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A STOICHIOMETRY UNIT

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ABSTRACT

A STOICHIOMETRY UNIT

BY

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Problem solving, especially stoichiometry, is very difficult for many students in an introductory chemistry class. The abstract, symbolic nature of chemistry is especially difficult for students who aren't strong analytical thinkers. These students may be primarily visual, linguistic or other nonanalytical thinkers

Research shows that there are ways to approach problems that will improve a student's success. The purpose of this unit is to implement some of these methods to help students solve stoichiometry problems more successfully. The activities accentuated concrete and visual representations of the concepts to make the skills necessary to solve stoichiometry problems accessible to more students.

Although not all students were successful the posttest showed that most of the students could successfully solve the stoichiometry problems and many did exceptional work.

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I. Introduction

A. Rationale and study group

Solving stoichiometry problems is a very difficult task for most chemistry students. Successful problem solvers must master naming compounds, balancing equations and finding amounts. This unit stresses proper chemical formulas and names, finding amounts of chemicals, balancing equations and establishing mathematical relationships between the compounds. The skills necessary to solve stoichiometry problems recur throughout the year. If a student doesn't successfully master these skills, they will have trouble in chemistry throughout the year. The skills in this unit are essential to understanding fourteen of the eighteen chapters that we cover in chemistry class. In addition to stoichiometry these skills are necessary to understand gas laws, chemical bonds, solutions, colligative properties, thermodynamics, reaction rates, equilibrium and acids and bases. Improving these skills should help students be more successful throughout the year.

This unit employs activities to help students who are not strong analytical thinkers. These activities stress mastery of the skills necessary to solve stoichiometry problems by using concrete models of the molecules, representing concepts and procedures visually, and writing about the concepts.

This study took place in Dexter High School, located in western Washtenaw County. During the 2003-2004 school year there were 1030 students in grades nine through twelve. About ninety percent of Dexter students will go to a two- or four-year college.

There are three chemistry teachers at Dexter High School. We offer an introductory chemistry class typically taken by juniors. There is also an advanced chemistry class that is taken by seniors. Both classes are electives. One hundred sixty eight juniors and five seniors are taking chemistry in seven classes during the 2003-2004 school year. Approximately seventy five percent of the junior class at Dexter High School will take chemistry before they graduate. Over sixty percent of the senior class will take science in the senior year, with about half of the senior class taking physics.

We use the text Chemistry by J. Dudley Herron, David V. Frank et al. published by D.C. Heath, 1996 and its accompanying laboratory book. We supplement these tests with other labs and materials. The three teachers follow a common syllabus.

The chemistry teachers do not emphasize memorization. Students are encouraged to write facts and formulas that they want to remember for a test on an index card. At least one of the chemistry teachers is available before school and after school each day for extra help. Few students take advantage of these study sessions.

Student grades are based on a percent of points earned on tests, quizzes, labs and questions. An A is given for a score of 90% or greater, a B for 80 to 89%, a C for 70 to 79%, a D for 60 to 69%. Grades below 60% are failing.

Students are encouraged to retake chemistry tests that they do poorly on after getting individual help. We do this so that students will have a better understanding of the concepts that they will need as they continue to study chemistry. On average only one or two students take advantage of this opportunity in my class.

Fifty-two students participated in this study, 30 males and 22 females in the two chemistry classes I teach. One of the female students transferred out of the district at the end of the first quarter before the stoichiometry unit began. There are few minority students in Dexter High School and none included in this study. Fifty students are planning to go to college. One student is not sure at this time. About half of the students plan to study science or medicine in college and about half plan to take chemistry in college. The classes in this study met during the fourth and sixth hours of our six-hour school day.

B. Review of literature related to problem

Chemistry is a challenging class for many students. There are many terms to learn and a great number of skills to master. To solve problems a student must learn to sort through the given information, identify what the problem asks, organize the information and choose an appropriate strategy to find the solution. They must translate the given information into symbolic form and use a number of mathematical skills in a logical manner to reach a correct solution. The student must check to see if the answer is consistent with the chemistry of the problem. Often a student needs to be willing to try different methods to reach a correct solution.

As the year goes on the concepts and skills used to find solutions are refined and used to understand more complex concepts. If a student doesn't master these basic skills, they will continue to have trouble with chemistry.

David Frank (Herron, et al., 1996), one of the authors of our text, says that problem solving is one of the most difficult aspects of chemistry to teach. Even students who get correct answers often don't really understand the underlying concepts. Too many students rely on algorithms that they have memorized to solve problems. Any change in the organization of a problem, even a simplification, can make a problem seem much more difficult for these student to solve.

Stoichiometry is one type of problem that is especially difficult for students. Stoichiometry uses the equation for a reaction to relate the amount of one chemical in a reaction to the amounts of other chemicals in the reaction. These problems are especially difficult for students because they are presented in a complex, analytic manner.

Numerous authors (Bodner, Johnstone, Gabel, Herron et al.) have investigated problem solving in chemistry. Many of the early articles on problem solving focused on strategies based on the authors' classroom experience. Some of these, especially those directed at high school teachers, talk about the best way to learn the algorithms used to solve simple problems.

Johnstone (2001) divides chemistry problems into eight categories according to the nature of the data, the clarity of methods and the nature of the results. Most of the problems in an introductory chemistry class are of the most straightforward kind with given information, clearly defined methods and a specific result in mind. Even these problems are difficult for many students.

Gabel, Sherwood and Enochs (1984) report that successful problem solvers in high school often use algorithms to solve chemistry problems involving moles, stoichiometry, gas laws and molarity. These students tend not to have an understanding of the conceptual basis of the problem. Because of this they cannot transfer what they know to new problems. Gabel, Sherwood and Enochs recommend that the students understand the underlying concepts qualitatively before trying to solve the problems. Their research shows that successful problems solvers approach problems systematically.

Lythcott (1990) suggests that the types of problems we give first-year chemistry students lend themselves to using algorithms. Since students can use algorithms to solve problems without understanding the basic concepts they don't develop a deeper understanding of the underlying concepts. This leads to difficulty later in chemistry. They don't understand why the algorithms work. More importantly, they cannot transfer their skills to new situations. If the instructor makes even superficial changes in the problem you may hear "We never did a problem like that." Or you get a detailed but wrong answer to a problem because the students are solving the problems mechanically rather than understanding the underlying concepts.

Herron and Greenbowe (1986) and Bodner (2003) tell about a number of college students who had received good grades on their chemistry tests. When they were interviewed about how they solved problems these students gave inconsistent or nonsense answers to questions about the concepts underlying these problems. These students often resorted to memorized algorithms to solve problems that look familiar but didn't really understand either what the question is asking or what their answer means.

Although there is a place for algorithms in solving problems, a reliance on them without understanding the basic concepts will hinder the students' chances of being successful as they progress in science. Most real world problems do not lend themselves to using algorithms. As the problems become less clearly defined, students will have more trouble solving the problems. This is frustrating and discouraging for students who previously had been successful in chemistry.

In addition, problem solvers need to be flexible in how they represent the information in the problem. Bodner (2003) reports that successful problem solvers often are able to represent the information in a number of ways, especially with a picture or a diagram.

Reif (1983) says that one way to improve success in problem solving is to make the underlying assumptions about the concepts explicit. The visual representation of what is happening at a molecular level helps students understand what the symbols represent and what is happening in the reaction.

Bodner and Domin (1995) report that students who can construct more than one representation of the information of a problem are more likely to successfully solve the problem. In fact, students who test high on visualization will solve novel problems better even if the problem doesn't seem to involve pictures.

Bodner (2003) indicated that successful problem solvers often first generate a picture of the problem. Then they develop a general outline, a "hierarchical structure," of the solution before getting into the details of the problem. This effectively divides the problem into a series of smaller tasks.

One of the vexing aspects of solving stoichiometry problems for students is that the actual mathematics the student must use is a simple proportion. Students often have trouble getting to the point where they can use the proportion to solve the problem. Students have shown that they can readily do these problems when they are applied to everyday situations like sports and buying groceries. Gabel and Samuel (1986) tell us that there is a limited transference between successfully solving everyday problems and solving analogous chemistry problems.

Another aspect of stoichiometry that is difficult for students is the complexity of the language used. Problems are often presented in the specialized language of chemistry. A study conducted by Marais and Jordaan (2000) asked students to evaluate the validity of five statements about a concept or symbol commonly used in chemistry. They describe the understanding of a symbol as "very problematic" if less than twenty percent of the students had all five of the parts of the answer correct or more than fifty percent had two or more of the five parts of the interpretation incorrect. Fifty percent of their students got at least two answers wrong per symbol and thirty-nine percent got at least two uses of the words wrong. In the same study Marais and Jordaan (2000) remind us that it can require over ten cognitive steps to understand all the information given in an equation.

The information needed to solve stoichiometry problems can quickly overwhelm a student's working memory. Johnstone (1984) and Niaz (1989) have written on how working memory affects a student's ability to solve problems. Working memory is the amount of information that a person can accommodate when they are performing a task like solving a problem. Most students can readily solve problems that need only a few steps. The number of students who can solve a problem goes down nearly sigmoidally as the number of steps goes up. Problems that require more than five steps become increasingly difficult for most people. Johnstone (1997) reports that nearly ninety percent of sixteen-year-old students in his study could correctly solve problems involving moles if the problem had five or fewer pieces of information. Fewer than thirty percent could solve problems that required six or seven steps. For more than eight steps the number of successful solutions fell to less than ten percent.

To help lessen this overload of working memory students can improve their understanding of the basic skills. As students understand these concepts better they can "chunk" the skills and move it to long-term memory. One way to chunk information is to develop a framework for the skills. The necessary skills can be developed to the point where they can be grouped together and transferred to long-term memory. If that doesn't happen the number of steps needed to solve a problem can quickly overcome the student's working memory. By mastering the skills in the stoichiometry unit described in this thesis, the demand on the student's memory should be lowered.

For example, finding the moles in a given mass of a compound can be seen as being one task for the experienced chemist. For beginning students it requires identifying the type of compound, looking up the elements, writing the formula, finding the atomic masses, finding the molar mass and changing the mass into moles.

If the student does not have a good grasp of the basic skills, their working memory is quickly used up. This helps explain why students can often follow the steps of a problem but cannot solve the problem by themselves. When I taught stoichiometry in previous years I emphasized the mathematical part of the problem solving. This worked well for students who were sophisticated mathematical thinkers, but other students had trouble with the problems. These students soon became frustrated. They continued to have trouble with other topics that required a mathematical interpretation. Even students who were successful solving problems had trouble when even minor changes were made in the problem.

Rowe (1983) reports that introductory college chemistry texts can have fifteen new concepts per page. High school texts have fewer new concepts per page but for beginning chemistry students nearly everything is new. Often this information is presented at a rate that quickly overcomes a student's ability to assimilate it. In a study cited by Johnstone (1997) an average of 130 formulas, equations or other "units of sense" are delivered per lecture. These ranged from a low of 117 to a high of 170. In their notes students recorded as much as 75% of the information at the lower rate of delivery to only 52% of the information delivered at the higher rate. Rowe (1983) reports an even lower rate of gathering information of 30% even for the best note takers.

One reason my students have trouble with stoichiometry is that the problems in the text seem to be like the story problems that they study in mathematics class. Students can mechanically solve these without understanding the underlying chemical concepts. Another problem is that the labs traditionally done in my class for stoichiometry aren't a very good introduction to the underlying concepts because they gave such poor results. We have used a single replacement reaction of one metal replacing another in a compound. It requires three days of reacting, drying and massing before the students can determine the amounts of reactants produced. Often the results are poor with error rates above 25%. Errors include losses while heating, contamination, mismeasurement etc. These factors combine to form a barrier to students understanding the underlying concepts of stoichiometry, how the amounts of reactants and products are related to each other.

A number of researchers (Bodner (2003), Bodner and Domin (1998), Johnstone (2001)) have shown that successfully problem solvers often are systematic in their approach to a problem. For stoichiometry problems students must develop a way to organize the data and learn the methods to solve the problem. Watkins (2003) shows a way of organizing the data for stoichiometry and equilibrium problems in a reaction table. He gives four reasons for its usefulness. The table follows the same pattern for each type of problem. It helps organize information so what is known, what is important and the answer are easy to identify. The algebra is applied the same way each time. There are built in checks on for accuracy for many problems.

Johnstone (1997) says that we don't fully understand a concept in chemistry unless we can understand it at the macroscopic (tangible) level, the atomic level as well as the symbolic level. Students and teachers may emphasize only one of these representations. Stoichiometry often emphasizes the symbolic. By focusing on only one aspect of a concept, chemistry students are less likely to really understand it or be able to use it in a new context. Gabel, Briner and Haines (1992) show that focusing on just one of these aspects can limit a student's understanding of chemistry. They say that requiring students to show what is happening at the atomic and molecular level can also improve the student's understanding of the sensory and symbolic nature of chemistry. Each of the concepts covered in this unit was modeled to show what occurs at a concrete, particulate level. Most often this was demonstrated using colored round magnets on the white board. Students could see how in a chemical reaction the atoms were rearranged but conserved. They also saw how the relative numbers of compounds compared. Many of the activities had students representing the concepts with a model or in a pictorial form.

Other studies do not show the same transfer for understanding if the instructor focuses on the symbolic nature of chemistry. Yarroch (1985) describes a limited study of fourteen students who could successfully balance equations. Of these fourteen nine could not properly represent the molecules involved in the reaction.

Johnstone (2000) reports that there is both a logical and a psychological aspect to learning chemistry. The logical part includes the facts, concepts and structure of chemistry that we teach. The psychological aspect is how students learn the chemistry we are teaching them. Johnstone (2000) reports that students can only learn topics that fit into what they already know. Researchers have focused on what is going on in the student's mind that helps or hinders his/her learning of chemistry, the psychological aspects of chemistry.

Howard Gardner (1993) writes that there are eight different intelligences: linguistics, logical, spatial (visual), bodily-kinesthetic, intrapersonal, interpersonal and naturalist. These are the primary ways that people interact with and understand the world. People learn best when the material is presented in a manner that reflects their predominant intelligence. Kwen (2003) writes, "Teachers should structure the presentation of material in a way that engages most or all of the intelligences." In an activity described by Simpson (2001), a class of twenty-nine students had twenty-three different combinations of primary and secondary intelligences. A problem with presenting material that is accessible to all these combinations of intelligences is discussed by Stenvold and Wilson (1992). In their study they found that using concept maps that appealed to visual learners lowered the understanding of students with high verbal skills.

The activities in this unit emphasize three of the intelligences described by Gardner that are especially important in chemistry: spatial, verbal and logical. The three-dimensional nature of compounds means that the ability to visualize concepts is essential even at the high school level. In addition, students must be sophisticated linguistically to understand the many new terms and the new meanings given to old terms in chemistry. They also need to decode the information in a problem and solve it logically. The activities in this unit emphasize breaking down the skills needed to solve problems into simpler concrete steps. By emphasizing the spatial, verbal and concrete representation of the problems students will have a better understanding of what the problem asks them to do.

In stoichiometry problems the logical and analytical are often stressed. But other intelligences are important to understand the concepts underlying chemistry. From Kekule and benzene to Watson and Crick and the double helix to Einstein and his thought experiments, the ability to form visual images has been essential to scientific progress. Gardner (1993, page 192) says "after individuals have achieved certain minimal verbal facility, it is skill in spatial ability which determines how far one will progress in science."

In fact, Bodner and McMillen (1986) found that the most successful problem solvers scored high on their ability to visualize the concepts. This was especially true of novel problems even if the problem did not seem to have a visual component. In another study Bodner (2003) found that the most successful problem solvers could represent the information in the problem a number of ways, especially using pictures and diagrams.

Carter, LaRussa and Bodner (1987) expanded on this study and found that the spatial ability was especially important at the stage where students understand what the problem says and they begin to restructure it to begin their solution. Bodner (2003) tells us that representing information, often with a picture, is an important first step as the student experiments with a problem. This allows the student to try different approaches and determine if the answer they get makes sense.

Although Gardner (1993) does not agree with Piaget's view of the supremacy of logical intelligence or definite chronological stages, he does acknowledge the importance of Piaget's research into the development of logical thought. Piaget did extensive research into the development of what Garner calls logical intelligence. He studied how a student's ability to interact with the world changes. Piaget proposed that students go through a series of stages as their mind matures. The initial stages rely on concrete interactions with the world. Gradually, a student may develop the ability to use formal operations. The use of logic and symbolic operations are especially important in chemistry. Only students who have reached the formal operational level can use proportions to solve stoichiometry problems.

Herron (1976) discusses how Piaget's theories relate to the way students learn chemistry. He tells us how important it is to distinguish between abstract and concrete concepts that we teach in chemistry. Many students must use concrete activities to help them understand the more abstract concepts in chemistry.

High school age students are often in a transition between concrete operations and formal operations. Renner (1979) states that half the students in college still use concrete thought. This is even more of a problem in high school classes. When we teach a topic like stoichiometry many of the concepts we are trying to teach are too abstract for the students to understand. Herron gives us an extensive list of what students at a concrete level can and cannot do. They may be able to memorize algorithms to mimic methods used to solve problems but they will not be able to explain what they are doing or to generalize these methods to solve new problems.

Pallrand (1997) reports that the transition from concrete to formal thought is gradual and varies with the type of task. The use of proportions lagged behind other tasks requiring formal thought. Proportions are an essential skill needed to solve stoichiometry problems. In addition, Pallrand reports that situations that use complicated laboratory equipment can hinder the use of formal thought.

Beistel (1975) suggests that students who are in a transitional stage can develop more abstract thinking, but they must be led to those levels by using concrete activities. Gabel et al. (1992) report that using magnets as a concrete representation of the particles involved in a reaction helped improve the students understanding of the concepts of chemistry.

Meers and Wiseman (2002) discuss using multiple intelligence testing to evaluate a student's understanding of the concepts and choose the appropriate science class for the student. Other researchers have looked into activities that involve other intelligences like cooperative learning, history (personal), lab activities (bodily-kinesthetic) and creative writing (linguistic) to improve student success in chemistry but the logical and spatial intelligences seem to offer the most promise for improving problem solving.

Interventions designed to help groups with specific intelligences run the risk of being less effective with groups with other intelligences. For instance, Stenvold and Wilson (1992) report that using concept maps, a visual organization of information, appears to raise the understanding of concepts by students with low verbal skills but the grades of students who have higher verbal skills went down.

In previous years in my classes, student achievement showed a decline as the work required more mathematical and analytical skills. As we studied concepts that relied on these skills the students got farther and farther behind. Up to ten percent of the students dropped chemistry at the end of the semester. The class average for the remaining students went down a full grade from the first semester.

Students may be able to solve some problems by relying on memorized algorithms. But these students aren't likely to transfer these skills to new situations. Even a small change in the problem may make a problem impossible for them to solve. In an editorial in the *Journal of Chemical Education* John W. Moore (2004) stated that using algorithms makes chemistry harder not easier. Students need to accumulate a large number of algorithms for the different types of problems they encounter in chemistry and then pick the right one for the problem they are trying to solve.

Solving stoichiometry problems is difficult for most students. Literature suggests that students can more readily learn the skills needed to solve these problems if they are presented in ways that match how students think. The activities in this unit emphasize representing the concepts in a concrete, visual manner to make them accessible to more students.

II. Implementation

Fifty-two students in two chemistry classes took part in this study. The students spent forty class hours during weeks four through twelve of the first semester learning the skills necessary to solve stoichiometric problems. The topics covered were *naming compounds*, *balancing equations*, finding *amounts* and *stoichiometry*. For each of these topics there was a pretest and a posttest (Appendix D). Concepts were introduced with demonstrations and a short lecture. Table 1 is a summary of the activities in the unit.

Table 1 - Unit outline. New activities indicated with an asterisk.

Topic	Classes	Activities	Tests
Naming	Six class periods	Ion naming handout C1*, Ion sticks activity, poster C2* Ion cards B1 Solubility activity C3*	Pretest D1 Quiz D2 Posttest D3
Balancing	Eight class periods	Hydrocarbon cards B2* Balance Practice C4*, C5* Poster C6*	Pretest D4 Quiz D5 Posttest D6
Amounts	Eighteen class periods	Mole lab C7* Percent composition C8 Poster C9*	Pretest D7 Quiz D8 Posttest D9
Stoichiometry	Eight class periods	Gas production lab C10*-C12* Stoichiometry Practice B3*, B4*	Pretest D10 Quiz D11 Posttest D12

The activities used to explain these concepts divided the necessary skills into simpler steps and presented the concepts visually as well as analytically. The activities each had concrete manipulatives to make the concepts accessible to more students. In class students had time to get individual help and to work on problems from the book and handouts together.

For *naming compounds*, *balancing equations* and finding *amounts* teams of two students made a poster that summarized the key ideas for each skill. The balancing equations and amounts posters showed what was happening on a symbolic level, the particle level and in written form. Examples of the three posters on the wall formed the outline of the steps needed to solve most of the stoichiometry problems for the class.

A. Naming Compounds

Most students do not have trouble writing or naming simple binary ionic compounds. For most students making the positive and negative charges match is not difficult. Some students may have trouble naming ionic compounds with transition metals or polyatomic ions. Our book doesn't introduce types of bonding until much later in the year so the distinction between naming ionic and molecular compounds is confusing to many students. The students were given a sheet with the names of common ions on it (Appendix C1) to help them learn the names of ionic compounds. They would use this sheet for the subsequent activities.

A PowerPoint presentation introduced the key ideas of naming compounds. Two activities were used to help these students learn how to form and correctly name ionic compounds.

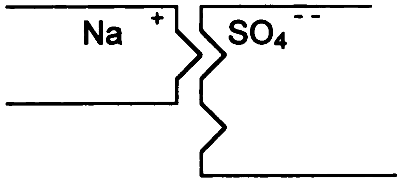


Figure 1 Sample ionic compound forming card

The first activity used laminated cards with triangular projections to represent the charges on the ions (Figure 1 and Appendix B1). These cards had the names and symbols of about twenty common ions. Positive ions had one projection on the right edge for each of its charges. Negative ions had triangular depressions on the left edge for each negative charge. These "charges" fit into each other. Any unmatched charges showed that the proper compound was not yet formed. By matching positive and negative charges the correct numbers of ions in a formula unit could be readily seen and the proper formula could be written out.

The students were given an ion sheet (Appendix C1) to familiarize themselves with ion names. We have a large ion sheet on the wall. I named a cation and an anion at random and the students made a formula from the ions. At the end of the activity the students exchanged papers and corrected each other's work. These cards would be used again when we studied molar masses.

The second page of the handout provided students with practice in understanding some of the difficult parts of naming ionic compounds. It helped them see which metals need special names and how polyatomic ions are named.

A similar activity (Appendix C2) was used to help students see how ionic compounds form. Different colors of craft sticks were assigned to different positive and negative ionic charges. The colors of the sticks matched the colors of the element families on the classroom periodic table. Each student had four sticks of each color. On the front they wrote the charges: a plus sign on one end for positive one, a plus sign on each end for positive two and a plus sign on each end and one in the middle for positive three. Negative ions where handled in a similar manner. On the back of the sticks they wrote the symbols of the different ions with that charge. Students assembled models of ionic compounds so the charges matched. The students then wrote the proper name and formula of the compound and drew pictures of the different types of compounds on the accompanying handout. Students saw that each pairing of sticks could stand for dozens of different ionic compounds. This helped students concentrate on how ionic compounds form without getting bogged down in specific compounds. Questions on the accompanying handout led students to concentrate on the pattern of the ions instead of the specific compounds.

Each pair of students made a poster that showed one specific pairing of charges of a cation and an anion. The students represented what they learned about forming these ionic compounds on a poster.

One advantage of these two activities is that they can be used again later in chemistry. For example, students used the ion cards to find molar masses and to represent single and double replacement reactions. The ion sticks can be bound together to get a concrete model of how an ionic solid forms. This model can show why ionic solids have some of the properties they have like a high melting point. By using the same model for a number of topics the students can gain a deeper understanding of the concepts.

Naming compounds was reinforced by a solubility activity (Appendix C3). The class was divided into two groups. One group represented positive ions and the other negative ions. Each student was given a specific ion and a solubility chart. Each student would go to students from the other group. They wrote down the name and the formula of the compound formed. After at least four compounds were formed, the students sat down the next time they encountered an ion that formed a precipitate. The students then wrote down the pattern that they saw of the ions that formed precipitates. The students moving around the class modeled ions in solution. When the students sat down they represented a precipitate forming.

B. Balancing Equations

We began our study of balancing equation with an activity involving hydrocarbon combustion reactions. This type of reaction was chosen because it follows a fairly simple pattern: hydrocarbons combine with oxygen to form carbon dioxide and water. For most of these reactions each element only is present in one reactant and one product. By keeping the reaction simple and familiar the students can focus on the process.

To learn balancing equations each pair of students were given a set of laminated hydrocarbon cards (Figure 2 and Appendix B2). The set contained ten simple hydrocarbons and alcohols as well as oxygen cards in the reactant packet and carbon dioxide and water vapor cards in the product packet. At the bottom of each card the symbols of the elements in the compound were written. There was one symbol for each atom of that element that was in the compound.

Students added more compound cards until the atoms on each side balanced. The number of cards corresponded to the coefficients in the balanced equation. These reactions were modeled on the board using different colored magnets to represent different atoms.

C_2H_6
C C H H H H H H

Figure 2 Sample hydrocarbon balancing card

Students were given a number of combustion reactions to balance. They represented the different hydrocarbon combustion reactions with their cards and recorded the number of cards they used to show the coefficients of the balanced equation.

These reactions had the same products each time so the students could concentrate on developing techniques to balance equations. These cards can be used again when we study Hess' Law to organize the enthalpies of formation. Most students found the activity useful. Some students understood the concepts quickly and found the repetition unnecessary.

We used the ion cards (Figure 1) from the naming activity to show how metathesis and single replacement reactions work and how to balance these reactions. By interchanging the cation cards students could see how new compounds were formed. They used their knowledge of solubility and activity tables to see if a reaction actually occurred. If a reaction occurred they determined if the atoms balanced. They continued to add compounds to each side until the atoms on each side balanced.

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

	CH_4	O_2	CO_2	H_2O
C	1		1	
H	4		2	
O	2		3	

Figure 3 Balancing scheme for hydrocarbon combustion activity

In addition to these specific types of reactions the students were taught a general balancing strategy shown in Figure 3. Students were advised to list the atoms for the reactants and products. Then they listed the number of each type of atom that was in the problem. As they changed the coefficient of a compound they changed the number of atoms in their list. The students used these methods and the manipulatives (Appendices B1 and B2) to complete a traditional practice sheet (Appendix C4).

Pairs of students were assigned an equation to show the processes involved in balancing the equation (Appendix C5). They made a poster of their reaction, which had three parts: the equation written in words, the equation written in symbols and a concrete representation of the atoms involved in the equation.

About half the students reported in the post unit survey (Appendix E2) that they found making posters "helpful" or "very helpful". This activity was especially useful because it accentuated the meaning behind the symbols of the equation.

C. Amounts: moles, molar mass and molarity

Although students use names like "dozen", "football teams", "classes" etc. to stand for groups of things the concept of the mole is difficult for many of them. The pretest for this topic (Appendix D6) asked students questions about numbers of eggs, dozens and masses of eggs. They were very successful converting numbers to "dozens". When they converted masses of eggs to numbers of eggs one third of the mathematically correct answers included fractions of eggs in their answer. This showed that they had a correct rule that they could follow but they did not correctly interpret the meaning of the question.

To help with this concept the students determined how many pieces of cereal were in boxes of three different types of cereal (Appendix C6). The students found the mass of one, twelve and twenty-four pieces of cereal. From the mass of the cereal in the box they predicted the number of pieces of cereal in the box.

This activity showed one of the complications they will discover in chemistry: how do you count large numbers of particles. The answer lies in knowing how mass and amounts are related to each other.

After they established a relationship between mass and amount they determined the mass of a bowl of cereal and how many bowls of cereal are in the box. The class discussed what it means to be a bowl of cereal in terms of mass and amounts. Students compared answers with other groups that had the same cereal, as well as with other groups that had different types of cereal to look for patterns in the results and methods. In class students justified their answers and errors and their sources were analyzed and discussed. The class discussion focused on ways to eliminate these errors.

Students looked at how the mass of a compound and the mass of its components are related. Students were asked to determine what is the smallest number of formula units of NaCl you could measure on the digital balance. In addition to being a practice problem for molar mass this reinforces the importance of significant figures and the effect of the uncertainty of measurement.

To help in understanding molar mass we used the handout from Appendix C1. On this sheet there was a place for the mass of each ion. This sheet reduced the number steps necessary to find the molar mass of a compound with polyatomic ions. For example, to find the molar mass of a compound like sodium sulfate students need to add two atomic masses of sodium to the mass of the sulfate ion instead of adding the masses of the individual atoms. Students found this chart useful and referred to it throughout the rest of the year.

Students were shown how to solve problems involving moles one of three ways: "ratios", "circles" and "unit factors". "Circles", Figure 4, are a mnemonic device relating the moles of a chemical, mass and/or number of particles of a chemical. In the circle when two quantities that are next to each other are known multiplying gets the third quantity. When they are above each other it is necessary to divide to get the third number.

There are also circles to remember number of particles and molarity. Some students even needed a circle to convert between milliliters and liters.

Approximately half of the students used ratios and half used circles to find amounts of chemicals. Some students were comfortable with either method. Students who use "circles" tend to be weaker in mathematics. The ability to use proportionality is one indication of being able to use formal operational thought.

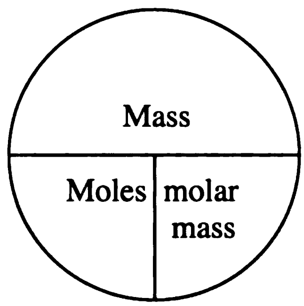


Figure 4 Sample conversion circle

In the percent composition lab (Appendix C7) students found out how much carbon dioxide was released when vinegar was added to sodium bicarbonate. Students calculated the percent of carbon dioxide in the sodium bicarbonate.

To show the different ways that chemists represent amount pairs of students made a poster (appendix C8) to represent the mass, the moles and the volume and molarity of 7.59×10^{22} particles of a specific compound. These posters showed how to convert between these different ways of representing amounts.

D. Stoichiometry

The unit was developed to help students solve a stoichiometry problem by organizing the information of the problem. The students used activities to picture the reactions, identify the known quantities, put the data into a form that is more readily useful, to solve the problem and to evaluate the reasonableness of the answer.

To help understand how amounts of reactants affect the amounts of products we looked at the production of hydrogen gas by the action of hydrochloric acid on magnesium. The gas production lab was designed to use a reaction the students had already used in the second lab of the year. In that lab we generated different gases and identified them by their properties. They would use that reaction again when we studied the ideal gas law

In the main lab (Appendix C 10) for stoichiometry, two students measured approximately 1.10 cm of magnesium ribbon. This short piece of magnesium was put in a 20 ml syringe and approximately 25 ml of 0.95 molar hydrochloric acid was drawn into the syringe. The acid was allowed to leave the syringe as the hydrogen gas was generated.

After the reaction reached completion the pressure inside and out was equalized and the volume of the gas was recorded. Knowing the volume of gas produced and the density of gas the students determined the mass and number of moles of gas that was produced. By comparing the number of moles calculated and predicted they could tell how accurate the procedure was.

For the second day of the lab I gave the class a volume of gas they needed to produce in a gas collection tube using the same reaction. This helped the students establish the idea that the amount of a reactant determines the amount of product produced.

The lab partners discussed the errors involved the experiment and how these errors affected their results. Sources of error discussed were contamination of the magnesium, errors in measurement of the magnesium and the hydrogen gas. None of the students discussed the water vapor in the tube.

This lab used a reaction that the students were familiar with from a previous lab and introduced some of the concepts that would be useful when we studied gas laws. This lab served as a bridge between previous skills learned and helped serve as a precursor for the skills needed for the chapters on the gas laws.

To evaluate their understanding of the relationship between amounts of reactants and amounts of products the students determined how much magnesium they needed to produce a volume of hydrogen that I specified. Some groups could not agree on a method and they formed new groups.

The other lab that we used was taken from the text. We mixed a solution of strontium chloride with a solution of sodium carbonate and filtered out the precipitate. The filter paper and the filtrate was dried. The students massed the resulting strontium carbonate and sodium chloride. The results of this lab were poor because of improper filtering or loss of salt while heating. Because of the errors in the lab it was harder to see the stoichiometric relationships.

To help overcome the difficulty students have solving stoichiometry problems student were taught ways to translate and organize the data in problems. The data, the compounds and the key words and phrases of stoichiometry problems were written on separate sheets of paper. Each of these was affixed to the board with magnetic holders. When each sheet was removed the words from the problem could be translated into symbols. The purpose of this is to help students focus on the important parts of the problem and the process of translating it into symbolic form. This gave a visual and dynamic representation of the translation of the problem into symbolic form.

To solve the problem we used an organization chart shown in appendix B3. This chart is similar to one I have used in my class for many years and I have refined it for this unit. A detailed example of this chart is shown in Appendix B3. The equation provides the structure for the problem. There is a specific place in the chart for each type of data for each of the chemicals in the reaction. The chart pairs the information with the formula needed to change that information into moles. The student then takes the amount of the chemical in moles and makes a ratio with the coefficients from the balanced equation. The information from the problem was used to determine the number of moles of the compound given in the problem. The students used the moles from the chart and the coefficients from the problem to calculate the moles of the answer. By using the chart in reverse the proper form of the answer can be calculated.

Students were given a form of the stoichiometry chart to organize the problems at their desks. They were given individual color coded laminated cards (Appendix B4) with the possible forms the data could take: grams, moles, volume, molarity and coefficients. The information from the problem was written on the cards. By arranging the cards in order they could do the calculations in smaller steps. This is similar to a jigsaw activity that some mathematics teachers use to teach proofs. This helps the students develop the relationships between the steps in the solution.

Students were encouraged to express the relationship between the coefficients by using terms like "twice", "the same", "half" etc. rather than strictly algebraic forms. Initial problems had simple amounts of chemicals. The amounts in the problem were represented visually with magnets. The students were encouraged to verbally compare the amount from the problem with the coefficients to help them see if their answer was reasonable.

One advantage to using the color-coded cards is that it is very easy to tell which students are making progress and which students need help.

Students reviewed for the test by solving stoichiometry problems from the book and from a handout (Appendix C12). Then they developed a question similar to one of the questions on the review sheet and an answer key. Students exchanged these questions with each other and corrected their peer's answers.

III. Results evaluation

The students were given an introductory survey (Appendix E1) about their science and mathematics background and their future plans and the results are summarized in Appendix E1. An exit survey (Appendix E2) asked their opinions of the activities in the unit. Their responses from question 4 are given in Table 2.

Table 2 - Survey results reporting student's success on unit tasks

	rarely	sometimes	often	usually	always
Naming compounds	0	6	5	22	18
Writing formulas	2	2	3	24	18
Balancing equations	1	2	11	18	9
Finding moles	0	3	6	16	26
Finding molarity	0	2	6	16	26
Stoichiometry	4	11	9	13	14
Reading text	7	8	5	13	14

Table 3 records the results of a survey of the student's opinion of the effectiveness of the activities in this unit from Appendix E2. For most of the activities there was little difference between the number of students who found a particular activity "helpful" or" very helpful" and those who found the activity "not helpful" or "somewhat helpful".

Of the fifty-one students surveyed forty-one (80%) of the students said that the practice handout (Appendices C4, C5, C12 and C13) were "helpful "or very "helpful". Thirty-four students (67%) said that making the balancing poster was "helpful" or "very helpful".

Students were also asked in the survey (Appendix E2) to identify the activity they found most helpful and least helpful overall. Nineteen students reported that getting "individual help" was the most helpful of all the activities. Thirteen students said "examples done in class" was most helpful. Eight students (16%)

said that they learned the most in this unit by making the posters. Eleven students (22%) said that reading the text was the least helpful activity of the unit and nine students (18%) said that the labs were least helpful.

Table 3 - Survey results of student's opinion of the tasks in the unit

	Not helpful	Somewhat helpful	Helpful	Very helpful
Stoichiometry chart	4	16	21	8
Balancing cards	9	23	13	5
Posters	5	19	17	10
Percent composition lab	1	23	23	2
Gas production lab	3	20	21	6
Gas prediction lab	4	23	19	7
Balancing equations poster	5	14	24	7
Picturing reactions	4	20	15	12
Practice handouts	2	8	22	19
Book problems	7	15	20.5	8.5
Solubility activity	3	25	14.5	8.5
Reading the text	14	23	10	4
Examples done in class	0	5	12.5	33.5
Lectures	0	13	19	16
Individual help	0	2	10	39
Ion sticks	6	24	21	0
Mole lab	4	15	21	11
Reaction cards	6	19	17	8

Table 4 records the class average for each of the topics in this unit. This table also includes the probability based on a t-test of the on the pretest and posttests for each of the topics in this unit. The individual student scores for each pretest and posttests are listed in Appendix D11.

Table 4 Class average for each topic, n = 52

	Naming	Balancing	Moles quiz	Molarity test	Stoichiometry
Fourth hour	86.3%	80.1%	83.1%	84.6%	73.0%
Sixth hour	91.7%	82.6%	85.4%	86.8%	83.3%
All students average	89.0% n = 52	81.35% n = 52	84.3% n = 51	85.7% n = 51	78.1% n = 49
Pretest average	29.6%	30%	81.2%		28%
Probability	.001	.001			.001

A. <u>Naming Compounds</u>

Students learned some rules for naming compounds in ninth grade physical science class. Table 2 shows that the students had a score of 29.6% for the naming (Appendix D1) pretest. They had their highest posttest average of the unit for this topic. One third of the students reported (Appendix E2) that naming compounds was the easiest skill to learn of the four topics of the unit and approximately 80% say that they can usually or always write the correct name and formula for a chemical compound. The major sources of error on the posttest was not properly naming polyatomic ionic compounds or not indicating the charge on transition metal ions.

Only 23 of the students (35%) found the solubility activity (Appendix C3) "helpful" or "very helpful." This activity had the least favorable response of any of the activities.

As shown in Table 4 students had their highest average for the *naming* topic of this unit. A t-test for the stoichiometry tests gave a value of 26.1 with100 degrees of freedom. This indicates a probability less than 0.001 that the difference between the pretest and posttest was due to chance.

B. Balancing

The average score for the pretest for the balancing section was 30%. After instruction seventy-two percent of the student reported (Appendix E2) they can usually or always balance equations.

The questions that gave students the most trouble involved translating the names of chemicals into their formulas and predicting the products.

Students had two reactions to the balancing cards (Appendix B2): "Can we use them on the test?" and "Do we have to use them?"

The average for the posttest was 81.35%. A t test for the balancing test gave a value of 16.9 with 100 degrees of freedom. This indicates a probability less than 0.001 that the difference between the pretest and posttest was due to chance.

C. Amounts

This unit taught students about moles and molarity. Since this is a new concept for nearly all students the pretest for this unit (Appendix D3) asked about how well students could solve analogous problems about relationships between number of eggs, dozens of eggs and masses of eggs. Most students could readily solve these problems. A t-test was not done for this topic because the pre- and posttests were not related.

After this topic forty-two students (82%) said that they could usually or always use moles or molarity to find amounts. There was a quiz and a test for moles and molarity. The quiz (Appendix D7) covered conversion between mass, moles and number of particles. The class average for this topic was 84.3%. The posttest (Appendix D8) covered molarity. The average for this test was 85.7%.

D. Stoichiometry

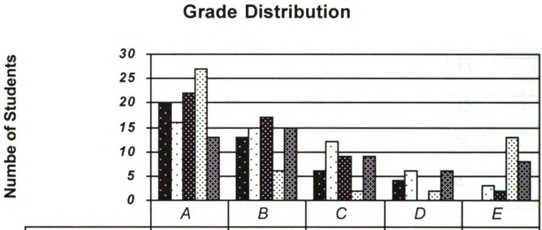
Thirty-seven students (73%) reported (Appendix E2) that stoichiometry was the most difficult topic we studied in this unit and their grades reflected that. Thirteen students failed the stoichiometry test. On each question of the test at least six students did not attempt an answer. This is true whether the question asked for a computational, visual or written answer (Appendix D10). None of the seventeen students who got less than 80% on the test used the stoichiometry chart (Appendix B3).

Although too many students failed the test, many others were very successful. As shown in Appendix D11 twenty-seven students (55%) got an A on the test. Twenty-five percent of these students got perfect or near perfect scores on the stoichiometry test.

One student in fourth hour didn't take the test on stoichiometry. His score is not included in the class average. Another student took a different version of the test when she returned from vacation and her score is not included in the average.

A t-test for the stoichiometry tests gave a value of 11.6 with 96 degrees of freedom. This indicates a probability less than 0.001 that the difference between the pretest and posttest was due to chance.

Figure 5 gives the letter grade distribution for the individual topics in this unit. The “naming” and “amounts” topics had the highest percentage “above average” (A or B) grades. The scores for the “balancing” test showed the lowest number of A’s for this unit. The grades also showed the most even distribution with nearly equal numbers of A’s, B’ and C’s. The test for “stoichiometry” showed the widest variance. Figure 5 shows that the stoichiometry posttest scores are bimodal, with most of the grades A’s (54%) or E’s (26%) with a smaller numbers of B’s (12%), C’s (4%) and D’s (4%).



	A	B	C	D	E
naming	20	13	6	4	0
balancing	16	15	12	6	3
amount	22	17	9	0	2
stoichiometry	27	6	2	2	13
nuclear	13	15	9	6	8

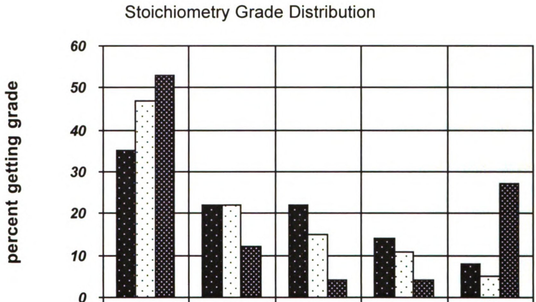
Figure 5 - Grade distribution for 2003

For comparison I have included the average grades for the stoichiometry posttest for the 2001-2002, 2002-2003 and 2003-2004 school years in Table 5. In the fall of 2001 I taught seventy-eight students in three sections of chemistry, and in the fall of 2002 I taught one hundred students in four sections of chemistry. In 2001 the average on the stoichiometry test was 78.7%, in 2002 the average was 84.1% and in 2003 the average was 78.6%. These averages were approximately the same but the standard deviation did change significantly.

Table 5 - Comparison of averages and letter grades for stoichiometry tests for 2001, 2002 and 2003

	Stoichiometry 2001	Stoichiometry 2002	Stoichiometry 2003	Atomic Structure 03-04
average	79.7%	84.1%	77.1%	76.0 %
A	27	47	27	13
B	17	22	6	15
C	17	15	2	9
D	11	11	2	6
E	6	5	13	8
Number of students	78	100	50	51
Standard deviation	10.3	9.1	14.1	9.2

To see if this distribution persisted for other topics this year, I have included the scores for the test for atomic structure in Table 5. The topics for this test were atomic number, atomic mass, and nuclear decay. This was the next test that didn't involve moles. Table 5 shows that the distribution of grades and the standard deviation on the stoichiometry test in this unit are different from the distribution of grades and the standard deviation of both past stoichiometry tests and the atomic structure test this year.



	A	B	C	D	E
2001-2	35	22	22	14	8
2002-3	47	22	15	11	5
2003-4	53	12	4	4	27

Figure 6 Percent of students getting specified grade for stoichiometry posttest for 2001-2002, 2002-2003 and 2003-2004.

The standard deviation was much larger for the stoichiometry test this year than the other years. This reflects the bimodal distribution of scores shown in Figure 6. The percentage of A's and E's increased. The percentage of B's, C's and D's decreased significantly from the scores on stoichiometry tests in the other years reported in Table 5.

IV. Discussion and Conclusions

The activities in this unit concentrated on presenting the skills necessary to solve stoichiometry problems in concrete and visual manners. Their effectiveness is discussed in the following sections.

A. Naming

Although the ion card activity (Appendix B1) was concrete and visual it was cumbersome to sort through all of the ion cards to get the correct formulas. Next year I will use cards with the same shape but without the chemical symbols on them. The same card could represent silver or sodium or potassium or any other positive one cation. These cards can also be used to find the molar mass of a compound and to demonstrate ionic bonds.

Most students did not need two activities to learn how to name compounds. Consequently, I will use the ion sticks activity (Appendix C2) as a demonstration. We will continue to make posters showing the naming of compounds.

B. Balancing.

Using colored round magnets to model the reactions was a very useful and flexible technique. This approach was used to represent atoms in the reaction during *balancing* and the number of molecules or ions when we talked about *amounts* and *stoichiometry*. Modeling concepts with magnets gave a concrete, visual representation that helped students understand abstract concepts. This continued to be helpful when we studied bonds, collligative properties, acids and bases and many other processes.

A number of students said they did not like the trial and error nature of balancing equations. Balancing requires a familiarity with numbers and the willingness to try different combinations of numbers. Students who were not successful did not use the balancing scheme shown in Figure 3 or any other organized attempt to balance equations.

Although only thirty-five percent of the students found the hydrocarbon balancing cards (Appendix B2) "helpful' or "very helpful," some students were very enthusiastic about using the cards. In addition, the hydrocarbon cards were useful to demonstrate Hess' Law. Students have trouble with this concept. The cards are a concrete and visual way to keep track of the enthalpies involved in the reaction.

Thirty-four students thought the balancing poster was "helpful" or "very helpful." The poster helped show how the written, symbolic and particle representation of the equation are related to each other.

C. Amounts

The mole lab (Appendix C6) included too many concepts. In the future I will limit the scope of the activity to how amount and mass are related and use it as an introductory activity. This activity will show how we can find the number of particles when we can't conveniently count them. We will revisit the activity and expand it to include moles when we actually talk about chemical amounts.

The percent composition lab (Appendix C7) was straightforward and easy for the students to follow. Most students had a large percent of error so the concept of percent composition was not clear to them. I will look to revise or replace this lab for next year.

The problem on the quiz (Appendix D7) that caused students the most trouble asked students to calculate the number of ions when they were given the moles of the ionic compound. Many students could not see a connection between the number of particles and the number of ions. When students were told to draw a representation of the problem like we had done in class most students could solve the problem.

D. Stoichiometry

Twenty-three students got their highest score of the year on the stoichiometry test. Eight students had prefect scores; seven had near perfect scores and eight had A's instead of the B's or C's that they got on the other tests during the year. The concrete and visual activities in this unit helped more students be successful on the stoichiometry test than they were on other tests during the year.

Thirteen students failed the test for stoichiometry (Appendix D10). Since their tests did not show any attempt to use the methods taught in the class it is not possible to say if the activities in this class would have helped them. On nearly every question between six students and ten students did not even attempt the problem. This was true not only for mathematical problems but also for the questions that asked for a verbal or pictorial answer.

The question that caused the most trouble on the stoichiometry posttest (Appendix D10, question 3a) involved finding the theoretical yield of a reaction. The solution to this problem involved over eight steps. Eighteen students of forty-nine students (37%) had a wrong answer and eight (16%) did not attempt the problem.

Question 2a of the posttest was also informative. Students were given a balanced equation and the moles of one reactant and were asked to find the number of moles of one product. Despite the fact that this was a two-step problem eight students (16%) got an incorrect answer and six students (12%) didn't attempt a solution.

This year there was a marked increase in both A's and E's as seen in Figures 5 and 6. The higher number of failures for this topic may partially be explained by the students' mathematical background. Thirteen students report (Appendix E2) that they have trouble with mathematics. Eight students reported in the survey (Appendix E2) that they rarely can solve "story problems" or only can solve them with help. These students would be expected to have trouble with the stoichiometry test because of the mathematical nature of the problems.

To help overcome these difficulties students were taught different ways to organize and translate the data in a problem that corresponds to the different ways that students think. This unit presents a systematic approach to solving stoichiometry problems.

The students were introduced to techniques to help organize the information in the problem and to provide a guide to the steps needed to solve introductory problems. These organizational approaches give the student the flexibility to start the problems they are going to encounter in class without overwhelming them with large amounts of information.

As shown in the stoichiometry labs, these problems can start with a number of different types of information. Students may be given the amounts of chemicals in a reaction as mass, the molarity and volume of a solution or the volume of a gas. In other problems students are given information about the amounts of two or more chemicals and the student must decide which of the chemicals would be used up and which chemical was in excess. From this information they could determine the theoretical yield of the products.

Twenty-nine students found the stoichiometry cards a helpful way to organize the data. The concrete and visual representations seemed to help the students who would usually be B or C students. Eight students who got A's on the stoichiometry test got B's for the quarter and four of the students who got B's on the stoichiometry test got C's for the quarter.

The stoichiometry cards allowed students to focus on one step at a time. They could record the information on the appropriate stoichiometry card. From the cards they could calculate the amount of the compound. They could use this information to make a proportion with the coefficients of the equation.

The primary premise of this unit was that students learn in different ways. As such these activities will not help all students equally. For many of the activities there was nearly an even split between students who found the activities "helpful" or "very helpful" and those who found it "somewhat" or "not helpful" (Appendix E2). For instance, there were two student reactions to working with the organization structures (Appendices B2 and B3): "Do we need to use them?" and "Can we use them on the test?" These two reactions accentuate the differences between two groups of chemistry students. Some quickly grasp the methods of analytic problems and can solve similar problems with little or no difficulty. Many of these students do not see a reason for using manipulatives. Others flounder with the abstract nature of the problems and have trouble organizing the information without a structure to guide them.

Some of the students who were successful on the tests didn't find the activities in this unit helpful. In many cases they didn't use the methods taught in class. That may be due to the rather straightforward nature of the problems that we were solving, which allowed the students to solve the problems using algorithms. Huffman (1997) indicates that students, especially males, resist using explicit problem solving techniques. They prefer methods with which they are comfortable.

Later in the semester some of the students who had success solving problems using algorithms had trouble when the problems became more complicated. They hadn't developed a strategy to solve novel problems.

Representing the information in problems visually was a useful technique for many students. This approach helped students who are not strong mathematically solve some problems. Four students who had a C for the quarter and eight students who had a B for the quarter raised their score at least one full grade. The visual representation also helped me see if the students understood the underlying concepts. These activities will be expanded in the future.

Bodner (2003) say that teachers who model a visual approach to problem solving will see more successful problem solvers. Both the research and the results of this unit showed the importance of representing ideas visually. This allows students to keep the reality behind the symbols clear in their mind and gives them a starting point to solve the problems.

This unit originally was designed to help students who were having trouble solving stoichiometry problems in chemistry. The number of A's and B's on the stoichiometry test seemed to show the activities implemented in this unit helped many of the students. As I read the literature and analyzed the data it became clear that some of the students who successfully solved the problems might still have a superficial understanding of the underlying concepts. For many problems they could count on their mathematical ability to get a solution without necessary-ily understanding the concepts of chemistry. I will need to introduce problems of the other types as described in Johnstone (2001) that aren't easily solved by algorithms. This will help the more mathematical students focus on the chemistry of the problems rather than just the mathematics of the problem. One way to do this is to ask questions that are more conceptual. Often these questions require a visual representation of the concepts.

Another approach would be to have questions that have less clearly defined methods of solve them. Because there is such a mixture of skills in the high school classroom it is necessary to challenge, but not overwhelm the students. Dori and Hameiri (2003) detail a method to classify the difficulty of problems based on the type of problem and the skills needed to solve the problems. This method is based on the three levels of understanding of chemistry that

Johnstone posits. This system, as well as working memory considerations, will guide my construction and choice of problems.

The use of concrete and visual activities seemed to be helpful for the students who used them to organize and solve problems. For these students having a structure to help organize problems improved their work immensely. It helped them focus on one step of the solution at a time without being so structured that they solved the problems mechanically.

The gas production lab (Appendix C9) engaged the students and got good results. Fifty-three percent of the students said it was "helpful" or "very helpful" (Appendix E2). It included many of the concepts that we had studied and it provided a simplified version of a lab we would be doing later. There was some lively discussion by the students about how best to obtain the correct answer. The lab had an imbedded assessment and the students could tell immediately if they were right or not. Many students asked to work alone or with another group. I will change some of the error analysis to include class data. In the future I will emphasize the inclusion of more factors as we improve our understanding of gases. One important aspect of the stoichiometry lab for producing hydrogen gas was that it was an expansion of a lab that they have done before and a precursor of a lab we would be doing when we studied gas laws. The process of refining our knowledge of a concept, having it develop as we include more factors is an important concept for the students to learn about chemistry.

While the activities in this unit helped many students become successful problem solvers some students were not successful. The number of students who failed the test indicates that I need to find other ways to involve these students in chemistry. Most of these students continued to have trouble throughout the year. Since none of these students used the methods introduced in class and most did not complete in-class assignments it is difficult to determine if they would benefit from the new activities introduced in this unit.

Tileston (2000) gave one possible explanation. She says that there are two ways to help students internalize information. One is to establish patterns. That approach worked for many of the students in this unit. The more powerful way is to make the information relevant. The lack of effort on the activities and the number of questions on the test that weren't even attempted means that a number of students weren't engaged with the material. I feel that nearly every student should be able to use the methods in this unit to solve the problems in high school chemistry; so getting these students involved in class will be a priority for next year.

I will continue to incorporate activities that are concrete and visual. From what I saw in this unit it helped many students get a deeper and more thorough understanding of chemistry.

During this year I introduced concrete and visual representations of the concepts. These representations helped many students but these were introduced rather piecemeal into the class. I feel these activities and models work better when they are used in a more coherent and connected manner.

One concrete and visual activity we used later in the year was a three-dimensional modeling of the periodic table. In this activity each student represented the electronegativity of an element with a length of a straw. These were put into a foam periodic table. This activity was especially informative because two students made mistakes in their calculations. These errors were apparent because the results did not fit into the pattern. This helps the students move beyond looking at an array of numbers and helps them see pattern of the concept.

In the same chapter I used rubber bands of the same length but different widths to represent the strength of the pull on the bonding electrons. The knot where they are connected stays closest to the stronger rubber band. Activities like these help make abstract concepts like the types of bonding and atomic and ionic sizes clearer for many students.

Giving students a place to start solving problems is important to novice problem solvers. Bodner (2003) says that trying something, even if you are not sure where it is going to lead, is an important part of problem solving. The stoichiometry chart will remain a central part of the stoichiometry unit.

Many of the students found the visual representation of concepts to be helpful. The posters helped accentuate the different ways we describe chemical reactions: verbal, visual and symbolic. I used posters as extra credit opportunities this year but I will incorporate them in different topics throughout the year.

Focusing on representing each of the three aspects of chemistry was very helpful to many of the students. It helped students determine if the answers made sense or not. Some students still have trouble distinguishing between atoms, element and ions. The concrete representation of what is going on in the reaction at the molecular level was especially important.

Presenting concepts in concrete, visual ways helps make stoichiometry accessible to more students. Although the topic is still difficult for students most students can learn the basic skills necessary to be successful.

Appendix A Syllabus

September 12 Pretest (Appendix D1), PowerPoint on naming

September 15 Ion forming cards (Appendix B1)

September 16 Ionic naming compounds sticks activity, poster (Appendix C1)

September 17 Half day of school, no class

September 18 Red ion sheet (Appendix C2), questions naming pages 75-77

September 19 Solubility activity (Appendix C3)

September 22 Test naming (Appendix D2)

September 23 Lab 3.1 Observing Chemical Change

September 24 Balancing hydrocarbons activity (Appendix B2)

September 25 Balancing hand out (Appendix C5), predictions Appendix C4)

September 26 Balancing single and double replacement activity (Appendix B1)

September 29, 30 Balancing poster (Appendix C6)

October 1 Review balancing

October 2 test balancing

October 3 In service, no classes

October 6 Moles lab (Appendix C7)

October 7,8 lab 4.1 Determining the empirical formula of a $MgCl_2$

October 9 Ion chart molar mass, questions molar mass, moles page 135, 157

October 10 Mole day show and tell

October 13 Quiz moles (Appendix D7)

October 14 Molarity demonstrations and molarity questions pages 157-158

October 15 Questions continued.

October 16, 17 Percent composition lab (Appendix C7)

October 20 Percent composition problems page 158

October 21 Empirical and molecular formula

October 22 Empirical and molecular formula problems page 158

October 23 Mole Day

October 24, 27 Lab pages 154-155 Production of NaCl and $SrCO_3$

October 28 Poster amounts

October 29 Poster amounts continued

October 30 Test amounts (Appendix D8)

October 31 Halloween demonstrations

November 3 Stoichiometry lab (Appendix C8)

November 4 Stoichiometry lab prediction (Appendix C9)

November 5 Half day, no class

November 6 Stoichiometry lab, error analysis (Appendix C10)

November 7 No class

November 10 Stoichiometry questions page 187-188

November 11 Stoichiometry practice handout

November 12 Answer and correct each other's questions. Make up question

November 13 Finish review and questions

November 14 Stoichiometry Test, End of unit

November 17 Survey Appendix E2 Gas law demonstrations

Appendix B Hands On Activities

Appendix B1 Sample ion cards

Mg^{2+} magnesium	SO_4^{2-} sulfate
Fe^{3+} iron (III)	Cl^- chloride
	CO_3^{2-} carbonate

Appendix B2 Balancing Cards
Original font size was 72

CH_4

C H H H H

C_2H_5OH

C C H H H H H O H

CO_2

C O O

H_2O

H H O

O_2

O O

$.5O_2$

O

Appendix B3 Sample Stoichiometry Problem and Chart

13.2 grams of zinc reacts with an excess of hydrochloric acid. How many grams of hydrogen gas will be released?

Volume

Temp

Pressure

Volume
molarity

Mass	13 g				
Molar mass	65.4 g/mol				
Moles from problem	_____	_____	→	_____	_____
Coefficients (moles) from equation	1	2		1	1

Equation $1\ Zn\ (s) + 2\ HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2(g)$

front:

Volume (aq) X Molarity

back: moles

front:

mass (grams)/molar mass

back: moles

<u>moles from problem</u>

coefficient

Appendix C Activities and Labs

Appendix C1 Ion Chart

CATIONS (positive ions)

Mass	ION	symbol
______	aluminum	Al^{3+}
______	ammonium	NH_4^{1+}
______	barium	Ba^{2+}
______	cadmium	Cd^{2+}
______	calcium	Ca^{2+}
______	chromium (II)	Cr^{2+}
	chromium (III)	Cr^{3+}
	chromium (VI)	Cr^{6+}
______	cobalt	Co^{2+}
______	copper (I)	Cu^{1+}
	copper (II)	Cu^{2+}
______	hydrogen	H^{1+}
______	iron (II)	Fe^{2+}
	iron (III)	Fe^{3+}
______	lead (II)	Pb^{2+}
______	lead (IV)	Pb^{4+}
______	lithium	Li^{1+}
______	magnesium	Mg^{2+}
______	manganese (II)	Mn^{2+}
______	mercury (I)	Hg_2^{2+}
	mercury (II)	Hg^{2+}
______	nickel	Ni^{2+}
______	potassium	K^{1+}
______	scandium	Sc^{3+}
______	silver	Ag^{1+}
______	sodium	Na^{1+}
______	strontium	Sr^{2+}
______	tin (II)	Sn^{2+}
	tin (IV)	Sn^{4+}
______	zinc	Zn^{2+}

ANIONS (negative ions)

Mass	ION	symbol
______	acetate	CH_3COO^{-}
______	bromide	Br^{-}
______	carbonate	CO_3^{2-}
______	bicarbonate	HCO_3^{-}
______	chlorate	ClO_3^{-}
______	chloride	Cl^{-}
______	chlorite	ClO_2^{-}
______	chromate	CrO_4^{2-}
______	dichromate	$Cr_2O_7^{2-}$
______	cyanide	CN^{-}
______	fluoride	F^{-}
______	hydride	H^{-}
______	hydroxide	OH^{-}
______	iodide	I^{-}
______	nitrate	NO_3^{-}
______	nitrite	NO_2^{-}
______	oxalate	$C_2O_4^{2}$
______	oxide	O^{2-}
______	perchlorate	ClO_4^{2-}
______	permanganate	MnO_4^{2-}
______	phosphate	PO_4^{3-}
______	monohydrogen phosphate	HPO_4^{2-}
______	dihydrogen phosphate	$H_2PO_4^{-}$
______	sulfate	SO_4^{2-}
______	bisulfate	HSO_4^{-}
______	sulfide	S^{2-}
______	hydrogen sulfide	HS^{-}
______	sulfite	SO_3^{2-}
______	bisulfite hydrogen sulfite	HSO_3^{-}

Ion chart continued. Naming patterns:
Use your ion sheet to answer these questions.

1. Which ions have more than one charge?

Where are these elements on the periodic table?

2. Where on the periodic table do you find the ions with a positive one charge?

3. Where on the periodic table do you find the ions with a positive two charge?

4. Where on the periodic table do you find the elements that form a negative one charge?

5. Write down groups of ions that have similar names.

Describe what the prefixes and suffixes on the polyatomic ions tell you about them.

These are the two polyatomic ions of arsenic and oxygen: $AsO_4{}^{3-}$ and $AsO_3{}^{3-}$. From the pattern you saw what should be the name of these.

Appendix C2 Ionic Sticks

IONIC COMPOUNDS NAMES

Your ion sheet tells you the type of ion each atom forms. You will use these colored sticks to show how ionic compounds form.

For the cations (positive ions) use the purple stick for a positive one ion. Put a plus sign on one end of the stick. Use the green stick for a positive two ion. Put a plus sign on one end of the stick and one in the middle. Use the yellow stick for a positive three ion. Put a plus sign on each end of the stick and one in the middle.

Repeat for negative ions using blue for negative one, gold for negative two and red for negative three. Write the symbols of the element that form each of these ions on the stick. Don't forget the polyatomic ions.

Part I 1. Form a compound from the positive one and negative one ion sticks. Draw a picture of the compound.

Write a formula for the compound formed using P for purple and B for blue.

How many compounds could be formed from these ions?

2. Form a compound from the positive one and negative two ion sticks. Draw a picture of the compound.

Write a formula for the compound formed.

How many compounds could be formed from these ions?

3. Form a compound from the positive two and negative one ion sticks. Draw a picture of the compound.

Write a formula for the compound formed.

How many compounds could be formed from these ions?

4. Form a compound from the positive two and negative two ion sticks. Draw a picture of the compound.

Write a formula for the compound formed.

How many compounds could be formed from these ions?

5. Form a compound from the positive two and negative three ion sticks.
Draw a picture of the compound.

Write a formula for the compound formed.

How many compounds could be formed from these ions?

6. Form a compound from the positive two and negative three ion sticks.
Draw a picture of the compound.

Write a formula for the compound formed.

How many compounds could be formed from these ions?

Part II 7. Do any of these pairs have similar patterns?
Which pairs?

8. Give an example of a formula for the compounds formed in questions 1 to 6.

1.	2.	3.
4.	5.	6.

9. Describe how you can tell what ionic compound will form from two ions.

10. Make a poster that shows how ionic compounds form following the directions we decided on in class.

Appendix C3 Solubility Activity

Name

Take out your element card. Write the ions that your ion is soluble with and the ions that it isn't soluble with on this sheet.

soluble

insoluble

When everyone is done you are going to model a solution with a number of ions in it. Stand up, walk around and talk to other "ions". Record the results of your encounters (soluble, insoluble, repulsed.) Find at least two ions that you would be soluble with and one that would not be soluble with your ion.

Your atom ____________ the ion(s) it forms (include polyatomics) ______

List the ions you encountered and what would be the result of:

ion you encountered ____________result_________________________

ion you encountered ____________result _________________________

ion you encountered ____________result __________________________

ion you encountered _____________ result _________________________

ion you encountered _____________ result _________________________

Formula of precipitate formed __________Name of the precipitate _______

Draw and label a picture of two solutions mixing.

When a precipitate forms. When a precipitate doesn't form.

How was this activity similar to the mixing of two solutions?

How was it different?

Appendix C4

Balancing Practice names ____________________

Use the ion and molecule cards to balance these equations.
Identify the type of reaction. If there is no product given predict what the products would be Type of reaction

a) $NaCl$ (aq) + $Pb(NO_3)_2$ → $PbCl_2$ (s) + $NaNO_3$(aq) ___________

b) Na (s) + $Pb(NO_3)_2$ (s) → Pb (s) + $NaNO_3$ (s) _____________

c) CaS (aq) + $FeSO_4$ (aq) → _____________

d) $NaClO_3$ (s) → $NaCl$(s) + O_2 (g) _____________

e) $C_{10}H_8$ + O_2 → ___________

f) Al (s) + $CuSO_4$(aq)→ $Al_2(SO_4)_3$(aq) + Cu(s) ___________

g) $CaCl_2$ → Ca^{++} (aq) + Cl^- (aq) ___________

h) $NaCl$ (s) → Na (s) + Cl_2 (g) ____________

In a double replacement reaction what would you see if both of the products are soluble?

In a double replacement reaction what would you see if both of the new products are not soluble?

Appendix C5 Balancing Review page 1

Part I 1. ____ $Fe(OH)_2$ (s) + ____ H_2O (l) + ____ O_2 (g) → ____ $Fe(OH)_3$ (s)

2. ____ K_2CO_3 (aq) + ____ $BaCl_2$ (aq) → ____ Ba CO_3 (s) + ____ KCl (aq)

3. ____ $Ca_3(PO_4)_2$ (s) ____ H_2SO_4 (aq) → ____ $CaSO_4$(s) + ____ H_3PO_4 (aq)

4. ____ Ag(s) + ____ S_8(s) + heat → ____ Ag_2S (s)

5. __ $NaHCO_3$ (aq) + __ $C_6H_8O_7$ (aq) → __ CO_2 (g) + __ H_2O + __ $Na_3C_6H_5O_7$ (aq)

6. ____ Au_2S_3 (s) + ____ H_2 (g) → ____ Au(s) + ____ H_2S (g)

7. ____ PbS(s) + ____ O_2 (g) → ____ PbO(s) + ____ SO_2 (g)

8. ____ $Ca(OH)_2$ (aq) + ____ H_3PO_4 (aq) → ___ $Ca_3(PO_4)_2$ (s) + ____ H_2O (l)

9. ___ Cu(s) + ___ H_2SO_4 (aq) → ___ $CuSO_4$ (aq) + ____ SO_2 (g) + ____ H_2O (l)

10. ____ Sn(s) + ____ KOH (aq) → ____ K_2SnO_2 (s) + ____ H_2 (g)

Part II 11. Ammonium nitrite decomposes into nitrogen gas and water

12. Liquid carbon disulfide reacts with ammonia (NH_3) to produce hydrogen sulfide gas and solid ammonium thiocyanate (NH_4SCN)

13. When ammonium dichromate is heated it gives off chromium (III) oxide, nitrogen gas and steam.

14. The liquid butane, C_4H_{10} burns

15. C_5H_{10} burns

16. When potassium chlorate is heated it loses its oxygen.

17. Solid lithium hydroxide reacts with carbon dioxide to produce lithium carbonate and water.

18. Nitric acid can be produced when water reacts with nitrogen dioxide. Nitrogen monoxide is also produced.

Balancing Practice page 2 name ______________

1. Balance the indicated equations. Keep track of which element that you started with to correctly balance the equation. Show all attempts. Do not erase wrong answers. Use another sheet of paper if necessary.

2. Write the steps you took to balance the equation.

3. Pair with your lab partner and correct each other's answers. Record the final correct answers.

4. Write the steps you took to correct your partner's answer.

5. With your lab partner make a poster that shows the process of balancing the equation you are given.

.

On your poster you should have correct formulas, the equation written in words and representations of the number of molecules at each step of the balancing the equation.

Appendix C6

Moles Lab name

Show all your calculations. Compare your answers with other groups doing the same calculations.

Safety: Never eat or drink anything in the lab area.

The language of Chemistry can sometimes be challenging. If you understand the ideas behind these words you will find Chemistry class much simpler.

The problem: Molecules react with each other, one at a time. Molecules are so small that even a billion of them would be too small to see. It is difficult to directly measure how many molecules you are mixing together.

It is very easy to find the mass of a sample you use in the lab though. Just put it on the balance. So the problem is that the answer we need is impossible to find directly and what is easy to do isn't what we want.

There is a way to solve this problem. After completing this lab you should be able to see how chemists count molecules.

I. How much cereal is in the box? If you want to know the mass you can just look on the box or put it on the balance. If you want to know how many pieces of cereal are in the box that is harder. Counting them would not be impossible but it would not be easy. What we need to do is to relate the mass of the cereal to the number of pieces.

Write the name of the cereal. _________________________mass ______

Find the mass of a dozen pieces of cereal. Record your answer.________

Find the mass of two dozens pieces of cereal. Record your answer________

What pattern are you seeing?

What is the average mass of one piece of cereal? __________

Predict the mass of 100 pieces of cereal. _____________

Use a ratio to find out how many pieces of cereal are in a box.

II. Cereal is usually not measured by the dozen but rather by the bowl. How could you find out how many pieces of cereal are in a bowl?

Figure it out.

How many bowls of cereal are in a box?

III. Suppose you were on a very strict (and very strange) diet. This diet requires you to eat exactly 602 pieces of cereal. Tell, in detail, how you would measure them. 602 pieces of cereal are called a **bole.**

People used a number of different types of cereal for this activity. Fill in this chart for the each of the types of cereal.

Name of cereal	Mass of 2 dozens	Average mass of 1 piece of cereal	Mass of 1**Bole** (602 pieces)

IV a. Explain how knowing the mass of one particle and the mass of a sample allows you to know how many particles you have.

Draw a picture of this

Give an example of this.

b. If you know the mass of one particle and the number of particles you should be able to figure out the mass of the whole collection.
Describe how this works.

Draw a picture of this

You can't see an atom. You can't see a thousand atoms. You can't see a million or a billion atoms. To get to a human sized sample you need about a million, billion, billion of these atoms. The name they gave to this rather large number of particles is the **mole**. The exact number of particles in a mole is 6.02×10^{23}. Yes, that is a strange name but "dozen" and "bunch" had already been used. (OK, so I was kidding about the **bole** and especially about the diet.)

The atoms that make up chemicals come in different sizes and different masses. To find the mass in one mole add the masses of the parts that make it up. Figure out the masses of a mole of these particles:

Particle	H atom	H_2	H_2O	NaCl	Cu	Na_2O	$(NH_4)_2CO_3$
Atoms that make it up							
mass of each part							
Total mass of particles							
Mass of a Mole of particles							

If we want to know how many moles of copper make up the sample at your lab station describe how you would do that.

How many moles are in the sample?

Find the number of atoms in the sample.

Describe how you figured this out.

In your own words describe how mass and the number of particles are related to each other.

What is the smallest number NaCl particles you can measure out using the balances in the lab?

Explain.

Appendix C7
Percent Composition. Name______________

A compound is made up of two or more elements. These elements always combine a certain way according to the compound's formula. The simplest way of combining the elements in the formula is called its empirical formula. Empirical means that is what you find in the laboratory by finding the ratio of the moles of elements that combine. The actual way that the compound is put together is called its molecular formula.

Hydrogen peroxide is composed of hydrogen and oxygen. Its empirical formula is HO and its molecular formula is H_2O_2. The HO molecule doesn't really exist but in the lab you would see that you need the same number of moles of hydrogen and oxygen to make the hydrogen peroxide molecule.
What is the mass of one molecule of hydrogen peroxide? ______________
How much of that is due to oxygen? ____________________________
What percent of the molecule's mass is due to oxygen? _____________
How much of that is due to hydrogen? ____________________________
What percent of the molecule's mass is due to hydrogen? _____________

THE LAB: When we put an acid with a bicarbonate a reaction occurs that releases a gas. In this lab you will find out how much gas is released and what percent of the sodium bicarbonate is the gas.
Write down the formula for sodium bicarbonate ______________
What possible gases could be released? ____________________________
How could you tell what gas was being produced?

Mass a microplate and a pipette filled with acetic acid as accurately as possible. Record your data on an appropriate chart.

Add about one gram of a bicarbonate to the center of the microplate and remass the microplate, pipette and chemicals. Record your answer.
Slowly add one drop of acid. Write down what you see.

After the reaction appears to stop add another drop of acetic acid. Repeat until the reaction stops.

Mass the microplate, pipette and left over chemical.
Record the difference in mass in your date table.
Record the percent change of the mass lost to the original mass of the chemical.
Explain possible sources of error between your answer and 52%, the actual answer.

Appendix C8
Moles Poster.

You have already made posters that show how to name chemical compounds and how to balance equations. These are two of four important skills to be successful in chemistry. Review these first two ideas.

In this poster you and a partner will show how you will deliver 7.59×10^{22} particles of the chemical that you will be given.

You and your partner should make a poster to show the three ways to get 7.59×10^{22} particles: molarity, mass and moles.

Your poster must include:

a. A correct name for the compound.

b. A correct formula for the compound.

c. A demonstration of each of the three ways of getting that number of particles.
Do not use a trivial example for molarity (one liter or 1.0 molar solution). Show each of the methods of finding these quantities.

d. If your compound is ionic show how many ions of each type there are. If it is molecular tell how many of each atom you have.

e. A written description, on a separate piece of paper, of how you change from number of particles to mass to number of moles to molarity and volume.

1. calcium chloride	2. potassium chromate	3. dextrose
4. ammonium sulfate	5. nickel nitrate	6. sucrose
7. carbon dioxide	8. tin (IV) fluoride	9. sodium permanganate
10. uranium (VI) fluoride	11. ammonia	12. ethanol
13. sodium sulfide	14. silver nitrate	15. ammonium acetate
16. lithium nitrite	17. aluminum sulfate	

Appendix C9

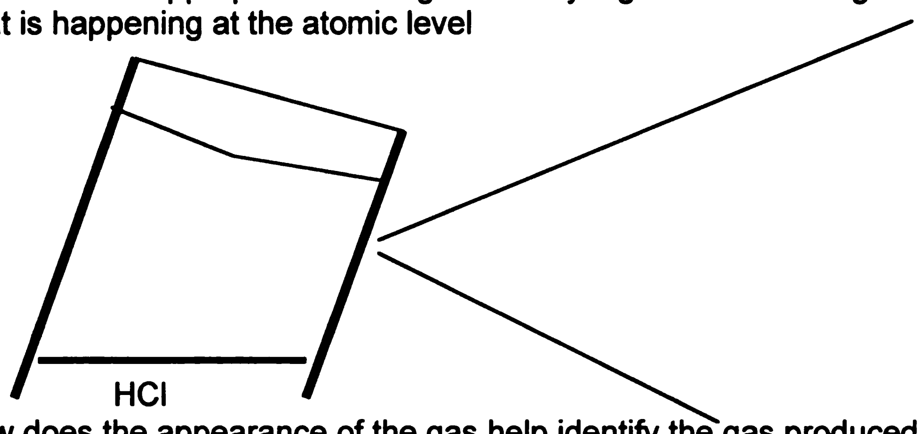
Stoichiometry Lab name

Safety: Goggles must be worn at all times. HCl is corrosive to skin and eyes. Make sure the end of the syringe is not blocked during the reaction. Read the directions completely before starting the lab.

Fill one small beaker with water and another about half full of the HCl. Put less than 1.3 cm of magnesium in the syringe. Record this length exactly. Squeeze the plunger to the bottom of the syringe. Put the syringe in water and draw in about 2ml of water. Get out any bubbles that are in the syringe. Put the syringe in the acid and pull up close to the maximum measured amount the syringe will hold. Record this volume. Quickly move the syringe and hold upright in the beaker of water. Don't move the plunger. When the reaction is complete make the level of the liquid inside the plunger equal to the level of the water outside the plunger and record the volume.

Ia. Describe the changes that are occurring in the syringe and its content.

b. Illustrate with appropriate drawings of the syringe. Show a magnified view of what is happening at the atomic level



c. How does the appearance of the gas help identify the gas produced?

d. What tests could help you identify the gas?

e. When you are measuring the gas what shape is the gas occupying

f. Describe how you will measure the exact volume of the gas.

g. What are some of the errors that can happen when measuring the volume of the gas?

h. In your experiment will the errors in collecting and measuring the gas cause the volume to be too big of too small?
Explain

II. Calculations. Show all appropriate work.

a. What length of magnesium did you use? ______________

b. What mass of magnesium did you use? ______________

c. What volume of gas did you collect? ______________

d. This gas, at room temperature and pressure, has a density of 8.4×10^{-5} g/ml. What is the mass of gas that you collected? ______________

e. How many moles of gas did you collect? ______________

f. How many moles of magnesium reacted? ______________

g. What is the ratio of moles of gas to moles of magnesium? ___________

h. If the ratio should be 1 to 1 what error did this experiment produce?

i. What percent error is this?

j. If you used twice the length of magnesium how would that affect the volume of gas produced?

Explain

k. How would that affect the number of moles of gas produced?

l. If you used twice as much HCl how would that affect the volume of gas produced?

Explain

m. What other metals could be used in this lab?

Explain

n. How could the results be improved?

Appendix C10

Stoichiometry Lab part 2 name

Share your data with the other group at your lab station.
You will be given a volume of hydrogen to produce. As a group, calculate how much magnesium you will need to produce that volume. You will be graded on how close you get to the goal. I must check your result.
Write your procedure here. Include what needs to be done to get the best result.

Show your calculations here in an orderly manner. Consider and describe how much of your error from part one can be eliminated and how much is a part of the experiment.

Describe how you determined the amount of magnesium you needed. Be thorough.

In this lab tell what would happen if you added more HCl? More magnesium

Draw pictures to show what happened in each part of the experiment. Indicate sources of error.

Part 1 part 2

Appendix C11
Stoichiometry lab part 3
Names in group_________,____________, ___________,___________.
Answer these questions together with the group that you worked with on the lab. Use the back of this sheet if necessary to give specific, quantitative answers.

1.What are possible sources of errors in finding the amount of magnesium?

2. What are possible sources of errors in finding the amount of hydrogen gas?

3a. Which errors were random?

3b. Which errors were systematic?

4. How did you compensate for these errors in making your prediction?

5. What error did your prediction have?

What were the major sources of error in your prediction?

6. How could the lab be changed to produce more consistent results?

7. How could the lab be changed to produce more accurate results?

Appendix C12 Stoichiometry Practice   Name ________________________

Solid aluminum reacts with a sulfuric acid solution to form aqueous aluminum sulfate and hydrogen gas.

1. Write a balanced equation for the reaction.

2. Draw a picture that shows the reactants and products for the balanced equation. Use these symbols: ♦ for aluminum, ∇ for sulfate, ⊗ for hydrogen and for sulfate ions.

3. Draw a picture that shows how much of each substance is present at the beginning and the end of the balanced equation. Use ∩ to represent each 10.0 grams, Δ to represent 5.0 grams and ♥ to represent one gram or less.

aluminum   sulfuric acid   ➔   aluminum sulfate   hydrogen .

How does the mass at the beginning compare with the mass at the end of the reaction?

4a. What volume of 5.3 M sulfuric acid will combine with 12.73 grams of aluminum? Show all appropriate steps in a clear and orderly manner.

4b. If the reaction is 85% effective how much hydrogen gas would be produced?

Appendix C13

Chapter 5 Stoichiometry Practice Part two Names __________, ___________

1. Make up a problem similar to question 4a for the reaction of 2.7 M solution of silver acetate with zinc.

2. On a separate sheet write an answer key for the problem that you made up. Show all appropriate steps.

Correct formulas, balanced equation, organization, ratios, solution

Appendix D Pretest and Tests

Appendix D1 Pretest naming compounds name

Give your best answer to these questions. Put a question mark by any question you're not sure of. Circle the number of any question you don't know.

1. What is the name of the compound KCl? ____________________

2. Write the formula for sulfur trioxide. ____________________

3. What is the name of this compound $Ca(NO_3)_2$? ____________________

How many atoms are in this formula?

4. Write the formula for potassium oxide. ____________________

5. What does $BaCl_2$ tell you about the compound?

6. Write "correct" if the name is correct. If it is wrong tell why.

a. iron oxide

b. calcium iodide

c. carbon oxide

d. silver nitrogen oxide

e. dilithium bromide

7. Write the formula for the correctly named compounds in question six.

a. b. c.

d. e.

8. Write the formula for the compound that could be made from

a. sodium, Na and sulfur S

b. carbon, C and oxygen O

Appendix D2 Naming Quiz
Give you best answer to these questions

1. What is the name of this compound $Ca_3(PO_4)_2$? _______________

How many atoms are in the formula?

2. Write the formula for sodium dichromate __________________

3. Write the formula for tetrasulfur dinitride.

4. Write the formula for the compound that could be made from calcium and sulfur.

Give the missing name or formula for these compounds. If the given information is incorrect explain why and correct it.

Name	formula	explanation
5.	K_2O	
6. iron (III) chloride		
7. phosphorus pentoxide		
8.	PbI_2	
9.	Al_2O_3	
10. ammonium nitrate		
11.	P_2O_4	

Appendix D3 Naming test

Name ______________________Hour______Chemistry Chapter 2 Test
Show all appropriate work for mathematical problems.

1. A sample of carbon tetrachloride is analyzed and found to contain 8.0 g carbon and 96 g chlorine. Another sample of a similar liquid is analyzed and found to contain 11 g carbon and 132 g chlorine. Could these two liquids be the same compound? Explain.

2a. We heated magnesium in the experiment to form magnesium oxide. If we kept the cover on during the entire class time how would that have affected our results? Explain.

b. How would that have affected the ratio that you measured?

c. If the mass ratio of Magnesium to Oxygen is about 1.52/1, how much oxygen would combine with 4.5g of Mg?

How much magnesium oxide would form?

3. What is the charge of the metal ion in each of the following compounds?

A. $SnCl4$ __________B. $Cu(NO_3)_2$_________C. $Th(OH)_4$ ____________

4. Give the name for each formula given.

A. ____________________________________$Al(OH)_3$

B. ____________________________________ N_2O_4

C. ____________________________________ Na_2CrO_4

D. ____________________________________ $FeCl_2$

E. ____________________________________ SF_6

F.________________________________ $MgSO_4$

G. ________________________________ $Pb_3(PO_4)_2$

5. For the expression $Ca_3(PO_4)_2$

Name the ions that make it up:

How many elements are there?

How many atoms are there?

6. Write the formula for each name given.

A. ____________________copper (I) sulfide

B.____________________gallium (III) acetate

C ____________________ tetrasulfur dinitride

D. ____________________ potassium sulfite

E. ____________________nickel carbonate

F. ____________________diphosphorus hexoxide

G. ____________________iron (III) chlorate

Appendix D4 Pretest Balancing Name

1. What does the left side of a chemical equation tell you about a chemical reaction?

2. Describe what this equation tells you

$$2Na\ (s) + 2H_2O\ (l) \rightarrow 2\ NaOH\ (aq) + H_2\ (g)$$

Draw a picture of what you would see before and after the arrow

3. If 28 cm of wire has a mass of 2.0 grams how much wire would have a mass of 3.6 grams? Show appropriate work.

4. In this expression $3H_2O$ combines with $5SO_2$

How many elements are there? ___________

How many atoms are there? ______________

How many ions are there? ________________

How many molecules are there? ___________

If you used twice as much water how much of the sulfur compound should you use?

5. During an experiment you decompose a compound and get 14.6 grams of chlorine gas. If you decompose 50% more of the compound how much chlorine gas should you collect?

Appendix D5 Test Balancing name

1. Solutions of calcium nitrate and potassium sulfate combine to form a solution of potassium nitrate and the precipitate calcium sulfate.
   a. Write a balanced equation for this reaction indicating whether each substance is a solid, liquid or gas.

2. For these reactants $2Cr(NO_3)_3$ + 4LiOH find the:

   Number of Cr atoms___Number of N atoms____ Number of O atoms____

   Number of Li atoms___Number of H atoms___Total number of atoms____

   Write a **balanced** equation, using all the information for the following reactions:

3. Aqueous strontium iodide and aqueous tin(IV) nitrate react to give aqueous strontium nitrate and solid tin(IV) iodide

4. Zinc replaces the nickel in nickel acetate

Identify each reaction as combustion, decomposition, synthesis, single replacement, or double replacement. And balance the equation.

5. ___Na(s) +__ $NiCl_2$(aq) ➔ ___NaCl(aq) + _____Ni(s) Type __________

6. __$NaCO_3$(s) ➔ ____Na(s) +___O_2(g) + ___CO_2(g) Type___________

7. __C_2H_5OH (l) +_____O_2 (g) ➔____CO_2 (g)+ ____H_2O (g) Type_________

8. __ $CuNO_3$ + ___$FeCl_3$ ➔ ____ $Fe(NO_3)_3$ +____CuCl Type_________

Predict the products and then write a **balanced** equation.

9. ___ $C_8H_{18}(l)$ +____ O_2 (g) ➔ ______________________________

10. ____$NaBr(s)$ + _____ $Cl_2(g)$ ➔ _________________________

11. Dissolving calcium chloride in water ___________➔____________

12. Adding copper metal to a iron (III) chloride solution

__________________________➔_________________________________

13. Burning ethane, C_2H_6 ________________ ➔____________________

14. In lab 3.1 from this chapter, what evidence did you collect to verify that reactions occurred?
Be complete.

When were we able to make predictions?
Be complete.

Appendix D6 Amounts Pretest name

Show all work for these questions.

1. Eggs are sold by the dozen.
   a. How many dozen eggs are there in 1716 eggs?

51 C/ 0 W

   b. How many eggs are in 23.5 dozens? 46 C/ 5 W

   c. Eggs can also be sold by the gross. A gross is twelve dozen. How many dozens of eggs are in 58 gross?

36 C/ 15 W

   d. A dozen eggs has a mass of 684 grams. If you have 11631 grams of eggs how many eggs are there?

39 C/ 12 W
(13 correct but included decimal)

2. Hydrogen has a mass of 1, carbon has a mass of 12, sodium has a mass of 23, chlorine has a mass of 35.5 and oxygen has a mass of 16

a. What would be the mass of sodium chloride?

44 C/ 7 W

b. What would be the mass of $NaHCO_3$?

33 C /9 W / 9 no answer

Appendix D7 Amounts quiz

Name

Show your setup for each problem. Circle your answer.

1. Calculate the molar mass of Li_2SO_4

2. How many moles in 192.5 g of Li_2SO_4

3. What is the mass in grams of 2.45 moles of Li_2SO_4

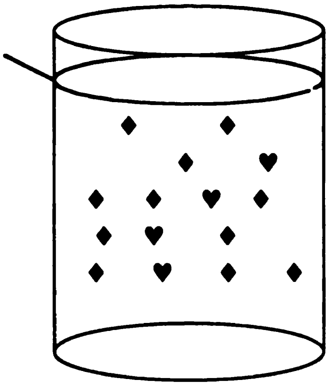
4. How many molecules in 2.3 moles of Li_2SO_4

5. How many lithium ions are in 3.1 moles of Li_2SO_4

Appendix D8 Amounts Test

Show all work for these problems. Circle your answers

1. 350 ml



Each symbol, ♦, stands for .02 moles of sucrose, table sugar $C_{12}H_{22}O_{11}$

a. How many moles of sugar are dissolved in the water?

b. What is the molarity of the sugar solution?

c. How many grams of sugar are in the solution?

d. How many atoms of carbon are in this solution?

e. What is the percent composition of each of the elements in the sugar?

f. Fructose is another type of sugar. It has a molar mass of 180 g/m. A 63 g sample of fructose has a 25.2 g of carbon, 4.2 g of H and 33.6 g of O. What is its empirical formula?

What is its molecular formula?

g. How can you change the volume to get a molarity that is half as big?

h. How can you change the mass to get a molarity that is 50% bigger?

2. If you dissolve 17.76 grams of calcium chloride in water to make 158 ml of solution. What is its molarity?

On the back of this sheet draw a picture, similar to problem 1 to show this solution. Use ♣ to represent .01 moles of calcium chloride

Write the dissociation equation for calcium chloride.
Do another picture to represent the ions that make up calcium chloride. Use ⊗ to represent .02 moles of Ca^{++} and ◊ to represent .02 moles of Cl^{-}.
How many of each ion are there in this solution?

Appendix D9 Stoichiometry pretest Name ________________

In this chapter you will need all the skills you learned in the first four chapters.

1. Balance these equations:

a. sodium carbonate and lead nitrate react to give lead carbonate and sodium nitrate

b. C_3H_7OH + O_2 → H_2O + H_2O

2. For these ratios write them as products and then solve them

ratio	product	solution
a. $\frac{.035}{6} = \frac{x}{18}$		

3. CH_2 (g) + 2 O_2 → CO_2 +2H_2O

In this equation: name the reactants ______ name the products _______

List the coefficients, in order _____________

As written , what is the mass of the reactants? _____, the products _____?

In words describe how the amounts of reactants compare with each other

In words describe how the amounts of products compare with each other

In words describe how the number of oxygen molecules compares with the number of water molecules.

In words describe how the number of carbon dioxide molecules compares with the number of water molecules.

In the equation wtrite down as many things that are the same as possible

4. Three molecules of hydrogen react with one molecule of nitrogen to make two molecules of ammonia.

a. How many molecules of ammonia would six molecules of hydrogen produce?

b. How many moles of hydrogen should react to get 12 moles of ammonia?

c. How many grams of ammonia do you get if you react 84 grams of hydrogen?

d. Describe what you would get if you react four molecules of nitrogen with six molecules of hydrogen.

5. Draw and label pictures of the molecules before and after the reaction.

Appendix D10 Stoichiometry Posttest name ____________________

Show appropriate work to receive full credit. Circle your answers.

1. For the reaction ___Al(s) + ___Cu_2SO_4 (aq) → ___ $Al_2(SO_4)_3$ +____Cu

a. Balance the equation. correct 42 wrong 6 no answer 1

b. How many grams of copper would be produced by 49.48 g of aluminum?_______

correct 30 wrong 17 no answer2

c. How many grams of aluminum would be needed to replace the copper in 440 ml of 0.65 M solution of copper (I) sulfate?

correct 26 wrong 20 no answer 3

____

2. $C_3H_7OH + 4.5\ O_2 \rightarrow 3CO_2 + 4H_2O$

a. If you burn 3.2 moles of propanol, C_3H_7OH, how many moles of water do you form?

correct 35 wrong 8 no answer 6

b. How many grams of carbon dioxide will be formed?

correct 32 wrong 12 no answer 5

3. A chemist adds 32.0 grams of hydrochloric acid, HCl, to an excess of magnesium. She collects .65 g of hydrogen gas.

a. Write a balanced equation for this reaction.

correct 33 wrong 14 no answer 2

b. Calculate the theoretical yield of hydrogen gas. ____________

correct 23 wrong 18 no answer 8

c. Calculate the percent yield of hydrogen.

correct 23 wrong 16 no answer 10

Students were given credit for correct answer if they used the proper procedure with wrong answer from b.

d. Give two reasons why in chemical reaction the theoretical yield is bigger than the actual yield.

correct 30 wrong 14 no answer 5

4. You add 8.43 g of potassium phosphate and 560 ml of .36 M calcium nitrate to a beaker. A precipitate forms.

a. What type of reaction is this?

correct 40 wrong 3 no answer 6

b. What two products should form?

correct 40 wrong 5 no answer 4

Explain

c. Write a balanced equation for this reaction.

correct 28 wrong 18 no answer 3

d. Which chemical is in excess?

correct 31 wrong 8 no answer 10

Show your work.

e. Determine the number of moles of each chemical that are formed.

correct 31 wrong 8 no answer 10

f. Draw and label a picture to represent the chemicals in the beaker after the reaction. Each symbol should represent .01 moles of particles.

correct 29 wrong 14 no answer 6

5. Describe in details the steps involved in finding the mass of a product formed when you are told the mass of one reactant.

correct 32 wrong 10 no answer 6

Appendix D11 Student scores.

stude nt	naming		balancing		amounts			stoichiometry	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	quiz	Post-test	Pre-test	Post-test
Out of	20	60	20	60	30	15	50	60	60
1	4	39	5	42	20	6	35	0	17
2	8	59	6	59	30	12	46	24	56
3	7	57	3	53	30	14	44	22	56
4	4	48	5	47	7	11	44	2	35
5	2	47	2	53	20	4	41	2	35
6	6	52	0	43	13	11	43	18	59
7	4	43	10	54	25	12	46	2	29
8	9	56	5	57	30	13	48	19	54
9	9	59	11	59	25	11	45	8	53
10	6	59	12	41	30	13	48	16	60
11	1	37	1	54	20	13	39	2	16
12	6	54	8	48	20	15	48	32	59
13	6	54	1	52	20	12	48	2	48
14	8	51	6	57	15	9	30	9	34
15	12	56	15	58	27	11	50	25	60
16	10	58	8	52	30	14	44	21	56

17	5	53	2	56	20	4	39	1	0
18	2	56	5	59	17	8	39	2	48
19	8	59	5	59	27	14	48	35	60
20	8	60	8	60	20	12	45	21	60
21	1	49	1	52	17	5	35	0	34
22	7	50	2	50	27	11	41	5	48
23	3	44	2	45	17	2	20	0	9
24	4	50	1	50	7	11	45	7	54
25	5	47	11	48	13	9	X	X	X
26	11	56	12	57	20	13	47	16	58
27	8	55	10	54	30	14	45	21	60
28	8	56	4	51	30	13	45	0	59
29	2	55	1	41	27	13	41	17	59
30	7	60	8	55	30	15	46	46	57
31	6	56	9	44	23	14	41	4	30
32	8	58	16	52	25	14	47	19	55
33	5	59	10	59	30	15	49	53	57
34	3	55	8	60	27	14	44	26	60
35	7	47	7	47	27	13	40	30	53
36	7	55	11	40	30	12	38	37	42
37	7	56	5	53	27	12	48	40	56
38	5	58	1	45	27	13	39	14	53

39	6	57	4	58	13	14	50	22	60
40	2	53	10	44	30	14	47	18	56
41	7	49	3	48	25	10	40	34	54
42	4	57	6	49	25	14	38	21	33
43	3	60	8	47	30	11	38	16	39
44	9	58	15	53	25	12	41	18	51
45	8	52	8	59	30	14	50	41	59
46	3	59	6	55	17	14	50	24	60
47	6	48	3	42	30	14	43	33	50
48	6	59	8	50	27	14	43	26	58
49	8	51	1	50	23	14	46	0	47
50	10	59	12	58	27	13	49	44	55
51	2	31	0	48	23	13	43	0	29
52	3	38	0	36	30	11	27	11	20

Students 1-27 were in fourth hour, students 28-52 were in sixth hour

Appendix E Surveys

Appendix E1 Introductory Survey

Please do not put your name on this survey. Circle the answer that best fits.

1. Do you plan on going to college or a trade school?
   Yes 50 No 0 Maybe 1 Don't Know 1

2. Will you take chemistry in college? Yes 25 No 26

3. Will you study science or medicine in college? Yes 25 No 26
Which?

4. What is a typical grade for you in math class? A 23 B 24 C 4
   In a science class? A 27 B 18 C 7

5. Which class do you do best in? math 15 science 15 English 9 social studied 5 foreign language 3 all 1

6. Which class do you have trouble with? Math 13 Science 13 English 10 none 6 Foreign Language 5

7. 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	Most 32	Least 11
____Ask a question in class	Most 21	Least 15
____Look at the pictures or diagrams in the text	Most 9	Least 33
____Ask the teacher	Most 38	Least 1
____Read the text	Most 9	Least 35
____Other teach self		

8. What do you find most distracting in class?
a. sounds 27 b. movement 8 c. actions 6 d. sights 6 other students 1, lights 2

9. When you are thinking do you

a. tap your pencil 26	b. hum or sing 6
c. walk around 1	d. daydream 14
e. doodle 8	f. other

10. When you try a "story problem" in math can you
a. always solve them 11
b. usually solve them 32
c. solve them with help 7
d. rarely solve them 1

11. Which part of science class do you like best?
labs 37, class work 8, homework 1, lectures 3, tests 1, other videos 1

12. Which part of science class do you like least?
labs 0, class work 4, homework 32, lectures 13, tests 24, other 0

13. In which part of science class do you learn the most?

labs 11, class work 17, homework 8, lectures 18, tests 2, other____

14. Which part (s) of a lab do you enjoy the most?

being in charge of the procedure 11 measuring the chemicals 19

doing the calculations 6 making sense of the results 16

mixing the chemicals 41 writing up the lab 4 other _____

15. Which part (s) of a lab do you enjoy the least?

being in charge of the procedure 7 measuring the chemicals 3

doing the calculations 25 making sense of the results 11

mixing the chemicals 1 writing up the lab 37
other

16. Which part (s) of a lab do you learn the most from?

being in charge of the procedure 4 measuring the chemicals 6

doing the calculations 18 making sense of the results 32

mixing the chemicals 13 writing up the lab 14

other 2 (discussion after)

17. Which part(s) of a lab do you learn the least from?

being in charge of the procedure	19	measuring the chemicals	16
doing the calculations	4	making sense of the results	1
mixing the chemicals	10	writing up the lab	16
other	1		

Appendix E2 Exit Survey

1. Which of these did you use to solve problems?

ratios 24 circles: 18 both: 6 unit factors: 0 no answer: 10

2. What was your grade on the last test? _____ for the first quarter? _____

3. Did you use the stoichiometry organization chart on the test?
Yes: 27 No: 19 No answer 2

4. Describe how successfully you can use these skills:

	rarely	sometimes	often	usually	always
Naming compounds	0	6	5	22	18
Writing formulas	2	2	3	24	18
Balancing equations	1	2	11	18	19
Finding moles	0	3	6	16	26
Finding molarity	0	2	6	16	26
Stoichiometry	4	11	9	13	14
Reading text	7	8	5	13	14

5. Which of these skills was hardest to learn?
Stoichiometry 37 balancing 4 naming 2 formulas 2 all 1

6. Which of these skills was the easiest to learn?

naming 17 moles 16 balancing 9 formula 4 reading 3

7. Describe how helpful these activities were.

	not helpful	Somewhat helpful	helpful	Very helpful
stoichiometry chart	4	16	21	8
balancing cards	9	23	13	5
posters	5	19	17	10
percent composition lab	1	23	23	2
gas production lab	3	20	21	6
gas prediction lab	4	23	19	7
balancing equations poster	5	14	24	7
picturing reactions	4	20	15	12
practice handouts	2	8	22	19
book problems	7	15	20.5	8.5
solubility activity	3	25	14.5	8.5
reading the text	14	23	10	4
examples done in class	0	5	12.5	33.5
lectures	0	13	19	16
individual help	0	2	10	39

ion sticks	6	24	21	0
mole lab	4	15	21	11
reaction cards	6	19	17	8

11. Which of the previous activities was least helpful?
Reading text 11 labs 9 posters 6 balancing cards 5 ion sticks 5

gas production 2 gas prediction 2 lecture 2 solubility 1 book problems 1

12. Which of the previous activities was most helpful?

Individual help 19, doing examples in class 13, posters 8, practice sheets 5, lecture 5 reading the book 4 reaction cards 3 lab 2 all 1 getting help from a student 1

13. Please make other comments about this unit.

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