaction.

The second section of the study, *Stoichiometry*, deals with the quantities of substances in chemical reactions. Balanced equations are used to compare the relative amounts of substance, expressed as moles. Stoichiometry problems are solved by using mole ratios from the balanced reaction as a conversion factor between the two substances. In a chemical reaction, the limiting reactant is that which is completely consumed in the reaction, thereby placing a limit on the amount of product that is formed. The theoretical yield is the amount of product that can be formed in a chemical reaction. The actual yield is the amount of product that is collected when a reaction is actually carried out. The percentage yield is the ratio of actual yield to theoretical yield multiplied by 100.

Theoretical Framework

Much research has been done in an effort to reveal the problems students encounter in solving stoichiometry problems. Both Huddle (1996) and Smith (1978) reported that the reason that many high school chemistry students encounter difficulty in problem solving is because they do not have the capacity for formal operational thought. Formal operational thought refers to the final stage of cognitive development in a theory proposed by psychologist Jean Piaget. The work of Piaget is well known by educators at all levels.

Piaget studied the cognitive development of children with the intent of learning how humans acquire knowledge (Bodner, 1986). Piaget's theory of cognitive development outlines four major stages: sensorimotor, preoperational, concrete operations, and formal operations, along with an age range for each stage. The stages commonly observed in the high school classroom are the final two stages, concrete operations (7 – 11 years of age) and formal operations (12 – 15 years of age).

Concrete operations, which according Piaget's theory appears between ages seven and eleven, is characterized by a student being able to carry out logical mental tasks tied to concrete objects or situations (Woofolk, 1998). In this stage, students are able to use symbols to represent physical things, and are able to manipulate these symbols, but only within the context of concrete situations. For example, children at this stage can imagine what their bedroom would look like with the furniture rearranged without actually moving the furniture (Woolfolk 1998). They can create a drawing symbolizing their furniture and how it could be arranged, but they can not do the same for pieces of furniture they have never seen even when provided with the dimensions. Students are literally in a "hands-on" thinking mode.

The final stage of cognitive development, formal operations, is reached between twelve and fifteen years old. Ideally, in accordance with the age ranges of Piaget's theory of cognitive development, all eleventh and twelfth grade students ages 16 to 18, such as those participating in this study, should be in this final stage of cognitive development. Students capable of formal operational thought are able to handle abstract thinking and reasoning. This is particularly important in the study of chemistry as much of it is unseen by the naked eye. Chemistry students do not have the opportunity to see atoms or molecules and yet are required to perform calculations involving the mole and Avogadro's number. Reporting the number of molecules at the end of a problem requires the use of formal operations as the student is writing about something they have never seen, or touched. The key characteristic of formal operational thought is hypothetico-deductive reasoning, a problem solving strategy in which an individual identifies the factors affecting the problem and then deduces and systematically evaluates solutions (Woolfolk, 1998). This method of thinking and reasoning is necessary in solving several types of chemistry problems, including stoichiometry problems.

The sample stoichiometry problem in Figure 1 below asks the question directly enough, but the onus is on the student to recognize that there are several steps that need to be taken to arrive at the correct answer. The first step is to balance the chemical equation. Arriving at the correct answer is impossible without this first

Sample Stoichiometry Problem:

As early as 1938, the use of NaOH was suggested as a means of removing CO_2 from the cabin of a spacecraft according to the following reaction:

$$NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

If the average human body discharges 925.0 g of CO_2 per day, what mass of NaOH is required each day for each person in the spacecraft?

(Davis et. al.)

Figure 1: Sample Problem

step; yet because the question does not overtly ask or tell the student to balance the equation many, including students who have seen this type of problem before, will skip the step altogether. This is an example of students failing to identify the factors that affect a problem, which is a possible indicator of lack of formal operational thought. Patricia Smith (1978), a high school chemistry teacher, noted that, "At least half of the students are unable, not necessarily unwilling, to understand such concepts as atomic structure, moles, polar and nonpolar bonds, and the periodic law."

Controversy has surrounded the age ranges associated with each stage of cognitive development since the publication of Piaget's theory. However, most important to the focus of this study is the controversy surrounding the final stage; formal operations. Piaget's theory tells us that the stage of formal operations is reached sometime between ages 12 and 15 and yet research has shown that this is not necessarily the case. Approximately 50% of high school students are unable to use formal thought processes (Smith, 1978). High school teachers are not alone in facing the challenges of teaching concrete operational students abstract topics; college professors also identify these students in introductory courses (Bodner, 1986). A study conducted in 1971 revealed that half of the college freshman participating in the study had not reached formal operations. (Good 1979). In a summary of studies concerning Piaget's cognitive levels, Ron Good (1979) provides the following conclusion:

> "Various studies indicate that from 25% to 75% of high school and college students do not successfully use components of formal reasoning as (1) using proportions, (2) making quantitative correlations, (3) making all possible combinations, (4) controlling variables, etc."

The formal thought processes listed by Good are key components in solving stoichiometry problems with success, particularly using proportions. Mole ratios are important proportions that are necessary to solve stoichiometry problems.

Even Piaget suggested that most adults may only be able to use formal-operational thought in a few areas where they have the greatest experience or interest (Woolfolk, 1998). It is therefore almost *unreasonable* to expect all students in a general chemistry class in high school to all succeed in thinking hypothetically about stoichiometry problems.

This does not mean that there are not students in the class capable of formal operational thought. Formal operations students are indeed present and capable of handling the task of solving stoichiometry problems. These students can also benefit from the incorporation of concrete activities into their learning almost as much as their concrete counterparts. It is common for people at all levels of cognitive development to revert to an earlier stage when confronted with a new area of learning (Bodner, 1986). When students arrive in General Chemistry at Redford Union, none of them have heard of stoichiometry before and all of them find the topic challenging if not difficult, formal learners included. Therefore all students should benefit from the incorporation of concrete learning experiences.

Piaget laid the groundwork for the constructivist model of learning which is neatly summarized by Bodner (1986) in a single sentence, "Knowledge is constructed in the mind of the learner". People do not discover knowledge, nor can it be transplanted from the mind of the teacher into the mind of a student. Rather knowledge is constructed as new information and models are incorporated into existing knowledge structures (Woolfolk, 1998). People do this in order to make sense of their experiences. When new knowledge is constructed it is then tested in real world situations and if necessary, modified based on new experiences (Bodner, 2001). An example of the testing of knowledge in physics is given by Bodner (1986) below.

> "The knowledge that a force must be applied to keep an object in motion is viable in such commonplace experiences as driving a car; it 'works'. When faced with the task of making a relatively heavy dry-ice puck move at constant speed across a smooth glass table, it is not surprising that students try to achieve this goal by using a constant blast of air from an air hose. For some students, it is only when they find that this does not work that they feel obligated to revise their 'knowledge' to incorporate Newton's laws. Once developed, the, the knowledge contained in Newton's laws is perfectly viable for engineers and even most physicists. It is only when this knowledge is tested in the domain of relativistic effects that it must be altered once more."

In science classes, it makes sense that students develop their understanding following the constructivist model. Students arrive in class with certain ideas and misconceptions that they may modify as they acquire and test new knowledge. If the student is responsible constructing new knowledge, then the student must be active. Patricia Smith (1978) writes, "Both students hands and minds must be actively involved for them to progress". This is where teaching a topic such as chemistry gets tricky. Sure, it's simple enough to get hands-on learning done in the laboratory, but how can the concepts of chemistry be *taught* in a hands-on manner when the explanations exist on a molecular level?

The world that high school students live in is essentially macroscopic. They deal with things that they can see; things that have mass that they can feel. Unfortunately students do not realize that chemistry is also part of this world. They cannot see the atoms or molecules undergo rearrangement during a chemical reaction. Gabel (1999) writes, "In order to understand the microscopic [molecular] level, a person must be capable of associating particles with models or analogies." The goal of the chemistry teacher then is to incorporate meaningful macroscopic models into instruction.

Creating macroscopic models of molecular events makes use of visual-spatial thinking. Matthewson (1999) defines visual-spatial thinking as follows, "Visual-spatial thinking includes vision – using the eyes to identify, locate, and think about objects and ourselves in the world, and imagery – the formation, inspection, transformation and maintenance of images in the "mind's eye" in the absence of a visual stimulus." The rearrangement of atoms and molecules during a chemical reaction lacks a visual stimulus for students; it is therefore necessary to give them a model and images for their "mind's eye". Images are important in learning in that images carry a large amount of information. An image has the power to show relationships between several ideas (Matthewson, 1999). Using a visual spatial representation increases the power of the instruction by including the relationships between items and not just a series of definitions linked together with even more words. Students working with language without imagery are on a time deadline when it comes to working memory as working memory serves as temporary information storage only.

Woolfolk (1998) defines working memory as, "... the 'workbench' of the memory system, the component of the memory where new information is held temporarily." The amount of working memory available is limited (Woolfolk, 1998). Learning chemistry can be very difficult because of the large number of unfamiliar terms. Gabel (1999) writes, "If a word or chemical species is unfamiliar, it will take up a much larger space in short-term memory than something familiar because of an inordinate amount of time must be taken to make sense of it." Woolfolk (1998) supports this opinion, "Working memory... holds five to nine bits of information at a time for 20 to 30 seconds." Powerful images and visual spatial representations can be processed within the 20-30 second time limit and carry the added meaning of relationships between the items. Matthewson (1999) writes, "Teaching strategies should foster a balance between the use of language and image by the learner. "

One method for bringing the molecular world of chemistry and stoichiometry into the macroscopic hands of teenaged students was developed by Liliana Haim , Eduardo Cortón, Santiago Kocmur, and Lydia Galagovsky, all of whom are university instructors in Buenos Aires, Argentina. Their method uses the analogy of fast food hamburger sandwiches to teach such concepts as chemical formulas, balancing equations, mass conservation and limiting reactants. In this analogy, the components of a hamburger sandwich symbolize atoms, which are the components of molecules. Each component is assigned a mass value, just as each type of atom has an atomic mass value on the periodic table. For example, a slice of bread (B) is assigned a mass of 25 g and a hamburger patty (H) is assigned a mass of 80 g. The formula for a hamburger is B_2H_2. From this information students can calculate the mass of the hamburger and see that the mathematical relationships between masses in chemistry is not inaccessible to them, but merely logical. Students are then able to move to the next level, the law of conservation of mass in a chemical reaction by using Haim's reaction for transforming HambChems (B_2P_2) and CheeseChems (B_2Ch_2) into MacChems (B_3ChP_2):

$$2\ B_2P_2 + 2\ B_2Ch_2 \rightarrow 2\ B_3ChP_2 + B_2Ch_2$$

By assigning mass values to each piece as above, students can calculate the mass of sandwiches before the rearrangement, or reaction, equals the mass afterward. This is a very simple example of the power of the analogy. Indeed, once the groundwork is laid the analogy can carry through to understanding percent yield. This hamburger analogy is excellent for teaching stoichiometry. Gabel (1999) writes, "Novice chemists, whether at the elementary or college level, are familiar with matter as ordinary objects that surround them. Taking this into consideration, chemistry instruction should be based on the familiar macroscopic world." The hamburger analogy accomplishes this nicely.

The ability to understand the molecular concept of a chemical reaction as a rearrangement of atoms is only the beginning of an understanding of stoichiometry. Learning stoichiometry requires conceptualization skills as well as mathematical and problem solving skills. The hamburger analogy allows students to solve the problems by intuition (Haim, 2003). This demonstrates to the students that there are simple mathematical procedures for solving stoichiometry problems, procedures with which they are already familiar. Chemical reactions are similar to kitchen recipes in many ways and because students are familiar with recipes and the numerical relationships therein, it seems a good place to begin with numerical relationship in stoichiometry. Haim, Umland, and Cain have all used recipes as a model for stoichiometry with success in their classrooms. Umland (1984) writes,

> "No one has any difficulty telling you that if a recipe says that it takes 2 ¼ cups of flour and 2 eggs (plus other ingredients such as sugar, baking powder, shortening, milk, and flavoring) to make 30 cupcakes and if you go to the refrigerator and you find you only have one egg you can only make half a recipe. You will need 1 1/8 cups of flour and will get 15 cupcakes."

This demonstrates the concept as well as the mathematics of limiting reactant as the chemical ingredient that will be used up first, thus limiting the amount of product.

Linda Cain (1986) developed a demonstration that highlights the relationship between recipes and stoichiometry. Cain's demonstration makes use of the traditional campfire treat, S'mores, to provide students with a concrete model for learning stoichiometry. The "recipe" Cain provides for making S'mores is as follows:

$$2\ Gc + 1\ M + 3\ Cp \rightarrow 1\ Sm$$

Where Gc represents graham crackers, M represents marshmallows, Cp represents chocolate pieces and Sm represents S'mores. In this demonstration simple, familiar macroscopic items are used to set-up a class discussion wherein a number of useful questions can be asked; such as, "If we started with 10 graham crackers, 5 marshmallows and 15 chocolate pieces, how many S'mores would we get?" Students can see how the amount of reactant relates to the amount of product and vice versa. Very quickly, the students realize that they already know something of stoichiometry. Having activated their prior knowledge, the students are ready to move on from the model and into the reality of chemical stoichiometry and begin to deal with atoms and molecules.

One theory which promotes a connection between students learning and curriculum is the humanistic view. Woolfolk (1998) defines the humanistic view as "An approach to motivation that emphasizes personal freedom, choice, self-determination, and striving for personal growth." Bretz (2001) writes that meaningful learning takes place when students are provided with experiences that require them to connect across three domains; cognitive, affective, and psychomotor. The humanistic view uses the affective domain to help connect abstract concepts. For example, students who learn about chemical reactions and stoichiometry may be able to apply the knowledge to their lives in making choices concerning recycling and feel empowered, activating the affective domain. The cognitive domain is activated upon reading and thinking the concepts through while the psychomotor domain can be activated through group activities or laboratory work (Bretz, 2001).

In order to thoroughly understand stoichiometry, students must solve quantitative problems. There are several methods with which this can be accomplished, the most traditional of which is dimensional analysis. Dimensional analysis is a problem-solving method that uses the fact that any number or expression can be multiplied by a ratio equivalent to one without changing its value. DePierro (2000) writes, "Dimensional analysis, ratio and proportion, and plug-in type calculations may lead to correct numerical answers without a clear picture of the associated physical situation and to the inability to write correct equations." He goes on to suggest that students struggle with problem solving in chemistry because they do not understand the ratios used in dimensional analysis; which follows logically from the suggestion that students may not be capable of formal operational thought. Understanding and using proportions is a trait of hypo-thetico deductive reasoning, the hallmark of formal operations. Patricia Smith has heard from her students the same thing that I have heard from mine, "I can solve the problem if you set it up" (Smith, 1978). This proves the point; students do not understand the ratios being used, or why the ratios are being used, and thus are unable to set up the problem themselves.

One method for enhancing student understanding of ratios used in dimensional analysis is to use the think aloud strategy (DePierro, 2000). Gunning defines think alouds as, "... procedures in which students are asked to describe the processes they are using as they engage in reading or another cognitive activity." Using a think aloud forces students to articulate the meaning of the ratios, rather than just knowing what ratio is to be used. When a student is able to describe the meaning of a ratio in words, there is evidence of qualitative understanding which sets the stage for success in quantitative problem solving (Depierro, 2000).

A natural setting for students to use the think-aloud strategy is in a cooperative group setting. Cooperative learning is simply students "...working together to achieve common learning goals." (Herron, 1999) Students solving problems together affords them a setting to articulate meaning verbally. Cooperative learning also "... encourages strong students to share their thoughts and learning skills with weaker students, and lets all students contribute to the team and experience the strength of team learning" (Bartholomew, 2006). Bartholomew suggests that a time limit be placed on work done in cooperative groups, "... a short time helps focus the students on the problem and may encourage groups to self-police team members who do not seem to participate." Chemistry students are most often afforded cooperative learning experiences in the laboratory. However, cooperative learning groups or teams can also be effective in learning problem solving.

Richard Felder uses group problem solving exercises in teaching stoichiometry processes to chemical engineering students at North Carolina State University. Felder writes, "Group problem solving exercises in class are an effective way to teach material: they give active learners something to do and reflective learners a chance to think" (Felder, 1990). It is important to engage students in any lesson, but to engage students in a problem solving lesson can be particularly difficult. Working in a group setting engages all students. Felder (1990) writes:

> "Once students become involved they tend to stay that way, even after the exercise is over; as little as five minutes of this type of activity spread over the course of an hour can be enough to keep the whole class engaged for the entire period."

Students working in cooperative groups produces benefits in problem solving exercises.

IMPLEMENTATION

This unit for teaching chemical reactions and stoichiometry was developed for use in General Chemistry, an introductory chemistry course for students in 11th and 12th grades. The prerequisite for general chemistry is a passing grade in the 9th grade science class, Geophysical Science. The unit covers two chapters from the text Modern Chemistry (Davies et. al. 1999); *Chemical Equations and Reactions and Stoichiometry*. The implementation of this unit began on the first day that school resumed after winter break. The planned sequence is summarized in Table 1 on page 19. Learning objectives were grouped into six phases, which were to take approximately one week per phase to accomplish. The order was chosen not only for logical progression, but to follow the textbook. Following the text gives the student a device which supports their learning and as such it is easier for the learner when the instructor works with the text rather than against it. Thus, the progression of lessons and acquired skills closely follows the text.

Table 1 below lists the phases of instruction in the order in which they were taught. Each phase included pieces of instruction used in previous years and activities that were developed in order to give greater support to concrete learners. Activities that were developed or altered for use in this study are denoted with an asterisk.

Table 1: Phases of Instruction

<table>
<tr><td colspan="2">Phase 1</td></tr>
<tr><td colspan="2">Objectives:
1. List three observations that a chemical reaction has taken place.
2. List three requirements for a correctly written equation.
3. Write a word equation and a formula equation for a given chemical reaction.
4. Balance a formula equation.</td></tr>
<tr><td>Instruction:
1. Chemical Reactions PowerPoint ®
2. Balancing Chemical Reactions PowerPoint ®
3. Symbols Used in Chemical Equations* PowerPoint ®</td><td>Activities:
1. Burger Chem*
a. Formulas and Equations
b. Mass Conservation
2. Balancing Race*
3. Symbol stories*</td></tr>
<tr><td colspan="2">Phase 2</td></tr>
<tr><td colspan="2">Objectives:
1. Define and give general equations for synthesis, decomposition, single replacement, and double replacement reactions.
2. Classify a reaction as synthesis, decomposition, single replacement, double replacement or combustion.
3. Predict the products of simple reactions given the reactants.</td></tr>
<tr><td>Instruction:
1. Types of Reactions; Visualization with Stick Figures</td><td>Activities:
1. Lab: Types of Reactions*</td></tr>
<tr><td colspan="2">Phase 3</td></tr>
<tr><td colspan="2">Objectives:
1. Explain the significance of the activity series.
2. Use the activity series to predict whether a given reaction will occur and what the products will be.</td></tr>
<tr><td>Instruction:
1. Activity Series PowerPoint®</td><td>Activities:
1. Lab: Recycling Copper*</td></tr>
<tr><td colspan="2">Phase 4</td></tr>
<tr><td colspan="2">1. Define stoichiometry.
2. Write a mole ratio relating two substances in a chemical equation.</td></tr>
<tr><td>Instruction:
1. Introduction to Stoichiometry PowerPoint®</td><td>Activities:
None</td></tr>
<tr><td colspan="2">Phase 5</td></tr>
<tr><td colspan="2">Objectives:
1. Calculate the amount in moles of a reactant or product from the amount in moles of a different reactant or product.
2. Calculate the mass of a reactant or product from the amount in moles of a different reactant or product.
3. Calculate the amount in moles of a reactant or product from the mass of a different reactant or product.</td></tr>
</table>

Table 1 Continued

4. Calculate the mass of a reactant or product from the mass of a different reactant or product.	
Instruction: 1. Ideal Stoichiometric Calculations PowerPoint® 2. Modeling problem solving	Activities: 1. S'more Lab* 2. Lab: Finding Stoichiometric Coefficients
Phase 6	
Objectives: 1. Describe a method for determining which of two reactants is a limiting reactant. 2. Calculate the amount in moles or mass in grams of a product, given the amount in moles or masses in grams of two reactants, one of which is in excess. 3. Distinguish between theoretical yield, actual yield, and percent yield. 4. Calculate percent yield, given the actual yield and quantity of a reactant.	
Instruction: 1. Limiting Reactant PowerPoint®	Activities: 1. Burger Chem Yield and Limiting Reactant* 2. Lab: Percent Yield*

In addition to the activities listed above, each day students were given a homework assignment that followed from the objectives covered in the lesson, in accordance with the school policy which requires teachers to assign homework each day. It is important to note that in addition to in-class activities, most students also completed individual practice.

Phase One

The first lesson introduced the concept of chemical reactions including the obligatory definitions and the law of conservation of mass. The information presented was aligned with objectives 1-3 in Table 1 and presented via Microsoft® PowerPoint® presentation. This lesson was simple and straightforward in order to give students the vocabulary with which to discuss chemical reactions. The most difficult component for the students was translating a word equation into a formula equation as it is essentially learning a new language wherein they have to know the atomic composition of each compound in order to be successful.

The second lesson (Appendix A-I) utilized the hamburger analogy developed by Haim. The premise for the analogy is that the principal of the school has a big meeting and has ordered lunch from a local burger restaurant, "Burger Chem". Although the principal has ordered a specific number of a specific type of burgers, the order is mixed up and the wrong sandwiches are delivered. Students must find a way to make the changes to the sandwiches that were delivered in order to provide the proper lunch for the principal's meeting without the principal discovering the error. Rather than simply make use of the analogy, Haim's original idea was extrapolated to create a concrete experience for high school students. Using Crayola® Model Magic ® modeling compound, small models of components of hamburger sandwiches were constructed. These components included bread, hamburger patties, and cheese. These re-usable components of hamburger sandwiches provided models for students to work with, employing visual-spatial skills. The models were used in four different activities in the unit.

To begin the first "Burger Chem" lesson, students worked in groups of 2-3 and the Formulas and Equations worksheet (Appendix A-I) was distributed along with a set of hamburger model components. The instructions were for each group to build models of the sandwiches following the given recipe, shown in Table 2.

Table 2: Burger Chem Recipes

Sandwich	Bread (B)	Cheese (Ch)	Patties (P)
HambChem	2	0	2
CheeseChem	2	2	0
MacChem	3	1	2

Students were required to work on the problems in groups to solve the problem. Students were provided 10 minutes to work together and then the class came together as a group to discuss the answers. The rationale for a short time limit for the group work was to reap the benefits described by Bartholomew; namely promoting focus on the task and self-policing by the group to keep all members involved. In order to have a purposeful class discussion following the group work the Microsoft ® PowerPoint ® presentation included in Appendix A-I was used. This lesson accomplished two tasks. First, it gave students the opportunity to carry out logical mental tasks tied to concrete objects, bringing the abstract concept of a chemical reaction to the concrete level through an analogy. This activity also provided a macroscopic model for a chemical reaction. In the activity, students are asked to write a reaction which symbolizes the transformation of sandwiches from one type (HambChems) to another type (MacChems). Performing such a task fits nicely into Gabel's recommendation for understanding molecular events. Gabel suggests that to understand molecular events, one must be able to associate the event with a model.

Continuing on the same day with the "*Burger Chem*" activities, the class went back to group work and completed the Mass Conservation worksheet (Appendix

A-II). Again, instructions were for students to build the models and again the group came together after 10 minutes to discuss the answers. In this activity students were most struck by the fact that no components of hamburgers had been created or destroyed in re-arranging the pieces. When they were asked if they had the same number of pieces that they had had at the beginning, they looked down at their desks to check and found that mass had been conserved.

These two *Burger Chem* lessons gave students their first experience in manipulating coefficients in a chemical equation while using concrete models. Students were able to view a chemical reaction in the same light as they would consider a recipe and understand that 100 B_2H_2 meant that there were 100 HambChem sandwiches. This set the stage for the next instructional piece, balancing equations.

The next lesson provided direct instruction in balancing equations by inspection. A Microsoft® PowerPoint® presentation was used for introduction. Students were first provided a set of rules for balancing equations and then a series of sample equations to balance. As the lesson progressed the teacher gradually tapered support and allowed students to become increasingly active in balancing the equations.

The following day students participated in a balancing race. To become an expert at balancing equations requires a lot of practice by the student, but long balancing assignments can be tedious and boring. In this activity students were in competition with each other for various prizes held in high regard by high school students. The prizes included such items as pencils, drink passes, one free tardy, a homework pass and a hierarchy of extra credit points. Students that were already capable of balancing equations had class time in which to practice and those students who were not yet able to balance equations on their own were able to get assistance from the teacher during this time. A copy of the equations race is included in Appendix A-III. The race was divided up into three sections of seven equations each. At the end of each section, students were required to check in with the teacher before proceeding to the next set of equations to get both feedback and assistance if necessary. The balancing race occupied the first half of a class period, at the end of which students had successfully balanced a total of twenty-one equations.

The second half of the class period was devoted to understanding symbols used in chemical equations. A Microsoft® PowerPoint® presentation was shown (Appendix C-I). The homework assignment for the day was to write a story using the symbols of chemistry in place of words. For example, NaCl (aq) is salt water and it is fun to go swimming in NaCl (aq) with fins and a mask. The rubric used in grading the stories in included in Appendix D. This activity concluded the first piece of the unit.

Phase Two

To provide direct instruction in the five different types of chemical reactions, a Microsoft® PowerPoint® presentation was shown. A grid was distributed for students to record their notes. A blank student grid and a completed grid are included in Appendix A-IV. The types of equations presented followed those in the textbook; synthesis, decomposition, single replacement, double replacement, and

combustion. A macroscopic model was employed to enhance understanding. After writing the equation type, definition and general equations, students drew stick-figure representations for the reaction. In this model students are able to draw on their experience about dating. A stick figure drawing representing a synthesis reaction is shown in Figure 2.

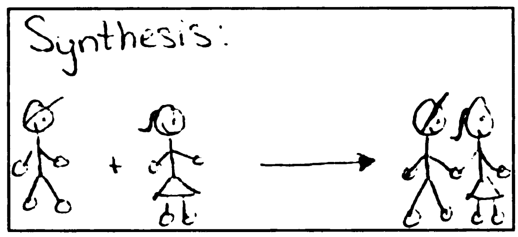


Figure 2: Stick Figure Model

Students are asked if they have any friends that behaved completely differently after acquiring a boyfriend or girlfriend. The response is an emphatic, "Yes!" and students understand that the same is true for the products in a reaction. While this model is not quite as concrete as the burger analogy, it does provide a powerful model for students to begin to understand reactions. The diagram provides an image for the "mind's eye" and creates a balance between language and imagery. The lesson proceeded with stick figure models for all types of reactions. The idea for utilizing stick figures to represent equations was borrowed from Tom Shalla, a retired chemistry teacher from Harrison High School in Farmington Hills, Michigan. Mr. Shalla taught reactions in this manner in 1987, and nearly twenty years later I am able to remember the symbols and pass them along to my students.

The next day students went into the laboratory to perform one of each type of reaction (Appendix B-I) The reactions performed are some that had been used only as demonstrations in the previous years' instruction and adapted to create a laboratory experience for students. In completing each of the reactions students had an opportunity to demonstrate mastery of a performance objective from the first phase of the unit: to make observations that indicate that a chemical reaction has taken place. At each station students were required to record their observations, as well as write and balance the chemical equation.

At the synthesis station, students performed the following reaction:

$$2\ Mg\ (s) + O_2\ (g) \rightarrow 2\ MgO\ (s)$$

Student observations included a change in color as well as the significant amount of heat and light produced in the reaction. As the decomposition station, students removed water from a hydrate and observed a simple color change which they reported to be quite uninteresting in the following reaction,

$$CuSO_4 \bullet 5H_2O(s) \xrightarrow{\Delta} CuSO_4 + 5H_2O\ (g)$$

At the single replacement station students performed a reaction in the fume hood which involved the evolution of hydrogen gas through the equation

$$Zn\ (s) + HNO_3\ (aq) \rightarrow Zn(NO_3)_2\ (aq)\ + H_2\ (g)$$

Students' observations for the reaction included noting the formation of hydrogen bubbles on the surface of the zinc. At this station they learned that the fume hood removes dangerous gases and makes it safe for them to carry out reactions like those above. At the next station students performed a double replacement reaction with a spectacular color change. The reaction is as follows.

$$2\ KI\ (aq) + Pb(NO_3)_2\ (aq) \rightarrow PbI_2\ (s) + 2\ KNO_3\ (aq)$$

The reactants are both colorless liquids, but the lead iodide precipitate that is formed is a very bright yellow. The final type of reaction was a combustion reaction. Students particularly enjoyed this station because they were able to produce a small fire on a watch glass. The combustion reaction used is shown below.

$$CH_3OH\ (aq) + O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (l)$$

The *Types of Chemical Reactions* laboratory experiment provided an opportunity for students to understand that the symbols that they had been using in class and in homework represented physical things, things that they handled in the lab. This is an important task for the concrete operational learner.

Phase 3

The activity series of the elements is a list of elements arranged by relative reactivity. An understanding of the activity series allows students to predict how certain elements are able to replace others in single or double replacement reactions. To introduce the topic a Microsoft® PowerPoint® presentation was used (Appendix C-II).

The following day students went to the laboratory to perform the *Recycling Copper Lab* (Appendix B-II). The pre-lab questions for this experiment reinforce the objectives of phases 1 and 2, related to indications that a chemical reaction has taken place and types of reactions. The experiment itself involves a series of reactions which ultimately produce copper metal. Students are required to write and balance the series of five reactions that take place in this experiment. All of the reactions are carried out in one standard sized test tube. Students begin with copper nitrate solution, and add sodium hydroxide:

$$Cu(NO_3)_2\ (aq) + 2\ NaOH\ (aq) \rightarrow Cu(OH)_2\ (s) + H_2O\ (l) + 2\ NaNO_3\ (aq)$$

Students recorded that they knew a reaction had taken place because of the formation of a precipitate. The second reaction is the decomposition of the copper hydroxide precipitate over heat to cupric oxide and steam following the equation below.

$$Cu(OH)_2\,(s) \xrightarrow{\Delta} CuO(s) + H_2O(g)$$

Again, it is easy to recognize that a reaction has taken place as the cupric oxide formed is a black solid. Students noted the color change in their observations. The third reaction put the copper back into solution through the following reaction.

$$CuO\,(s) + 2\,HCl\,(aq) \rightarrow CuCl_2(aq) + H_2O(l)$$

Students noted that a chemical reaction had taken place because the black cupric oxide was consumed and the product was a colorless liquid. To produce copper metal from the solution resulting from the reaction above, aluminum metal was placed into the test tube resulting in the reaction below.

$$3\,CuCl_2(aq) + Al\,(s) \rightarrow 2\,AlCl_3(aq) + 3\,Cu(s)$$

For this reaction, students' observations included the formation of the copper metal precipitate. A reaction that takes place simultaneously with the one above is

$$6\,HCl\,(aq) + 2\,Al\,(s) \rightarrow 3\,H_2\,(g) + 2AlCl_3\,(aq)$$

Students noted the formation of bubbles for the above reaction. Post lab questions required students to use the activity series of the elements to explain the movements of copper within the framework of the 5 reactions carried out in this experiment.

This laboratory activity allows for the activation of the cognitive, psychomotor and affective domains. The ultimate question in the lab is, "Do you think that people who design metal recycling processes need to know and use the activity series? Why or why not?" This question provides a direct link into the daily lives of students. When they choose to recycle a product, odds are good that there is a chemical process that will take that product from being trash back to being useful. In making the choice to recycle or not students experience empowerment. This laboratory experiment connects the three cognitive domains, the most effective combination for student learning.

Upon completion of the objectives of phase three, students completed exit surveys (Appendix D) for the first half of the study and a chapter test which was not included in this study was administered as this marked the conclusion of a chapter in the text book.

Phase 4

This phase began by defining stoichiometry as a quantitative study of chemical changes. The first day of instruction presented information in a Microsoft® PowerPoint® presentation (Appendix C-III). The main goal of this first day of instruction was to quickly review calculations with moles and to introduce the mole ratio as a conversion factor. This lesson attached additional meaning to the need to balance a chemical reaction, an objective from phase one, and also lays the groundwork for phase five, calculation of amounts of product from a chemical reaction.

Phase 5

The fifth phase of implementation involved mastery of quantitative relationships. The first day provided further instruction via a Microsoft® PowerPoint®

presentation (Appendix C-IV) which included steps for problem solving as well as several examples. The goal of the day's instruction was for students to be able to solve simple stoichiometry problems involving mole to mole calculations and mass to mass calculations.

The second day students were able to go into the lab and use the recipe for S'mores to model the quantitative relationships in a chemical reaction. Linda Cain (1986) developed a demonstration using S'mores to provide students with a concrete model for understanding stoichiometry. In order to make the situation even more meaningful for students, this demonstration was developed into a laboratory activity. The recipe "reaction" utilized in the lab was nearly identical to that used by Cain in her demonstration, the only difference being due to the size of the chocolate pieces used to make the S'mores.

$$2\ Gc + Mm + 2Cb \rightarrow S'm$$

where Gc is the symbol for graham cracker, Mm stands for marshmallow, Cb is the symbol for a miniature chocolate bar, and S'm symbolizes a S'more. In the activity students were able to verify the law of conservation of mass and then eat in the lab, a very big treat indeed. In order to ensure the safety of the food, only one Bunsen burner, which had been set aside for use with food, was used and wooden skewers were used to roast the marshmallows. Used skewers were discarded after the lab. Students certainly enjoyed the activity, but not all of them were able to connect the recipe to the equation that governed the making of the S'more. Several students required significant assistance in answering the post-lab questions which required calculations of amounts of a reactant or product given the amount of a different reactant or product.

Because many students who struggled in completing the *S'more Lab*, the day after the lab was dedicated to modeling good problem solving techniques for simple stoichiometry problems. The lab gave them a firm footing in dealing with amounts in a "recipe reaction" and prepared them to listen to how to handle a chemical reaction. While the students were not successful overall in completing the *S'more Lab*, the lab prepared them to listen and understand. The problem solving lesson consisted of a series of problems from the book solved by the teacher, while modeling the think-aloud strategy, and homework with similar problems was assigned.

The final activity of this phase was a lab entitled Finding Stoichiometric Coefficients, in which students carried out the following reaction:

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

At the start of the experiment, students weighed a piece of copper wire which served as the solid copper for the reaction. The wire was placed in a test tube containing 5 ml of 1 M silver nitrate solution, $AgNO_3$. From the information about the silver nitrate solution, students were able to calculate the number of moles of silver nitrate that reacted. After the reaction appeared to be complete students carefully washed and dried the remaining copper wire and silver precipitate and weighed each to determine how much copper had reacted and how much silver had been produced. Armed with these data, students determined the mole ratios for the three species measured and from there determined the stoichiometric coefficients and wrote the balanced reaction. This lab experience was fabulous for the students in that it took them outside of their comfort zone and forced them to think like chemists. It was particularly distressing to some students that the mole ratios obtained in the lab did not turn out to be perfect whole numbers as they had been in problems in class. Nonetheless, overall students were successful in using the mass-mole relationships to come up with the correct coefficients at the end of the lab.

Phase 6

The final phase dealt with determining the limiting reactant in a chemical reaction and then calculating the amount of product, and finally determining percentage yield for a reaction.

Following the routine of previous phases, the first day of instruction utilized a Microsoft® PowerPoint® presentation (Appendix C-IV) which introduced the vocabulary required for discussing limiting reactant and the steps for determining which reactant is the one which limits the amount of product obtained in a reaction. Percentage yield was also presented.

On the second day, the *Burger Chem* analogy was utilized to reinforce the concepts of limiting reactant and percent yield. Following the same procedure as the previous *Burger Chem* lesson, the *Limiting Component* worksheet (Appendix A-V) was distributed and students were given 10 minutes to discuss the answers in groups. The problem uses the same sandwiches as the previous *Burger Chem* lessons, but this time asks how many MacChems, B_3P_2Ch, can be made from a delivery of 10 kg HambChems, B_3H_2 and 10 kg CheeseChems, B_2Ch_2. In order to answer the question, students must use a process identical to that required to solve a limiting reactant problem, with HambChems as the limiting component. In order to direct the class discussion of this problem a Microsoft® PowerPoint® presentation (Appendix A-V) was used.

The second half of this lesson focused on yield. In this problem 20 % of the HambChems delivered were damaged by freshmen. Students discussed the problem in small groups before coming together as a class to review the answers. This time students had to use the stoichiometric coefficients and recognize the 1:1 relationship between HambChems and MacChems in order to arrive at the correct answer.

The final activity for this study was a lab experiment (Appendix B-IV) in which students determined the percentage yield for a chemical reaction. The reaction used in the experiment was one students are already familiar with, that of sodium bicarbonate, $NaHCO_3$, with acetic acid, $HC_2H_3CO_2$.

$$HC_2H_3CO_2\,(aq) + NaHCO_3\,(s) \rightarrow NaC_2H_3CO_2(aq) + CO_2\,(g) + H_2O(l)$$

In the pre-lab discussion, students are told that the acetic acid will be in excess and that they are to use 0.05 moles of sodium bicarbonate to perform the reaction. Students calculate the mass of sodium bicarbonate required and then carry out the reaction in a pre-weighed 250 mL flask. The water produced in the reaction is removed by heating the products to boiling on a hot plate. To determine the amount of sodium acetate remaining in the flask, the flask is allowed to cool and then weighed. Having carefully measured 0.05 moles of baking soda at the outset of the experiment, students then expect to get <u>exactly</u> 0.05 moles of sodium acetate at the end of the experiment. While none of the students measured a mass of sodium acetate equivalent to 0.05 moles, the majority of students achieved a percentage yield of 90% or greater.

The study was concluded with a review of the topics covered in the six phases with the post-test to assess student learning completed on the following day.

Assessments for the study included an introductory survey (Appendix D-I) given on the first day of the study along with a pre-test (Appendix D-II) to determine what unit objectives, if any, had been mastered in previous science courses. Throughout the implementation of the unit students wrote Weekly Reflections (Appendix D-VIII) each Friday which included a summary of the concepts studied during the week, the process used to study those concepts, and the student's attitude about what they had learned during the week. After the completion of the first three phases of instruction, an exit survey (Appendix D-IV) was given in order to gauge students' perceptions about how successful they felt they were in mastering the objectives. At the completion of phase six, a second exit survey was given (Appendix D-V). At the conclusion of the study the post-test was administered (Appendix D-VI) to determine what objectives student's had mastered during the instruction. Finally after the post-test students completed a Test Self-Evaluation (Appendix D-VII) which allowed for the collection of anecdotal data regarding test preparation and what the students felt they had learned during the unit.

RESULTS

Introductory Survey

At the beginning of the study an Introductory Survey (Appendix D-I) was given in order to gain insight into students' goals and perceptions about what helps them learn the most in a science class. The data is summarized in Table 3.

Table 3: Introductory Survey Data

Plan to attend college or trade school	100 %
Plan to take chemistry in college	48 %
Plan to study science or medicine in college	71 %
Science is best subject	0 %
Typically has trouble in science	19 %
Math is best subject	48 %
Typical math grade is an A	52 %
Typical math grade is an B	58%
Always solve story problems	23 %
Usually solve story problems	61 %
Usually solve story problems with assistance	10 %
Rarely solve story problems	3 %
Learns most from lecture	32 %
Learns most from lab	23 %
Enjoys lecture most	3 %
Enjoys lab most	65 %
Enjoys homework least	32 %
In the lab: enjoys mixing chemicals most	58 %
In the lab: learns the most from making sense of results	52 %
In the lab: learns the least from writing own procedure	49 %

All of the students surveyed answered that they planned to go to college or trade school after high school. 48% plan to take a chemistry class in college. This suggests that less than half of the students surveyed actually wanted to be in the class and learn chemistry. Yet 71 % answered that they would study science or medicine in college. The numbers do not add up, if 71% plan to study science or medicine, then 71% should plan to take chemistry in college. This appears to be a misconception students have regarding college and careers. They assume their future studies will be very narrow and in only one discipline when in reality the requirements for a college degree include courses from outside the major area of study and it is mandatory that in studying science, chemistry will be included and in studying medicine, chemistry definitely will be included.

The majority of the students surveyed (52%) responded that a typical math grade for them was an A and in science class the majority (58%) responded that a typical grade was a B. 48 % chose math as their best subject and zero chose science as their best subject. In fact, 19% chose science as the class with which they typically have trouble. When considering story problems, such as those commonly found in stoichiometry, 23 % responded that they always solve the problem, 61 % responded that they can usually solve the problem, 10% could solve the problem with help and 3% could rarely solve the problem.

In terms of methods of learning, the majority of students felt that they learned the most from lectures, with 32% choosing that mode as the most effective while 23 % responded that they learn the most from labs. As for what students like best, only 3 % like lectures, and 65% like the labs best. Homework is the part of science class that students like the least at 32%. Focusing specifically on lab work, students most enjoy mixing the chemicals (58%) but feel that they learn the most from making sense of the results of the lab. Nearly a majority of students (49%) felt that they learned the least from writing their own procedures, which they had done prior to this unit.

Pre-Test

A pretest (Appendix D-II) was given to students to assess prior knowledge. Some of the content of this study is taught in ninth grade physical science and therefore students should have some basic skills. In particular, Ninth grade students receive instruction in indicators that a chemical reaction has taken place, the law of conservation of mass, balancing equations, and types of chemical reactions.

Of the 18 students participating in the study, three of them demonstrated prior knowledge on the pretest as shown in Figure 3. Of those three, all were able to classify a chemical reaction by type and one of the three was also able to balance a chemical equation. The remaining 15 students were unable to answer any of the 10 questions correctly. Overall the prior knowledge of the group of participants was low, as expected.

Post-Test

At the conclusion of the study a post-test was given that was identical to the pre-test. The overall performance of the group was much better, a summary of the data is below in Figure 3. The lowest score was 2 out of 10, a test that was left mostly blank, and the highest score was 10 out of 10. Ironically the student who scored 10 out of 10 wrote in her weekly reflections for the class that she had not learned anything. Figure 3 below comparing pre-test and post-test scores shows that indeed she did learn something.

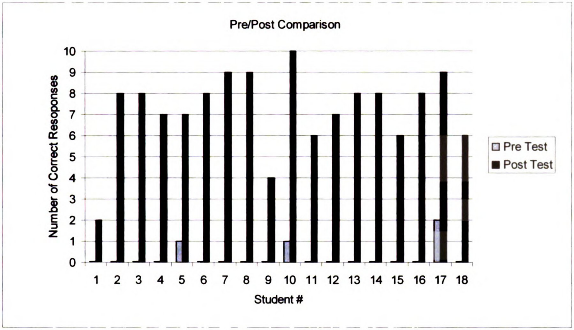


Figure 3: Pre-test/Post-test Comparison

Figure 4 summarizes the student responses for the post-test by item number. Each item number corresponds to an objective of the unit. Most items required the student to be successful multiple times. For example, item number 3 required students to balance 4 chemical reactions. The response was only counted as correct if the student balanced all four equations correctly.

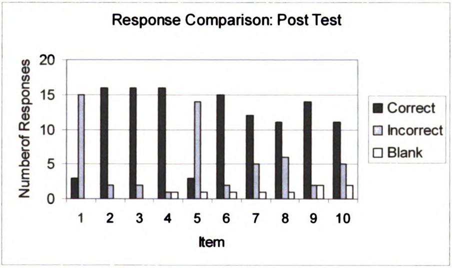


Figure 4: Post-Test Response Comparison by Item Number

Post-Test Item Analysis

Item 1 asked students to list the three requirements for a correctly written chemical equation. Following instruction only 17 %, or 3 of the 18 students, could correctly list all three. A response was counted as correct only if the student had all three requirements. Responses with two of three correct were counted as incorrect. A plausible reason for this is that item 1 was the first objective presented and after six weeks of studying reactions and stoichiometry, students focused much more on the quantitative aspects rather than on "simple" definitions such as this.

Item 2 required students to classify 4 chemical reactions by type and 16 of the 18, or 89%, were able to get all 4 correct. This was the area in which students had previous knowledge as was shown on the pre-test. Item 3 consisted of balancing 4 chemical equations, and again 89% of students were successful. Item 4 asked students to interpret the meaning of a chemical symbol, specifically the symbol (aq) which means the aqueous, and once again 89% students were successful.

Item 5 asked students to use the activity series to predict whether a given reaction would occur and what the products would be for four given reactions. Only 3 of the 18 participants, or 17%, completed the entire task successfully with correct responses for all four reactions. An additional 5 students managed to write correct, balanced equations for 3 of the 4 reactions, and 6 students wrote correct balanced equations for 2 of the reactions. Errors included failure to properly use the activity series, incorrect formulas written for products, and incorrect balancing of the reactions with the first two types of errors far outweighing the third. This was a difficult, daunting item for students even though they had practiced a similar task in homework. In a written Test Self-Evaluation (Appendix D-VII) following the post-test one student wrote that reading the beginning of a reaction, such as

$$Ni\ (s) + CuCl \rightarrow \_\_\_\_\_\_\_\_$$

they felt overwhelmed and gave up. Students had to decide first whether a reaction would occur based on the activity series, then determine the products, write the correct formulas for the products, and finally balance the reaction. It is reasonable that students felt overwhelmed in that they needed to be correct in 4 steps in each of the 4 equations in order to be correct for this item.

Item six asked students to define stoichiometry and explain how chemists use stoichiometry. 83% or 15 of the participants were able to do so successfully. One of the students simply gave the definition of stoichiometry with no explanation of its use, one student began to write an answer but failed to finish it, and one student left the question blank. In fact, the student left the entire page blank.

In item seven, students were asked to describe a method for determining which of two reactants is the limiting reactant. 12 students, or 67%, were able to correctly describe a method for determining the limiting reactant. One student, rather than answer the question asked, gave a rule of thumb and wrote, "The limiting reactant is usually the heavier reactant." The term "heavier" likely means the reactant with the higher molar mass. Item 8 asked students to compare actual yield to theoretical yield. 16 students, or 83 %, answered correctly, the two incorrect responses were both left blank.

Item nine was a quantitative problem in which students were required to determine the number of moles of product formed when given the mass of one of the reactants for a double replacement reaction they had observed in the lab. 13 responses, or 78%, were correct with 2 students who left the question blank. Of the incorrect responses, three students apparently did not refer to the balanced equation and failed use the coefficients properly in mole ratios.

The final item was a quantitative problem in which students were to determine the mass of reactant required to produce a given mass of product for a decomposition reaction. There were 10 correct responses, 61%, and 2 blank. Of the incorrect responses, 5 of them included only one error in calculating a molar mass. These 5 students had correctly used the coefficients of the equation, but made errors in calculating mass from the periodic table.

Exit Surveys

Two exit surveys were given during the unit. The first at the completion of phase three and the second at the completion of page six. Each survey contained two sections, the first dealt with learning objectives and in the second section students were asked to rank the classroom activities in terms of how helpful they felt the activities were.

Table 4 below shows a summary of student responses for the first section of exit survey 1.

Table 4: Summary of Skill Responses for Exit Survey 1

Describe how successfully you can use these skills:	Rarely	Some-times	Often	Usually	Always
Identify observations that a chemical reaction has taken place	0%	18%	4%	43%	36%
Identify a correctly written chemical equation	7%	43%	25%	18%	7%
Write a word equation from a given formula equation	11%	14%	29%	29%	18%
Write a formula equation from a given word equation	0%	11%	21%	43%	25%
Balance a formula equation	0%	11%	21%	25%	4%
Classify a chemical equation according to its type	21%	29%	32%	18%	18%
Predict the products of simple reactions given the reactants	21%	29%	21%	25%	4%
Use the activity series to predict whether a reaction will occur and what the products will be	14%	25%	25%	29%	7%

It is interesting that a total of 29% of students felt that they could always or usually balance a chemical equation whereas the post-test data showed that 89% of students had mastered this skill. Students often underestimate their skills. Only 36 % felt that they could always or usually classify a reaction according to its type, yet on the post test 89% of students were able to do so. It is unlikely that the students just managed to "get lucky" and guess correctly because for both of these skills the post-test required 4 correct answers in order for the response to be counted as correct.

When it comes to using the activity series to predict whether a reaction will occur and what the products will be students' perceptions about their abilities were a little bit closer to reality. 36% responded that they could usually or always accomplish this task successfully and 17% had 4 correct responses for item 5 on the post-test.

Table 5 shows student responses for the second section of exit survey 1.

Table 5: Summary of Activity Responses for Exit Survey 1

Describe how helpful these activities were	Not Helpful	Some-what Helpful	Helpful	Very Helpful
PowerPoint® Presentations	0%	21%	50%	29%
Burger Chem Lessons	4%	39%	39%	18%
Balancing Race	7%	32%	32%	29%
Symbol Stories	36%	36%	25%	4%
Types of Reactions Lab	4%	14%	50%	32%
Recycling Copper Lab	11%	21%	36%	32%
In-Class Demonstrations	0%	14%	36%	50%
Reading the Text	29%	54%	18%	0%
Homework Papers	11%	29%	43%	18%

Students apparently found the majority of the instructional activities to be helpful. There were not any activities that had a larger percentage of students rank it as "not helpful" versus those that ranked it helpful. The least helpful items were writing symbol stories and reading the text. The most helpful items were in-class demonstrations and the lab activities.

The *Burger Chem* lessons were a worthwhile activity to use. One of the students in the group suffers from attention deficit disorder and was very thankful to have the opportunity to use the burger models in chemistry. During the study she underwent therapy and changes in her medication and when asked by the doctor about school she mentioned the *Burger Chem* activities and how much they had helped her in chemistry. I received a note from the counseling office regarding this exchange and praising my efforts to keep this student engaged in chemistry. A total of 57% of students ranked the *Burger Chem* activities as helpful or very helpful. This, along with the high ranking of lab activities, indicates that high school students do still require instruction about abstract concepts to begin at the concrete level.

Table 6 shows student responses for the first section of exit survey 2.

Table 6: Summary of Skill Responses for Exit Survey 2

Describe how successfully you can use these skills:	Rarely	Some-times	Often	Usually	Always
Write a mole ratio relating two substances in a chemical equation	0%	5%	5%	42%	47%
Calculate the amount in moles of a reactant or product from the amount in moles of a different reactant or product.	0%	5%	16%	32%	47%
Calculate the mass of a reactant or product from the amount in moles of a different reactant or product.	0%	11%	5%	42%	42%
Calculate the amount in moles of a reactant or product from the mass of a different reactant or product.	0%	11%	16%	26%	47%
Calculate the mass of a reactant or product from the mass of a different reactant or product.	5%	5%	16%	32%	42%
Identify the limiting reactant in a chemical reaction.	5%	5%	11%	53%	26%
Calculate the amount of product (either mass or moles) in a limiting reactant problem.	11%	16%	26%	32%	16%
Calculate percent yield, given the actual yield and quantity of a reactant.	0%	5%	5%	37%	53%

The data in Table 6 shows that students had more confidence in their abilities in section 2 with fewer responses of "rarely". A direct comparison to the post-test can be made for calculating the amount in moles of a reactant or product from the mass of a different reactant or product as that was they type of question asked in item 9. Of the students surveyed, 74% responded usually or always for making this type of calculation. On the post-test 78% were in fact able to do so. This is the closest match of student's perceptions to what they achieved on the post-test.

Item ten on the post test asked students to calculate the amount of product in moles in a limiting reactant problem. 61% of the participants were able to complete the calculation without any errors. Only 48% felt that they could usually or always complete such a calculation successfully.

Table 7 below shows a summary of student responses for the second section of exit survey 2.

Table 7: Summary of Activity Responses for Exit Survey 2

Describe how helpful these activities were	Not Helpful	Some-what Helpful	Helpful	Very Helpful
PowerPoint® Presentations	11%	5%	53%	32%
Burger Chem Lessons	11%	47%	32%	11%
S'mores Lab	11%	32%	32%	26%
Finding Stoichiometric Coefficients Lab	5%	26%	63%	5%
Percent Yield Lab	0%	32%	58%	11%
Problem Solving Modeling by Teacher	0%	11%	42%	47%
Reading the Text	53%	37%	11%	0%
Homework Papers	5%	16%	53%	26%

In this section students felt that the modeling of problem solving by the teacher was most helpful to them with 89% ranking this as helpful or very helpful whereas reading the text was least helpful, even less helpful than in the previous section. This focus of the section was quantitative and it stands to reason that reading about problem solving is less helpful than actually practicing it. Students even felt that the homework was helpful to them in this section, ranking the homework higher than the lab activities.

Two of the three lab activities were quite helpful to students with 68% ranking them as helpful or very helpful. Students did not find the S'more lab to be as helpful as the others. The S'more lab provided a simple model, based on a recipe, for a chemical reaction. Perhaps the model was too simple. Students had a difficult time answering the post-lab questions and making the connection between the recipe they used in the lab and the reality of solving chemistry problems. Overall, the students felt that the activities were helpful and aided them in learning about chemical reactions and stoichiometry.

DISCUSSION AND CONCLUSION

Overall, the data collected indicates that including concrete activities in a unit about reactions and stoichiometry helps high school students to learn these concepts well. In comparing the pre-test scores to the post-test scores, the average improvement was 70% for the group. Although some students still struggled to master the difficult content, several wrote in their Weekly Reflections (Appendix D-VII) for portfolios that the concrete activities, laboratory activities and *Burger Chem* in particular, helped them to understand the molecular events that take place during a chemical reaction.

The post-test required multiple successes, such as four correctly balanced equations for that particular item to be counted as a correct response. Students could not just "get lucky", they had to demonstrate mastery. Three students achieved 9 out of 10 on the post-test. Two of those three had no correct responses on the pre-test. One student achieved a perfect score on the post-test and yet insists that she learned nothing from the unit. The difference in the pre-test and post-test scores was pointed out to her and she merely shrugged. An increase from 10% to 100% indicates that she learned something whether she is willing to admit it or not. There is no question that she improved. The unit was successful; the students that participated and did the work learned stoichiometry and were able to demonstrate the knowledge on the post-test.

The lowest grade on the post-test was 2 out of 10 and belonged to a student who neither participated in class activities nor completed her homework. Despite attempts to engage her and calls to her mother, her attitude did not change. She did spend time after school for individual help, but failed to show any improvement. This student reminded me of the students that Patricia Smith wrote about who say "I can solve the problem if you set it up" (Smith, 1978). In our after-school sessions, she would start her homework with my assistance, but she would never, in this case it was literally never, follow through and finish her homework on her own. The student did not accept responsibility in her role as a learner and there was little that I could do to help her. This student was also a transfer from a different state and arrived approximately one month before this unit was taught. This put her at a disadvantage for the remainder of the year as students who had been in the class all year had already learned how to read the periodic table, write formulas and calculate the amounts of substances in moles. Without these prerequisite skills, it was very difficult for this student. She commented on more than one occasion that her old school did not teach chemistry at the same pace as it is taught at Redford Union. However, I do not believe that the pace at Redford Union is particularly fast. In speaking with chemistry teachers from other high schools, most keep a similar or even faster pace.

The series of *Burger Chem* lessons, were successful. Table 5 shows that 57% ranked the *Burger Chem* lessons as helpful or very helpful. Students enjoyed using the burger models to build the sandwiches and were able to understand the rearrangement of the burger components to form new sandwiches as a model for a chemical reaction in the Formulas and Equations exercise. When I asked the students if any components had been created or destroyed in the process of rearranging the burger components they all looked down at their models before answering. This event made it clear to me that students do in fact have difficulty dealing with the abstract concept of a chemical reaction. They needed the reassurance from the models before they were willing to give an answer. After they looked and discovered that they still had exactly the same burger components, just rearranged, one of the students said, "Oh!" That sound was enough to prove the lesson worthwhile. Furthermore, the *Burger Chem* lessons provided cooperative learning with problem solving. Students discussed the processes that they needed to use in order to solve the problem The time limit for problem solving worked quite well; all of the students were on task during the group work time.

Another activity that was particularly memorable to the students, according to Weekly Reflections, was the visualization of chemical reactions with stick figures. Even at the end of the year, months after the lesson, they remember that decomposition is the equivalent of stick figure "divorce". Unfortunately this lesson was not included on the exit-survey and thus student perceptions can not be quantified. However, student writings in portfolios included stick figures as a highlight of the unit.

The most unpopular activity was the writing of *Symbol Stories*, with 36 % of students ranking it not helpful (Table 5). This assignment required students to be creative and write a story in which chemical symbols could be used in place of words. While this assignment is wonderful from the standpoint of including writing across the curriculum, students who are worried about understanding chemistry felt that this creative assignment was a waste of time and energy and did not help them to better understand the symbols used in chemistry. This is an assignment that I will not likely use again based on the results of the exit survey data. Students did not find the assignment helpful. I would rather spend time on items that they felt were helpful to them in learning reactions and stoichiometry.

All of the laboratory activities were successful in that the reactions occurred as planned and there were no unforeseen difficulties. Students enjoyed the *Types of Reactions Lab* in its simplicity as there was no quantitative data to be collected and analyzed. This lab was adapted from a set of demonstrations that had been done in previous years. Previously, rather than spend a day in the lab, demonstrations were done to show each type of reaction. This year in order to increase the interaction of students with the concepts they were learning, the demonstrations were adapted to a lab format. I found that this was worth the time spent in the lab. Students were able to write their own observations for each reaction and use the information they had learned in class on that very subject. The ability to recognize the physical changes that indicate that a chemical reaction has taken place was a skill that the students needed for future labs. The types of reactions lab gave them the opportunity to make those observations on their own rather than having them pointed out by a teacher.

Less popular were the *Recycling Copper Lab* and the *Finding Stoichiometric Coefficients Lab*. Table 5 shows that 11% of students ranked the *Recycling Copper Lab* as not helpful. Table 7 shows that 5 % ranked the *Finding Stoichiometric Coefficients Lab* as not helpful. Although less popular, the majority of students felt that these labs were helpful. *The Recycling Copper Lab* required the students to write five balanced chemical reactions when given the reactants and the reaction type. Students who asked for help usually only required assistance with the first reaction and once they understood the task, they were able to complete the other four reactions.

In the *Finding Coefficients Lab* many students required assistance when working to turn their calculated mole ratios into stoichiometric coefficients. This step required the students to use their mathematical knowledge in order to scale the numbers up and many were unable to do so without assistance from either myself or other students. One lab group skipped using the mole ratios altogether and simply wrote the balanced equation from their knowledge of the reaction, rather than from data collected during the experiment.

The *S'mores Lab* originally written as a demonstration by Linda Cain (Cain 1986) and adapted into a laboratory activity to show the analogy between stoichiometry and recipes. The idea was that students would realize that in using recipes, they already know how to make stoichiometric calculations. While the students enjoyed having S'mores for a snack, the questions they asked following the lab showed that they were not easily able to make the connection between the recipe and chemical reactions. Perhaps a pre-lab discussion which involves the calculation of "moles of marshmallow" would help students to understand where the lab is going to take them. In the future pre-lab questions will be written to assist students in getting ready to think about moles in the recipe analogy.

As I continue to teach chemistry I will incorporate concrete activities into the curriculum. As the saying goes, we have to play the hand we are dealt. In high school General Chemistry there will always be concrete level students in the course and it will always be my job to teach them to the best of my ability. This study has proved to me that it is not that concrete students are unable to learn stoichiometry, but that they require the special support of hands-on concrete models as well as strong mental models in order to be able to handle the level of abstraction in chemistry.

Appendix A

Classroom Activities

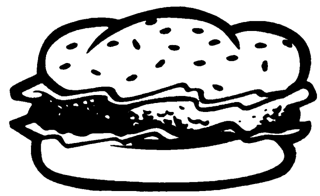
Appendix A-I

Burger Chem **Formulas & Equations**

Mrs. Scott is having a meeting of the Mega-League Principals and has asked you to order lunch from a hamburger chain called Burger Chem that makes sandwiches using two or three identical slices of bread. You ordered 100 MacChem sandwiches, but somebody made a mistake and 100 HambChem and 100 CheeseChem were delivered instead. You need to convert these other types of sandwiches into 100 MacChem before Mrs. Scott notices the error.

How many HambChem and CheeseChem do you need to obtain 100 MacChem sandwiches if compositions are:

Sandwich	**Bread (B)**	**Cheese (Ch)**	**Patties (P)**
HambChem	2	0	2
CheeseChem	2	2	0
MacChem	3	1	2



Try to think about this as a cook/chemist. A cook uses a recipe, a chemist uses a formula.

1. Write formulas for each of the sandwiches listed in the table above.

   HambChem: ______________________

   CheeseChem: ____________________

   MacChem: _______________________

2. Write the formulas for the reactants (stuff you're putting in).

3. Write the formula for the product (stuff you'll get at the end).

Appendix A-I

4. Write an equation that represents the change in sandwiches that is to occur.

5. Using the equation you wrote in number 4; use coefficients to represent the amounts of sandwiches. Balance the equation you wrote – make sure each side had the same amount of bread, same amount of cheese, same amount of patties.

Burger Chem:
Formulas and Equations Presentation

The Problem

- The Mega League Principals Meeting is expecting lunch in the RU Library.
- We ordered 100 MacChems but 100 HambChem and 100 CheeseChems were delivered.
- Oh no!
- We need to fix this before those principals finds out!

What We Know

- We have 100 HambChems and 100 CheeseChems.
- We need 100 MacChems.

Sandwich	Bread (B)	Cheese (Ch)	Patties (P)
HambChem	2	0	2
CheeseChem	2	2	0
MacChem	3	1	2

Let's simplify this by writing sandwich formulas.

Let's Write a Burger Equation

- We have 100 HambChems (B_2P_2) and 100 CheeseChems (B_2Ch_2.)
- We need 100 MacChems (B_3P_2Ch) .

Reactants → Products

(what we have) → (what we get)

$B_2P_2 + B_2Ch_2 \rightarrow B_3P_2Ch$ + leftovers?

What about coefficients?

$B_2P_2 + B_2Ch_2 \rightarrow B_3P_2Ch$ + leftovers

- We have 100 HambChems (B_2P_2) and 100 CheeseChems (B_2Ch_2.)
- We need 100 MacChems (B_3P_2Ch) .

100 B_2P_2 + 100 $B_2Ch_2 \rightarrow$ 100 B_3P_2Ch + leftovers

Predict the leftovers

$100\ B_2P_2 + 100\ B_2Ch_2 \rightarrow 100\ B_3P_2Ch$ + leftovers

400	B	300
200	P	200
200	Ch	100

At the end we will have 100 B, 0 P and 100 Ch.

We can make CheeseChems with that!

How many can we make?

Predict the leftovers

$100\ B_2P_2 + 100\ B_2Ch_2 \rightarrow 100\ B_3P_2Ch + 50\ B_2Ch_2$

400	B	~~300~~	400
200	P	200	
200	Ch	~~100~~	200

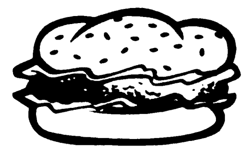
With 100 B, 0 P and 100 Ch, how many B_2Ch_2 can we make?

50

Questions to Answer

- What does a chemical formula tell you?
- **What does a chemical equation tell you?**

According to your textbook, what is the law of conservation of mass?



Use the data below to answer the questions that follow.

Item	Symbol	Mass
Bread	B	25 g
Patty	P	80 g
Cheese	Ch	15 g

1. What is the mass of 100 MacChem (B_3P_2Ch) sandwiches?

2. Is there any relationship between the mass of 100 MacChem (B_3P_2Ch) sandwiches and the masses of 100 HambChem (B_3P_2) plus 50 CheeseChem (B_2Ch_2)?
   If so, what is it?
   If not, why not?

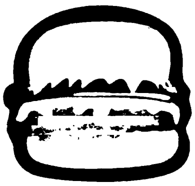
3. State the law of conservation of mass in your own words.

Burger Chem:
Mass Conservation Presentation

Mass Relationships

- What is the mass of 100 MacChem (B_3P_2Ch) sandwiches?

Item	Symbol	Mass
Bread	B	25 g
Patty	P	80 g
Cheese	Ch	15 g



(Subscript) x (Item Mass) = Total Item Mass

Sum of Total Items = Mass of Sandwich

Mass Relationships

- Let's find the mass of one MacChem (B_3P_2Ch) sandwich first.

Bread Mass: $3 \times 25g = 75g$

Patty Mass: $2 \times 80g = 160g$

Cheese Mass: $1 \times 15g = 15g$

B_3P_2Ch Mass: $= 250g$

The mass of 100 MacChems would be: 2500 g or 2.5 kg

Mass Relationships

- Is there a relationship between the mass of 100 MacChems and the masses of 100 HambChems plus 50 CheeseChems?

Of Course!

$$100\ B_2P_2 + 100\ B_2Ch_2 \rightarrow 100\ B_3P_2Ch + 50\ B_2Ch_2$$

Mass in equals mass out.

Atoms in equals atoms out.

Questions to Answer

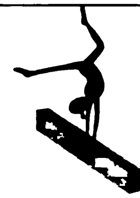
- What does a chemical formula tell you?

- What does a chemical equation tell you?

Appendix A-III

RACE: Balancing Chemical Equations

Balance the equations below showing all work. Each time you complete a section, bring it up to be checked before proceeding to the next section.



Balance with care.

1. ____ N_2 + ____ H_2 → ____ NH_3

2. ____ $KClO_3$ → ____ KCl + ____ O_2

3. ____ $NaCl$ + ____ F_2 → ____ NaF + ____ Cl_2

4. ____ H_2 + ____ O_2 → ____ H_2O

5. ____ $Pb(OH)_2$ + ____ HCl → ____ H_2O + ____ $PbCl_2$

6. ____ $AlBr_3$ + ____ K_2SO_4 → ____ KBr + ____ $Al_2(SO_4)_3$

7. ____ CH_4 + ____ O_2 → ____ CO_2 + ____ H_2O

End of Section 1: Time to Check-In

8. ____ C_3H_8 + ____ O_2 → ____ CO_2 + ____ H_2O

9. ____ C_8H_{18} + ____ O_2 → ____ CO_2 + ____ H_2O

10. ____ $FeCl_3$ + ____ NaOH → ____ $Fe(OH)_3$ + ____NaCl

11. ____ P + ____O_2 → ____P_2O_5

12. ____ Na + ____ H_2O → ____ NaOH + ____H_2

13. ____ Ag_2O → ____ Ag + ____O_2

14. ____ S_8 + ____O_2 → ____ SO_3

End of Section 2: Time to Check-In

Appendix A-III

15. ____ CO_2 + ____ H_2O → ____ $C_6H_{12}O_6$ + ____ O_2

16. ____ K + ____ $MgBr_2$ → ____ KBr + ____ Mg

17. ____ HCl + ____ $CaCO_3$ → ____ $CaCl_2$ + ____ H_2O + ____ CO_2

18. ____ HNO_3 + ____ $NaHCO_3$ → ____ $NaNO_3$ + ____ H_2O + ____ CO_2

19. ____ H_2O + ____ O_2 → ____ H_2O_2

20. ____ NaBr + ____ CaF_2 → ____ NaF + ____ $CaBr_2$

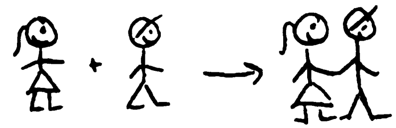
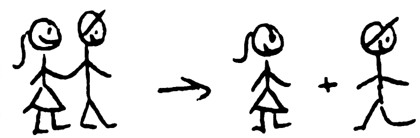
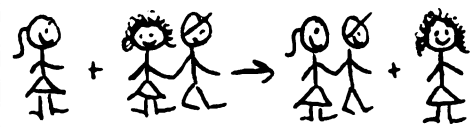
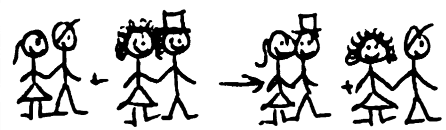
21. ____ H_2SO_4 + ____ $NaNO_2$ → ____ HNO_2 + ____ Na_2SO_4

End of Section 3: Time to Check-In

Appendix A-IV

Types of Chemical Reactions

Type	Definition	General Equation	Artist's Rendering

Types of Chemical Reactions			
Type	**Definition**	**General Equation**	**Artist's Rendering**
Synthesis	When 2 or more simple substances combine to form a new, more complex substance.	A + B → AB	
Decomposition	When a complex substance breaks down into two or more simpler substances.	AB → A + B	
Single Replacement	When an uncombined element replaces another element as part of a compound.	A + BC → AC + B	
Double Replacement	When different atoms from different compounds replace each other in those compounds. The positive ions swap negative partners.	AB + CD → AD + CB	
Combustion	Hydrocarbons combine with oxygen to produce light and heat. The products are always carbon dioxide and water.	$C_xH_x + O_2 \rightarrow CO_2 + H_2O$	Drawings varied.

Burger Chem **Limiting Component**

In an earlier exercise, *Formulas and Equations*, you were asked to make 100 MacChem sandwiches from a delivery of 100 HambChem and 100 CheeseChem sandwiches.

Important information:

Item	Symbol	Mass
Bread	B	25 g
Patty	P	80 g
Cheese	Ch	15 g

Sandwich	Formula
HambChem	B_3P_2
CheeseChem	B_2Ch_2
MacChem	B_3P_2Ch

1. How many MacChem sandwiches could be made from a delivery of 10 kg HambChem and 10 Kg CheeseChem sandwiches?

2. Why did you eventually have to stop making MacChem sandwiches?

3. What sandwich determined the total number of MacChem sandwiches that could be made?

4. What have you learned about the limiting component in a chemical reaction?

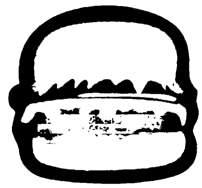
Appendix A-V

Burger Chem:
Limiting Component Presentation

Limiting Component

- How many MacChems (B_3P_2Ch) could be made from 10 kg HambChem (B_3H_2)and 10 kg CheeseChem (B_2Ch_2)?

Item	**Symbol**	**Mass**
Bread	B	25 g
Patty	P	80 g
Cheese	Ch	15 g



Let's figure out how many HambChems & CheeseChems we actually have.

Limiting Component

What is the mass of a HambChem? **235 g**

What is the mass of a CheeseChem? **80 g**

What is the mass of a MacChem? **250 g**

How many HambChems are in 10 kg?

$\frac{10{,}000\ g}{235\ g}$ = **42.6 HambChems = 42 HambChems**

How many CheeseChems are in 10 kg?

$\frac{10{,}000\ g}{80\ g}$ = **125 CheeseChems = 125 CheeseChms**

Limiting Component

- We have 42 HambChems and 125 CheeseChems. How many MacChems can we make? **42**

$42\ B_2P_2 + 125\ B_2Ch_2 \rightarrow B_3P_2Ch + B_2Ch_2$

What component will we run out of first?

The patties.

There are 2 patties in a HambChem and 2 in a MacChem.

When we run out of HambChems, we're done.

Questions to Answer

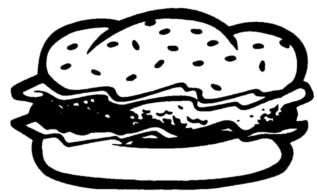
- Why did we have to stop making MacChems?
- What sandwich determined the number of MacChems that could be made?
- What did you learn about the limiting component?

Appendix A-VI

Burger Chem **Yield**

In an earlier exercise, *Formulas and Equations*, you were asked to make 100 MacChem sandwiches from a delivery of 100 HambChem and 100 CheeseChem sandwiches. This time your job is further complicated by damage to some of the sandwiches. 20% of the HambChems were ruined during the assembling of the MacChems.

Sandwich	**Formula**
HambChem	B_3P_2
CheeseChem	B_2Ch_2
MacChem	B_3P_2Ch



1. How many MacChems can you produce?

2. How has the destruction of 20 % of the HambChems affected the efficiency of the whole process?

3. How does the limiting component in a chemical reaction effect the efficiency (or yield) of the reaction?

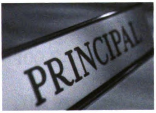
Burger Chem:
Yield Presentation

Yield

- Theoretical Yield: The calculated amount of product you expect to get in an experiment
- Actual Yield: The amount of product you actually get (measured amount).
- Percent Yield:

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theo. yield}} \times 100\%$$

The Problem



- The Mega League Principals Meeting is expecting lunch in the RU Library.
- We ordered 100 MacChems but 100 HambChem and 100 CheeseChems were delivered.
- Oh no!
- We need to fix this before those principals finds out!

Delegating work…

- Being very busy, you grab a group of reliable looking freshmen.
- You set them to work rearranging the sandwiches.
- This crack squad of savvy kids damages 20% of the HambChems.
- How many MacChems can you produce now?

Recall Our Burger Equation

- We had 100 HambChems (B_2P_2) and 100 CheeseChems (B_2Ch_2.)
- We need 100 MacChems (B_3P_2Ch) .

$$100\ B_2P_2 + 100\ B_2Ch_2 \rightarrow 100\ B_3P_2Ch + 50\ B_2Ch_2$$

The freshmen destroyed 20% our HambChems.

We have 80 left.

Now what?

Recall Our Burger Equation

$100\ B_2P_2 + 100\ B_2Ch_2 \rightarrow 100\ B_3P_2Ch + 50\ B_2Ch_2$

From our equation we know that if we have 100 HambChems we can make 100 MacChems.

With 80 HambChems, we can make 80 MacChems.

This is a one to one relationship; the coefficients are the same.

Questions to Answer

- How has the destruction of 20% of the HambChems affected the efficiency of the whole process?

- How does the limiting component in a chemical reaction effect the efficiency (or yield) of the reaction.

Appendix B

Laboratory Experiences

Appendix B-I

Types of Chemical Reactions

In this lab you will be investigating the four types of reactions that we studied in class. Each lab station will take 10-15 minutes. If you finish before time is called, use the extra moments to answer questions at the end of each station. Each station will support more than one pair of experimenters; share nicely. It is important to wear goggles at every station, even if you are answering questions. Chemicals are in use around you and you have only one set of eyes.

Purpose:
To gain an understanding of the five types of reactions by performing each type as well as writing an equation for each type.

Materials:
Materials for this lab are organized by station. At each station, goggles are required.

Station 1	Station 2	Station 3	Station 4	Station 5
Magnesium Ribbon	Copper (II) sulfate pentahydrate	1 piece of mossy zinc	0.25 M potassium iodide	Ethanol
Bunsen Burner	Ring stand	10 mL beaker	0.125 M lead nitrate	pipet
Tongs	Clay triangle	pipet	watch glass	watch glass
	Bunsen burner	5 M nitric acid	waste beaker	1 match
	forceps	gloves	pipet	
	crucible			
	Waste beaker			

Procedures:
Station 1: Synthesis Reaction

At this station, you will observe the reaction of magnesium metal with atmospheric oxygen to form magnesium oxide. This reaction gives off a great deal of light and heat.

1. Obtain a small piece of magnesium ribbon (about 5 cm in length).

2. Light a Bunsen burner and adjust it so that the blue cone of the flame is clearly visible.

3. Using your crucible tongs, hold the magnesium ribbon directly over the blue cone of the flame until the reaction starts.

4. Record your observations.

5. When the reaction is finished, clean up your lab station by sweeping the magnesium oxide residue into the trash.

<u>Station 2: Decomposition Reaction</u>

At this station you will decompose copper (II) sulfate pentahydrate into copper (II) sulfate anhydrate and water.

1. Set up a ring stand with a ring, clay triangle, and Bunsen burner.

2. Use forceps to place a crystal of copper (II) sulfate pentahydrate into a crucible. Use your crucible tongs to place the crucible in the clay triangle.

3. Light the Bunsen burner and heat the crucible for five minutes.

4. Record your observations.

5. When the crystal no longer appears to be changing color, turn off the Bunsen burner and let the crucible cool for five minutes. The copper (II) sulfate anhydrate should be placed into the labeled waste beaker for recycling.

<u>Station 3: Single Replacement Reaction</u>

At this station you will be observing the reaction between metal zinc and nitric acid, HNO_3 to form hydrogen gas and zinc nitrate.

1. In the fume hood, place a piece of mossy zinc into the 10 mL beaker.

2. Put on a pair of rubber gloves before handling the nitric acid.

CAUTION **Nitric acid is corrosive! Wear safety goggles. Avoid contact with skin and eyes. Avoid breathing vapors. If you spill some on you immediately flush the area with water and notify your teacher.**

3. Fill a pipet with 5 M nitric acid and squeeze it into the 10 mL beaker.

4. Record your observations.

5. When the reaction has stopped, carefully pour the contents of the 10 mL beaker into the waste beaker containing sodium bicarbonate. This will neutralize the remaining nitric acid. Wipe the countertop in the fume hood with a paper towel to ensure that no nitric acid droplets remain.

Station 4: Double Replacement Reaction

The reaction you will be observing is the reaction of lead (II) nitrate and potassium iodide to from dissolved potassium nitrate and lead (II) iodide precipitate. This reaction was once used in the manufacture of paint for household products. This reaction is no longer used due to the toxicity of lead.

1. In a watch glass, place drops of 0.25 M potassium iodide solution using the labeled pipet.

2. To this watch glass, add 5 drops of 0.125 M lead (II) nitrate solution using the labeled pipet.

3. Record your observations.

4. Rinse the precipitate into the labeled waste beaker.

Station 5: Combustion Reaction

At this station, you will observe the combustion of ethanol, C_2H_6O, a common gasoline additive.

1. Place about 10 drops of ethanol into a watch glass with a pipet.

2. Light and drop a match into the ethanol, making sure not to put your hand too close to the flame.

3. Record your observations.

4. Once it has cooled, throw the match into the trash.

Appendix B-I

Observations:

Station	Observations
1	
2	
3	
4	
5	

Analysis:

1. Station 1 Question: Write the chemical equation for the synthesis of magnesium oxide from magnesium and oxygen.

Appendix B-I

2. Station 2 question: Write the equation for the decomposition of copper (II) sulfate pentahydrate into copper (II) sulfate anhydrate and water.

3. Station 3 questions:
   a. Write the equation for the reaction you observed.

   b. What do you think the bubbles were that you saw being formed?

4. Station 4 questions:
   a. The precipitate you formed, lead (II) iodide, was once used as a pigment in paint for a common school product. What do you think used to be covered with this paint? Why?

   b. Why do two clear solutions form a colored compound when they are combined? After all, when you mix water with rubbing alcohol, the resulting solution is colorless.

   c. Write the equation for the reaction you observed at station 4.

Appendix B-I

5. Station 5 questions:
   a. Ethanol fires are far less hot than gasoline fires. This makes them safer to use in automobiles, but less capable of producing large amounts of energy. Keeping this in mind, do you think that ethanol is a good source of fuel for automobiles? Explain.

   b. Write the equation for the combustion of ethanol.

Appendix B-II

Recycling Copper

Background:

We can make a good new use of materials at the end of their natural life by recycling them. The material from the old object is reprocessed to make new things. Many recycled products undergo chemical processes to reclaim the material that is valuable. In this lab you will begin with a copper solution and end with copper metal which we will wash, dry and weigh to determine the amount of copper produced.

Pre-lab Questions:

1. Write the chemical formulas for the following:

   a. copper (II) nitrate ____________________________

   b. hydrochloric acid ____________________________

   c. sodium hydroxide ____________________________

2. List four indicators that a chemical change has taken place.

3. List and give the general equations for the four types of chemical reactions.

Reaction Type	General Equation

4. Explain the significance of the activity series. Can predictions be made about what will occur between two reactants based on the activity series?

Appendix B-II

Purpose: To put reaction writing and balancing skills to work in the recycling of copper.

Materials:

1.0 M copper (II) nitrate	ring stand	ruler
1.0 M hydrochloric acid	wire gauze	goggles
1.0 M sodium hydroxide	stirring rod	lab marker
100 mL beaker	Bunsen burner	filter paper
50 mL beaker	test tube	filter
12 cm aluminum wire	distilled water	

Procedure:

1. Place 50 mL of water in a 100 mL beaker and heat it. This will be the hot water bath used in step 5.

2. Use the lab marker to make 3 marks on the test tube that are 1 cm apart. Make the marks starting at the bottom of the test tube and moving toward the top. Measure accurately to insure that the proper volumes are marked.

3. Carefully place 1.0 M copper (II) nitrate to the first mark on the test tube.

4. Add 1.0 M sodium hydroxide up to the second mark on the test tube.

   CAUTION **Sodium hydroxide is corrosive. Be certain to wear safety goggles and avoid contact with skin and eyes. If you spill some on you immediately flush the area with water and notify your teacher.**

   Mix the solutions with the stirring rod. Rinse the stirring rod with water, then touch the outside of the test tube to see if heat has been released. Record your observations for reaction A.

5. Put the test tube into the water bath prepared in step 1. Heat it until no more changes occur. Record your observations for reaction B.

6. Remove the test tube from the hot water bath. Turn off the burner. Cool the test tube and its contents for 2 min in room temperature water. Add 1.0 M hydrochloric acid to the third mark on the test tube.

   CAUTION **Hydrochloric acid is corrosive. Be certain to wear safety goggles and avoid contact with skin and eyes. Avoid breathing vapors. If you spill some on you immediately flush the area with water and notify your teacher.**

   Mix with the stirring rod then rinse the stirring rod with water. Record your observations for reaction C.

7. Place a 12 cm piece of aluminum wire in the test tube. Leave it until no further reaction is observed. Touch the bottom of the test tube to check for any heat changes. Two reactions are taking place simultaneously in this step. Record your observations for reactions D & E.

8. Clean all glassware that you have used and your lab station. Return equipment to its proper place. Dispose of chemicals in the containers designated by your teacher. Do not pour any chemicals down the drain or in the trash. Wash your hands thoroughly before you leave the lab and after all work is finished.

Observations:

Reaction	**Observations**
A	
B	
C	
D & E	

Appendix B-II

Analysis:

1. Reaction A was a double replacement reaction. The reactants were copper (II) nitrate and sodium hydroxide. Use the activity series to write the complete balanced reaction below.

2. Reaction B involved the decomposition of the copper product of Reaction A. Refer to page 260 (Decomposition of Metal Hydroxides) of your textbook as well as the activity series to write the complete balanced reaction below.

3. Reaction C was a double replacement reaction between copper (II) oxide and hydrochloric acid. Use the activity series to write the complete balanced reaction below.

4. Reaction D was a single replacement reaction between the copper containing product of reaction C and aluminum. Use the activity series to write the complete balanced reaction below.

5. Reaction E involved the evolution of hydrogen gas. Use the activity series to write the complete balanced reaction below.

Appendix B-II

6. The chemical conversion of one product into another useful product is the basis for recycling. Explain how the type of reactions you observed in this experiment could be useful in the recycling of copper.

7. Do you think that people who design metal recycling processes need to know and use the activity series? Why or why not?

Appendix B-III

S'more Lab

Background:
S'mores are treats that campers enjoy making over a fire. The recipe for making a S'more is

$$2\,Gc + Mm + 2Cb \longrightarrow S'more$$

Just as a recipe tells you the amounts of ingredients you need, a chemical reaction tells you the amount of reactant needed to get a certain amount of product.

Purpose: To learn what stoichiometry is while using a simple recipe.

Materials: Graham crackers (Gc)
Marshmallows (Mm)
Mini Chocolate Bar (Cb)
Balance

Procedure:
1. Study the balanced reaction for making a S'more.

2. Gather the materials you need and record the mass of the reactants. Then add up the masses of all of the reactants to find the total mass of the reactants.

Mass of 1 Gc	
Mass of 2 Gc	
Mass of Mm	
Mass of 2 Cb	
Total Mass of Reactants	

3. Assemble your S'more then record the mass of the product.

Mass of S'more	
Total Mass of Products	

4. Do <u>NOT</u> eat your S'more until you have answered the Analysis questions.

Appendix B-III

Analysis:
Use the balanced equation from step 1 and your data to answer the following questions:

1. Does the total mass of reactants equal the total mass of the products? Use your data to support your answer.

2. Should the total mass of reactants equal the total mass of the products? Why or why not?

3. What law have you just verified?

Now you can eat the S'more.

Solve problems 4- 6 by using the masses that you obtained in your data table as if they were molar masses taken from the periodic table of S'more ingredients.

4. How many "moles" of Mm are present in 5.0 g of Mm?

5. What mass of Gc would be needed to react with 5.0 g of Mm?

6. What mass of S'mores could you make using 15.0 g of Gc and excess Mm and Cb?

This is stoichiometry! Stoichiometry is the relationship between the masses and quantities of reactants and products.

Going Further
Consider the reaction for the commercial preparation of ammonia. Chemists use the balanced equation below as their recipe for making ammonia.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Since there is not a mole of nitrogen or hydrogen available for you to measure the mass of on a balance, you'll have to use the periodic table to figure these out.

1. What is the mass of 1 mole of N_2?

2. What is the mass of 1 mole of H_2?

3. What is the mass of 1 mole of NH_3?

4. If you had 2.0 moles of N_2
   a. How many moles of H_2 would you need to react with all of the nitrogen?

   b. How many moles of ammonia, NH_3, could you produce (assuming enough H_2 is available)?

Appendix B-III

5. What mass of ammonia could you make using 14.0 g of H_2 and an excess of N_2?

6. What mass of H_2 would you need to react with 42.0 g of N_2?

Appendix B-IV

Percentage Yield Lab

Background:

In class, you've learned to calculate how much of a chemical product can be made when measured amounts of chemical reactants are mixed. In this lab, you will be using this information to predict how much product will be made; and then calculating the percent yield from the amount that is actually recovered.

The reaction you will be working is probably a familiar one: baking soda will react with vinegar to generate carbonic acid (which breaks up into water and carbon dioxide gas) and sodium acetate.

Common Name	Formula	Chemical Name
Baking Soda	$NaHCO_3$	Sodium Hydrogen Carbonate
Vinegar	$HC_2H_3CO_2$	Acetic Acid
	H_2CO_3	Carbonic Acid
Water	H_2O	Dihydrogen Monoxide
Carbon Dioxide	CO_2	Carbon Dioxide
	$NaC_2H_3CO_2$	Sodium Acetate

Prelab Questions:

1. Write a balanced equation for the double replacement reaction between sodium bromide, NaBr, and potassium chloride, KCl to produce sodium chloride, NaCl, and potassium bromide, KBr.

2. If 25 grams of sodium bromide are mixed with a large amount of potassium chloride, what will the theoretical yield of sodium chloride be?

3. If the actual yield from this reaction was 18 grams of sodium chloride, what would the percent yield for this reaction be?

4. Is the answer in question 3 reasonable? If so, explain why you think this was a reasonable answer. If not, explain what is wrong with it and discuss possible reasons one might get this answer in the laboratory.

5. What are some factors that might cause our percent yield to be greater than 100%? What are some factors that might cause it to be less than 100%? Discuss specific cases of how both might happen.

6. In this lab, you will perform a reaction where sodium hydrogen carbonate will react with an excess of acetic acid. By doing this, you will (hopefully) get 100% actual yield for the reaction.

   For the reaction, you will need to use 0.05 moles of sodium hydrogen carbonate. If more than 0.05 moles of sodium hydrogen carbonate is used, the reaction will be too large and some of the products may pour over the side of the flask when we mix it with the acetic acid.

   In the space below, calculate how much sodium hydrogen carbonate you will need for this lab:

   For this lab, I will use _________ grams of sodium hydrogen carbonate.

Procedure:

1. Measure out the weight of sodium hydrogen carbonate that you calculated the pre- lab. Record the exact amount of sodium hydrogen carbonate that you used in the Observations section.

2. Dissolve the sodium hydrogen carbonate in about 30 mL of water. Stir the solution until most or all of it is dissolved (if a little won't dissolve, that's OK).

3. Weigh a 250 mL flask. Record its weight in the Observations section.

4. Add the sodium hydrogen carbonate solution to the pre-weighed 250 mL flask.

5. Obtain 150 mL of acetic acid and ***slowly*** add it to the sodium hydrogen carbonate solution. You will observe the formation of bubbles when the acetic acid is added to the sodium hydrogen carbonate solution. Wait until the bubbling subsides before adding more acetic acid. When all of the acetic acid has been added, stir for two minutes before moving on to step 6.

6. When the solution is again calm (there may be a few bubbles rising from the bottom of the flask - this is normal), move the flask to a hot plate and heat it to boiling. Be careful that the flask does not boil over because this will cause you to lose some of the product of the reaction. Once the flask has started boiling, gently set a watch glass on its mouth to keep any of the liquid inside from splattering.

7. When all of the liquid in the solution has boiled away, remove the flask from the hot plate. The powder that you observe inside is the product of the reaction, sodium acetate. Once the flask has had a few minutes to cool down to room temperature, measure and record its weight.

8. When this is done, you can rinse out the flask and any other glassware you used. All waste can go down the sink.

Observations:

Amount of sodium hydrogen carbonate used: ______________

Weight of the empty 500 mL flask: ______________

Weight of the flask, after the reaction: ______________

Appendix B-IV

Analysis:

1. Write down the equation of the reaction you carried out in this lab. (Hint: The reaction is discussed in the introduction to this lab.)

2. Using the exact weight of sodium hydrogen carbonate that you measured in step 1 of the procedure and the equation that you wrote in the question above, what is the theoretical yield of this reaction?

3. Calculate the actual yield of sodium acetate that you recovered in this lab, using the weight of the empty flask and the weight of the flask after the reaction. Show your calculations below.

4. Using the actual yield of sodium acetate calculated in step 3 and the theoretical yield of sodium acetate calculated in step 2, calculate the percent yield of sodium acetate recovered in this lab. Show your calculations below.

5. Was your percent yield of sodium acetate 100%? What factors do you think caused any error that you found? Explain, using specific examples.

6. Do you think it is common for chemists to get 100% yields for chemical reactions? Why or why not?

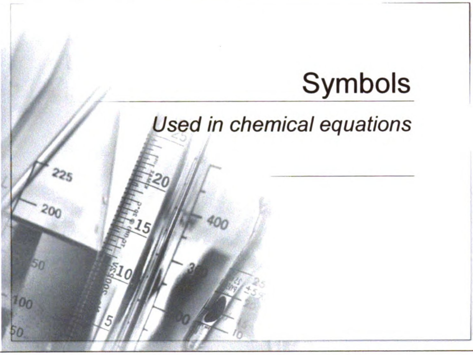
7. If you had to do this lab again, what would you do differently to improve your answers? Explain, using specific examples:

Appendix C

PowerPoint® Presentations

Appendix C-I

Symbols Used in Chemical Equations Presentation



$$\longrightarrow$$

- "Yields"
- Indicates the result of a reaction.

$\rightleftharpoons$

- Used in place of a single arrow to indicate a reversible reaction.

(s)

- Follows the formula of a reactant or product in the solid state.
- Used to indicate a precipitate.
  - Why?

Appendix C-I

↓

- Used to indicate a precipitate.

CAUTION

- For products only!

(l)

- Follows the formula of a reactant or product in the liquid state.

Appendix C-I

(aq)

- Follows the formula of a reactant or product in an aqueous solution (dissolved in water).
- NaCl $_{(aq)}$ is salt dissolved in water. Saltwater!
- I love swimming in NaCl $_{(aq)}$ with a mask, snorkel & fins.

(g)

- Follows the formula of a reactant or product in the gaseous state.

CAUTION

- Steam is just water in the gaseous state.

- To write steam into a formula equation, write $H_2O_{(g)}$

$\uparrow$

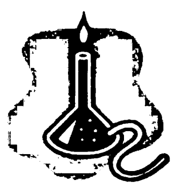
- Follows the formula of a reactant or product in the gaseous state.

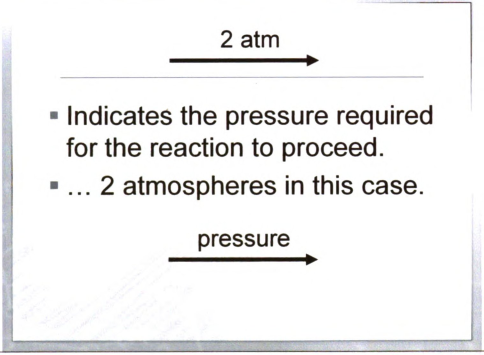
CAUTION

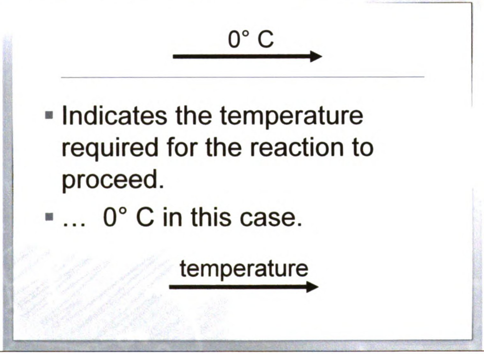
- Only use it for products!

$\xrightarrow{\Delta}$

- Indicates the reaction requires heat in order to proceed.




2 atm
Indicates the pressure required for the reaction to proceed.
… 2 atmospheres in this case.
pressure


0° C
Indicates the temperature required for the reaction to proceed.
… 0° C in this case.
temperature

$\xrightarrow{MnO_2}$

- Indicates the formula of catalyst, in this case manganese dioxide, used to alter the rate of reaction.

$\xrightarrow{\text{catalyst}}$

Assignment

- Write a Symbol Story.
- Can you tell a story and replace words with the symbols learned today?
- Read the grading sheet.

Appendix C-II

Activity Series
Presentation

Activity Series

- A list of elements organized according to the ease with which elements undergo certain chemical reactions.
- Page 266 Table 8-3

In replacement reactions, nothing lower on the list can kick out an element that is higher on the list.

Activity of Metals

Li Rb K Ba Sr Ca Na	React with cold H_2O and acids, replacing hydrogen React with oxygen forming oxides
Mg Al Mn Zn Cr Fe Cd	React with steam (but not cold water) and acids, replacing hydrogen React with oxygen forming oxides
Co Ni Sn Pb	Do not react with water React with acids, replacing hydrogen React with oxygen forming oxides
H Sb Bi Cu Hg	React with oxygen, forming oxides
Ag Pt Au	Fairly unreactive, forming oxides only indirectly

Examples

- Use the activity series to predict whether the following reactions will occur.

$Al + ZnCl_2 \rightarrow$

$Co + NaCl \rightarrow$

Examples

- Will rxn. Occur?
- What are products?
- Balance it!

$MgCl_2 + Zn \rightarrow$

$Al + H_2O \rightarrow$

Examples

- Will rxn. Occur?
- What are products?
- Balance it!

$Cd + O_2 \rightarrow$

$I_2 + KF \rightarrow$

Appendix C-III

Introduction to Stoichiometry
Presentation

Stoichiometry

- The branch of chemistry that deals with the mass relationships of elements in compounds and the mass relationships between reactions and products in a chemical reaction.

Important stuff

- Moles
- Calculations with moles (the old factor label)
- Balanced Equations

Calculations with Moles

- ☐ What is the mass of 2 moles of aluminum oxide?
- ☐ Steps:
  - Determine the formula of the compound.
  - Find the molar mass of the compound.
  - Multiply the molar mass by the number of moles.

Calculations with Moles

- ☐ What is the mass of 2 moles of aluminum oxide, Al_2O_3?
- ☐ Molar Mass:
  - For each element,

    $$\text{subscript} \times \text{atomic mass}$$

  - Then add the element masses together to get the mass of the compound.

Calculations with Moles

- PRACTICE!

- How many moles are there in 35.5 grams of aluminum hydroxide?

Mole Ratio

- A mole ratio is a conversion factor that relates the amounts in moles of any two substances involved in a chemical reaction.

- To do anything with this, the equation must be balanced.

$$Al_2O_3 \rightarrow Al + O_2$$

Mole Ratio

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

- The coefficients represent the relative amounts in moles of reactants and products.

- What is the ratio of Al to Al_2O_3?

$$\frac{4\ \text{mol Al}}{2\ \text{mol } Al_2O_3}$$

Mole Ratio

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

- Possible mole ratios

$$\frac{2\ \text{mol } Al_2O_3}{4\ \text{mol Al}} \text{ or } \frac{4\ \text{mol Al}}{2\ \text{mol } Al_2O_3}$$

$$\frac{2\ \text{mol } Al_2O_3}{3\ \text{mol } O_2} \text{ or } \frac{3\ \text{mol } O_2}{2\ \text{mol } Al_2O_3}$$

$$\frac{4\ \text{mol Al}}{3\ \text{mol } O_2} \text{ or } \frac{3\ \text{mol } O_2}{4\ \text{mol Al}}$$

Where we're going

- We will calculate the amount of product we expect to get from a reaction.

$$\text{Amount of GIVEN substance (mols)} \times \underbrace{\frac{\text{mol unknown}}{\text{mol given}}}_{\text{Mole Ratio}} = \text{Amount of UNKNOWN substance (mols)}$$

Example

- How many moles of aluminum will be produced from the decomposition of 13.0 moles of Al_2O_3?

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

$$13.0\ \text{mol}\ Al_2O_3 \times \frac{4\ \text{mol Al}}{2\ \text{mol}\ Al_2O_3} = \mathbf{26.0\ mol\ Al}$$

Stoichiometry
Presentation

Stoichiometry

- A quantitative study of chemical changes.
- Like
  - Calculation of how much product you will get in a reaction.

$$\text{Amount of GIVEN substance (mols)} \times \frac{\text{mol unknown}}{\text{mol given}} = \text{Amount of UNKNOWN substance (mols)}$$

- Given the following unbalanced equation:

$$N_2O + O_2 \rightarrow NO_2$$

  - Balance the equation.
  - Find the mole ration of NO_2 to O_2.

$$2N_2O + 3O_2 \rightarrow 4NO_2$$

- If 20 mol of NO_2 form, how many moles of O_2 must have been consumed?

- Steps:
  - Write down the given amount and compound.
  - Multiply by a mole ratio that cancels the given compound and yields the desired compound.

$$2N_2O + 3O_2 \rightarrow 4NO_2$$

- If 20 mol of NO_2 form, how many moles of O_2 must have been consumed?

$$20\ \cancel{mol\ NO_2} \times \frac{3\ mol\ O_2}{4\ \cancel{mol\ NO_2}} =$$

$$\boxed{= 15\ mol\ O_2}$$

- Given the following balanced equation:

$$4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O$$

  - Find the mole ration of NO to H_2O.
  - Find the mole ration of NO to NH_3.

$$4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O$$

- If 0.240 mol of NH_3 react according to the above equation, how many moles of NO will be consumed?

$$0.240\ \cancel{\text{mol NH}_3} \times \frac{6\ \text{mol NO}}{4\ \cancel{\text{mol NH}_3}} =$$

$$\boxed{= 0.360\ \text{mol NO}}$$

- Given the following balanced equation:

$$H_2 + F_2 \rightarrow 2HF$$

  - How many grams of HF gas are produced as 5 mol of fluorine react?

- Steps:
  - Find moles HF produced.
  - Multiply moles by molar mass of the compound to get grams.

$$H_2 + F_2 \rightarrow 2HF$$

- How many grams of HF gas are produced as 5 mol of fluorine react?

$$5\,\cancel{\text{mol}\,F_2} \times \frac{2\,\text{mol HF}}{1\,\cancel{\text{mol}\,F_2}} = 10\,\text{mol HF}$$

$$10\,\text{mol HF} \times \frac{20.01\,\text{g}}{1\,\text{mol HF}} \boxed{= 200.1\,\text{g HF}}$$

Limiting Reactant and Percent Yield Presentation

Limiting Reactant

$$Cu_{(s)} + 2AgNO_{3_{(aq)}} \rightarrow Cu(NO_3)_{2(aq)} + 2Ag_{(s)}$$

- The **limiting reactant** is the reactant that limits the amount of product that can form in a reaction.
  - The reaction stops when the limiting reactant is used up.
- The **excess reactant** is the reactant that is not completely used up in a reaction.

Steps for solving a limiting reactant problem

1. Write a balanced equation for the reaction.
2. Convert both reactant quantities to moles.
3. Determine the moles of the second reactant required to react the first reactant.
4. The least amount in step #3 identifies the limiting reactant. CIRCLE IT!
5. Use the number of moles of the limiting reactant to determine amounts of product.

Practice Problem
Page 289

Some rocket engines use a mixture of hydrazine, N_2H_4, and hydrogen peroxide, H_2O_2 as the propellant. The reaction is given by the following equation:

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O$$

a. Which is the limiting reactant in this reaction when 0.750 mol N_2H_4 is mixed with 0.500 mol of H_2O_2?
b. How much of the excess reactant, in moles, remains unchanged?
c. How much of each product, in moles, is formed?

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O$$

0.750 mol   0.500 mol

- Use moles of first reactant to determine moles required of the second reactant.

$$0.750\ \text{mol}\ N_2H_4 \times \frac{2\text{mol}\ H_2O_2}{1\text{mol}\ N_2H_4}$$

$$= 1.5\ \text{mol}\ H_2O_2$$

- We only have 0.500 mol H_2O_2.
- The limiting reactant is H_2O_2.

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O$$

0.750 mol 0.500 mol

- How much N_2H_4 is left after all H_2O_2 is gone?

$$0.5 \text{ mol } H_2O_2 \times \frac{1 \text{mol } N_2H_4}{2 \text{mol } H_2O_2}$$

$$= 0.25 \text{ mol } N_2H_4$$

- Only 0.25 mol N_2H_4 has reacted.

$$0.750 \text{mol } N_2H_4 - 0.25 \text{ mol } N_2H_4$$

$$0.5 \text{ mol } N_2H_4$$

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O$$

0.750 mol 0.500 mol

- Use the limiting reactant to calculate amount of products.

$$0.5 \text{ mol } H_2O_2 \times \frac{1 \text{mol } N_2}{2 \text{mol } H_2O_2}$$

$$= 0.250 \text{ mol } N_2$$

$$0.5 \text{ mol } H_2O_2 \times \frac{4 \text{mol } H_2O}{2 \text{mol } H_2O_2}$$

$$= 1.00 \text{ mol } H_2O$$

Percent Yield

- Theoretical Yield: The calculated amount of product you expect to get in an experiment
- Actual Yield: The amount of product you actually get (measured amount).
- Percent Yield:

$$\%\ \text{yield} = \frac{\text{actual yield}}{\text{theo. yield}} \times 100\%$$

Practice Problem
Page 294

- Methanol can be produced through the reaction of CO and H_2 in the presence of a catalyst. The reaction is given by the following equation:

$$CO + 2H_2 \xrightarrow{\text{catalyst}} CH_3OH$$

- If 75.0 g of CO reacts to produce 68.4 g of CH_3OH, what is the percent yield of CH_3OH?

$$CO + 2H_2 \xrightarrow{\text{catalyst}} CH_3OH$$

75.0g 68.4g

- Calculate moles of CO.

$$75.0\text{g CO} \times \frac{1\,\text{mol CO}}{28.01\text{g CO}}$$

$$= 2.68\ \text{mol CO}$$

- Use stoichiometry to calculate the mass (theoretical yield) of CH_3OH.

$$2.68\ \text{mol CO} \times \frac{1\,\text{mol } CH_3OH}{1\,\text{mol CO}}$$

$$= 2.68\ \text{mol } CH_3OH$$

$$CO + 2H_2 \xrightarrow{\text{catalyst}} CH_3OH$$

75.0g 68.4g

- Calculate mass of CH_3OH.

$$2.68\ \text{mol } CH_3OH \times \frac{32.05\ \text{g } CH_3OH}{1\,\text{mol } CH_3OH}$$

$$= 85.9\ \text{g } CH_3OH$$

- Calculate % yield.

$$\%\ \text{yield} = \frac{\text{actual yield}}{\text{theo. yield}} \times 100\%$$

$$= \frac{68.4\text{g } CH_3OH}{85.9\text{g } CH_3OH} \times 100\%$$

$$= 79.6\%$$

Appendix D

Assessments

Appendix D-I

Introductory Survey

***Circle** the answer that best fits. Please answer honestly.*

1. Do you plan on going to college or trade school?
   a. *Yes*
   b. *No*
   c. *Maybe*
   d. *I don't know*

2. Will you take chemistry in college?

   Yes *No*

3. Will you study science or medicine in college?

   Yes *No*

4. What is a typical grade for you in a math class?

   A *B* *C* *D*

5. What is a typical grade for you in a science class?

   A *B* *C* *D*

6. Which class do you do best in?
   a. *Math* b. *Science*
   c. *English* d. *Social Studies*
   e. *All*

7. Which class do you have trouble with?
   a. *Math* b. *Science*
   c. *English* d. *Social Studies*
   e. *All*

8. What do you find most distracting in class?
   a. *Sounds* b. *Movement*
   c. *Sights* d. *Lights*
   e. *Other students*

9. Put an **M** by the two methods that are most helpful to you when you have trouble with a class. Put an **L** by the two methods that are least helpful to you.

   _____ *Ask a friend*

   _____ *Ask a question in class*

   _____ *Ask the teacher*

   _____ *Look at pictures or diagrams in the text*

   _____ *Read the text*

10. When you are thinking do you
    a. *Tap your pencil*
    b. *Walk around*
    c. *Doodle*
    d. *Hum or Sing*
    e. *Daydream*
    f. *Other*

11. When you attempt a story problem in math you
    a. *Always solve them*
    b. *Usually solve them*
    c. *Solve them with help*
    d. *Rarely solve them*

12. Which part of science class do you like best?
    a. *Labs* b. *Class work*
    c. *Homework* d. *Lectures*
    e. *Videos* f. *Tests*
    g. *Other*

13. Which part of science class do you like least?
    a. *Labs* b. *Class work*
    c. *Homework* d. *Lectures*
    e. *Videos* f. *Tests*
    g. *Other*

14. In which part of science class do you learn the most?
    a. *Labs* b. *Class work*
    d. *Homework* d. *Lectures*

15. Which part(s) of a lab do you enjoy the most?
    a. *Writing my own procedure*
    b. *Measuring the chemicals*
    c. *Mixing the chemicals*
    d. *Doing the calculations*
    e. *Making sense of the results*
    f. *Writing the lab report*

16. Which part(s) of a lab do you enjoy the least?
    a. *Writing my own procedure*
    b. *Measuring the chemicals*
    c. *Mixing the chemicals*
    d. *Doing the calculations*
    e. *Making sense of the results*
    f. *Writing the lab report*

Appendix D-II

Chemical Reactions and Stoichiometry Pre-test

1. List 3 requirements for a correctly written chemical equation.
   a. ______________________________
   b. ______________________________
   c. ______________________________

2. Classify each of the following as synthesis, decomposition, single replacement, double replacement, or combustion.
   a. $2H_3PO_4 \rightarrow H_4P_2O_7 + H_2O$ ______________
   b. $HCl + AgNO_3 \rightarrow HNO_3 + AgCl$ ______________
   c. $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ ______________
   d. $AgNO_3 + Cu \rightarrow CuNO_3 + Ag$ ______________

3. Balance each of the following reactions.
   a. ____ $NaCl$ + ____ $F_2 \rightarrow$ ____ NaF + ____ Cl_2

   b. ____ H_2 + ____ $O_2 \rightarrow$ ____ H_2O

   c. ____ $AlBr_3$ + ____ $K_2SO_4 \rightarrow$ ____ KBr + ____ $Al_2(SO_4)_3$

   d. ____ CH_4 + ____ $O_2 \rightarrow$ ____ CO_2 + ____ H_2O

4. What does the symbol (aq) mean in the following: $AgNO_{3\,(aq)}$?

5. Use the activity series to predict whether a given reaction will occur and what the products will be. If a reaction will occur, write and balance the reaction. If no reaction will occur, just write "no reaction."

   a. $Mg_{(s)}$ + steam $\rightarrow$

   b. $Cl_{2\,(g)} + MgBr_{2\,(aq)} \rightarrow$

   c. $Ni_{(s)} + CuCl_{(aq)} \rightarrow$

   d. $Ni_{(s)} + H_2O_{(l)} \rightarrow$

6. Define stoichiometry and explain what chemists use stoichiometry for.

7. Describe a method for determining which of two reactants is the limiting reactant.

8. Compare actual yield to theoretical yield.

Write the answers to the following questions on the line to the left, and show your work in the space provided.

9. ____________________ For the reaction $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2\ KNO_3$, how many moles of lead iodide are produced from 300 g of potassium iodide?

10. ____________________ For the reaction $2KClO_3 \rightarrow 2\ KCl + 3\ O_2$, how many grams of potassium chlorate are required to produce 160 g of oxygen?

Appendix D-III

Chemical Symbol Story Grading Sheet

Student name: ____

Period: 1 2 3 4 5 6 Date: ___________

Teacher Evaluation

Appearance (4 points total):
- This grade sheet accompanies your story (1): ___ ______
- The writing is neat and presentable (2): ___ ______
- The title is appropriate, meaningful, and interesting (1): ___ ______

Scientific Content (12 points total):
- Concepts used are appropriate and accurate (5): ___ ______
- Vocabulary is appropriate and used correctly (4): ___ ______
- Visuals such as symbols, drawings, diagrams or pictures are used in an appropriate way to add information and interest (3): ___ ______

Story (10 points total):
- There is a clear theme to the story (2): ___ ______
- The plot centers around, develops, and resolves a problem. (2): ___ ______
- The story has an engaging, interesting conflict that captures and holds the attention of the reader. (2): ___ ______
- Each event or episode is important to the meaning of the plot. (1): ___ ______
- The plot follows logically. (2): ___ ______
- The story has a consistent point of view. (1): ___ ______

Mechanics (4 points total):
- Grammar is correctly used within the format (2): ___ ______
- There are zero spelling errors (2): ___ ______

Total Points: ______

Appendix D-IV

Section 1 Exit Survey

Describe how successfully you can use these skills	Rarely	Some-times	Often	Usually	Always
Identify observations that a chemical reaction has taken place.					
Identify a correctly written chemical equation.					
Write a word equation from a given formula equation.					
Write a formula equation from a given word equation.					
Balance a formula equation.					
Classify a chemical equation according to it's type.					
Predict the products of simple reactions given the reactants.					
Use the activity series to predict whether a reaction will occur and what the products will be.					

Describe how helpful these activities were	Not Helpful	Somewhat Helpful	Helpful	Very Helpful
PowerPoint® Presentations				
Burger Chem Lessons				
S'mores Lab				
Balancing Race				
Symbol Stories				
Types of Reactions Lab				
Recycling Copper Lab				
Reading the text				
Homework Papers				

Appendix D-V

Section 2 Exit Survey

Describe how successfully you can use these skills:	Rarely	Some-times	Often	Usually	Always
Write a mole ratio relating two substances in a chemical equation.					
Calculate the amount in moles of a reactant or product from the amount in moles of a different reactant or product.					
Calculate the mass of a reactant or product from the amount in moles of a different reactant or product.					
Calculate the amount in moles of a reactant or product from the mass of a different reactant or product.					
Calculate the mass of a reactant or product from the mass of a different reactant or product.					
Identify the limiting reactant in a chemical reaction.					
Calculate the amount of product (either mass or moles) in a limiting reactant problem.					
Calculate percent yield, given the actual yield and quantity of a reactant.					

Describe how helpful these activities were:	Not Helpful	Somewhat Helpful	Helpful	Very Helpful
PowerPoint® Presentations				
Burger Chem Lessons				
Finding Coefficients Lab				
Percent Yield Lab				
Reading the text				
Homework Papers				

Chemical Reactions and Stoichiometry Post-test

1. List 3 requirements for a correctly written chemical equation.
   a. ______________________________
   b. ______________________________
   c. ______________________________

2. Classify each of the following as synthesis, decomposition, single replacement, double replacement, or combustion.
   a. $2H_3PO_4 \rightarrow H_4P_2O_7 + H_2O$ ____________________
   b. $HCl + AgNO_3 \rightarrow HNO_3 + AgCl$ ____________________
   c. $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ ____________________
   d. $AgNO_3 + Cu \rightarrow CuNO_3 + Ag$ ____________________

3. Balance each of the following reactions.
   a. ____ $NaCl$ + ____ $F_2 \rightarrow$ ____ NaF + ____ Cl_2

   b. ____ H_2 + ____ $O_2 \rightarrow$ ____ H_2O

   c. ____ $AlBr_3$ + ____ $K_2SO_4 \rightarrow$ ____ KBr + ____ $Al_2(SO_4)_3$

   d. ____ CH_4 + ____ $O_2 \rightarrow$ ____ CO_2 + ____ H_2O

4. What does the symbol (aq) mean in the following: $AgNO_{3\,(aq)}$?

5. Use the activity series to predict whether a given reaction will occur and what the products will be. If a reaction will occur, write and balance the reaction. If no reaction will occur, just write "no reaction."

   a. $Mg_{(s)}$ + steam →

   b. $Cl_{2\,(g)} + MgBr_{2\,(aq)} \rightarrow$

   c. $Ni_{(s)} + CuCl_{(aq)} \rightarrow$

   d. $Ni_{(s)} + H_2O_{(l)} \rightarrow$

6. Define stoichiometry and explain what chemists use stoichiometry for.

7. Describe a method for determining which of two reactants is the limiting reactant.

8. Compare actual yield to theoretical yield.

Write the answers to the following questions on the line to the left, and show your work in the space provided.

9. ____________________ For the reaction $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2\ KNO_3$, how many moles of lead iodide are produced from 300 g of potassium iodide?

10. ____________________ For the reaction $2KClO_3 \rightarrow 2\ KCl + 3\ O_2$, how many grams of potassium chlorate are required to produce 160 g of oxygen?

Appendix D-VII

Test Self Evaluation

Test Name: ______________________________ Test Date: __________________

Score: ________ out of __________ Percentage: ___________%

1. What was the general topic covered by the test?

2. How did I prepare for the test?

3. What have I learned?

4. What do I need to improve?

5. How might I have prepared more effectively?

6. Am I satisfied with this performance?

Appendix D-VIII

Weekly Reflections

Week Ending Date: ____________

1. Concept: *State the concept being learned.*

2. Process: *Describe the process you (the class) used to learn the concept*

3. Attitude: *Describe your attitude toward the concept, the process, etc. Tell how you feel about what you are learning.*

Appendix D-VIII

Consent Letter

Dear Parent/Guardians and Students:

For the past three years, I have been enrolled as a graduate student in Michigan State University's Division of Science and Mathematics Education (DSME). I have chosen to do my thesis work on the implementation of a unit on stoichiometry in my chemistry classes. Stoichiometry is the quantitative relationship between reactants and products in a chemical reaction. My goal in teaching this unit is to give students a solid understanding of the relationship between amounts in chemical reactions through providing both traditional and multimedia instruction combined with memorable hands-on activities and laboratory experiences. An important aspect of this work is obtaining data about the effectiveness of this unit, which in turn will be the foundation of my thesis.

In order to evaluate the learning process, data will be collected from pre and post tests, responses from activities and laboratory experiments and surveys that will be given throughout the unit. With your permission I would like to include your child's data in my thesis. Your child's privacy will be protected to the extent that is allowable by law, and at no time will the student's name be used or connected with any part of my thesis paper. All data will remain confidential.

Participation in this study is voluntary. Your child will receive no penalty in regard to their grade should you deny permission for use of their data. Participation in this study will neither increase nor decrease the amount of work that is required by your child. All assignments will be graded within the regular framework of the course as set forth in the syllabus.

Please complete the attached form and return it to me by **DATE**. Should you have any questions or concerns feel free to contact me at Redford Union High School (313) 242-6732 or by email at pakkalj@redfordu.k12.mi.us. Questions about the thesis project may 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 any 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 (UCRIHS) by phone: (517) 355-2180, fax: (517) 432-4503, email: ucrihs@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.

Sincerely,

Jennifer Pakkala
Chemistry Teacher
Redford Union High School
(313) 242-6732

UCRIHS APPROVAL FOR
THIS project EXPIRES:

SEP 1 5 2006

SUBMIT RENEWAL APPLICATION
ONE MONTH PRIOR TO
ABOVE DATE TO CONTINUE

Please fill out the consent information on the attached page.

Appendix D-VIII

I voluntarily agree to have ______________________________ participate in this study.
(Print Student Name)

Please check all that apply.

Data:

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

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

Image:

_____ I give Mrs. Pakkala permission to use images of my child through photography during her work on this thesis project. My child will not be identified in these images.

_____ I do not wish to have my child'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)

BIBLIOGRAPHY

BIBLIOGRAPHY

Bartholomew, Martin (2006, April) Team Building – Problem Solving, Journal of Chemical Education, 599

Bodner, George et. al. (2001, August) The Many Forms of Constructivism, Journal of Chemical Education, 1107-1130

Bodner, George M. (1986, October) Constructivism: A theory of knowledge. Journal of Chemical Education, pp. 873-878

Bretz, Stacey Lowery (2001, August) Novak's Theory of Education: Human Constructivism and Meaningful Learning, Journal of Chemical Education, 1144-1152

Bunce, Diane M, (2001, August) Does Piaget Still Have Anything to Say to Chemists? Journal of Chemical Education, 1131-1143

Cain, Linda (1986, December) S'mores – A Demonstration in Stoichiometric Relationships, Journal of Chemical Education 1048-1049

Davis et. al. (1999). Modern Chemistry, Holt, Reinhart and Winston 274 - 299

DePierro, Ed et. al. (2000, September) Encouraging Meaningful Quantitative Problem Solving Journal of Chemical Education, 1166 – 1173

Deters, Kelly Morgan (2003, October). What Should We Teach in High School Chemistry? Journal of Chemical Education, 1153 – 1155

Felder, Richard M, (1990, Fall). Stoichiometry Without Tears, Chemical Engineering Education, 188-196

Gabel, Dorothy, (1999, April) Improving Teaching and Learning Through Chemistry Education Research: A Look to the Future, Journal of Chemical Education, 548 – 554

Good, Ron et. al. (1979, July) Piaget's Work and Chemical Education Journal of Chemical Education, 426 - 428

Gunning, Thomas G. (2000). Creating Literacy Instruction for All Children, 3rd Ed, Allyn and Bacon, 506-508

Haim, Lilliana et. al. (2003, December). Learning Stoichiometry with Hamburger Sandwiches. Journal of Chemical Education, 1021 – 1022

Herron, J. Dudley (1986, June) What Can We Do About Sue; A case Study of Competence, Journal of Chemical Education, 528-531

Herron, J. Dudley (1999, October) Improving Chemistry Learning, Journal of Chemical Education, 1354 -1360

Herron, J. Dudley and Greenbowe, Thomas J. (1986 June) What Can We Do About Sue: A Case Study of Competence. Journal of Chemical Education, 528 -531

Hibbard, K. Michael, Ph.D. (2001). Performance Assessment in the Science Classroom, Glencoe/ McGraw-Hill, 47, 85-87

Huddle, P.A. and Pillay, A.E. (1996, January). An in-depth study of misconceptions in stoichiometry and chemical equilibrium at a South African university. Journal of Research in Science Teaching, 65-77

Krieger, Carla R. (1997, March). Stoogiometry: A Cognitive Approach to Teaching Stoichiometry. Journal of Chemical Education, 306 -309

Mathewson, James H. (1999, January). Visual-spatial thinking: An aspect of science overlooked by educators. Science Education, 33-54

Smith, Patricia J. (1978, February). Piaget in High School Instruction. Journal of Chemical Education, 115 – 117

Steiner, Richard, P. (1986, December). Teaching Stoichiometry. Journal of Chemical Education, 1048

Umland, Jean B. (1984, December) A recipe for Teaching Stoichiometry. Journal of Chemical Education, 1036-1037

Woolfolk, Anita E. (1998). Educational Psychology, 7th Ed., Allyn & Bacon, 37-39; 295-306