WHAT ARE THE EFFECTS OF VISUALIZATION TOOLS ON THE CONCEPTUAL UNDERSTANDING OF BASIC CHEMICAL PROCESSES AND CHANGES?

by

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July 2013

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - CONTINUED

ABSTRACT

This paper explored the effects of university students' understanding of fundamental concepts as various tools were used to help see ideas from a different perspective. Changes in student attitudes toward types of problem solving along with a growth in knowledge base were also explored. The results indicated that these tools help more in the long term vs. short term and attitudes and knowledge base are difficult to change.

INTRODUCTION AND BACKGROUND

Montana State University is located at the southern end of Bozeman, Montana, in a ranching and agricultural valley with mountains to the north and south. These mountains are littered with hiking trails and host a number of other outdoor activities the year round. With a climate free from extremes and plenty of clean air, Bozeman has been described as “an ideal place to reside and recreate” ("Area Chamber of,"). The number of students attending the university has been increasing in recent years with total enrollment in the fall of 2012 reaching 14,660. Montana State University covers a wide range of interests and offers 61 major areas of study, with 90 programs and 20 areas of specialized study ("Montana State University,"). The majority of students, 85.2%, are of Caucasian ancestry. International students comprise the second largest group at 4.1% of the total population. Overall, the proportion of male students is 53.4%, but among graduate students it is the female portion that predominates with 53.3% ("Montana State University,").

This study was conducted with the spring 2013 Chemistry 143 class at Montana State University, Bozeman. Chemistry 143 is a semester-long course, the second class in a series designed for students intending to major in a science field. The class was composed largely of students from rural Montana, spread over several lab sections with a maximum of twenty students in each section. Overall, the students were motivated and capable, with students continuing to email questions over the weekends.

This study focused on the use of a combination of annotated diagram and graphic organization visualization tools to determine the learning benefits to students. An annotated diagram is a graphic or picture form of a problem that includes three elements: a statement of the problem in pictures, a statement of the problem in words and a statement of the problem in a formula of mathematical relationships (Figure 1). A graphic organizer can take many shapes, but is designed to link basic ideas together in such a way that helps the student to map out an overall concept.

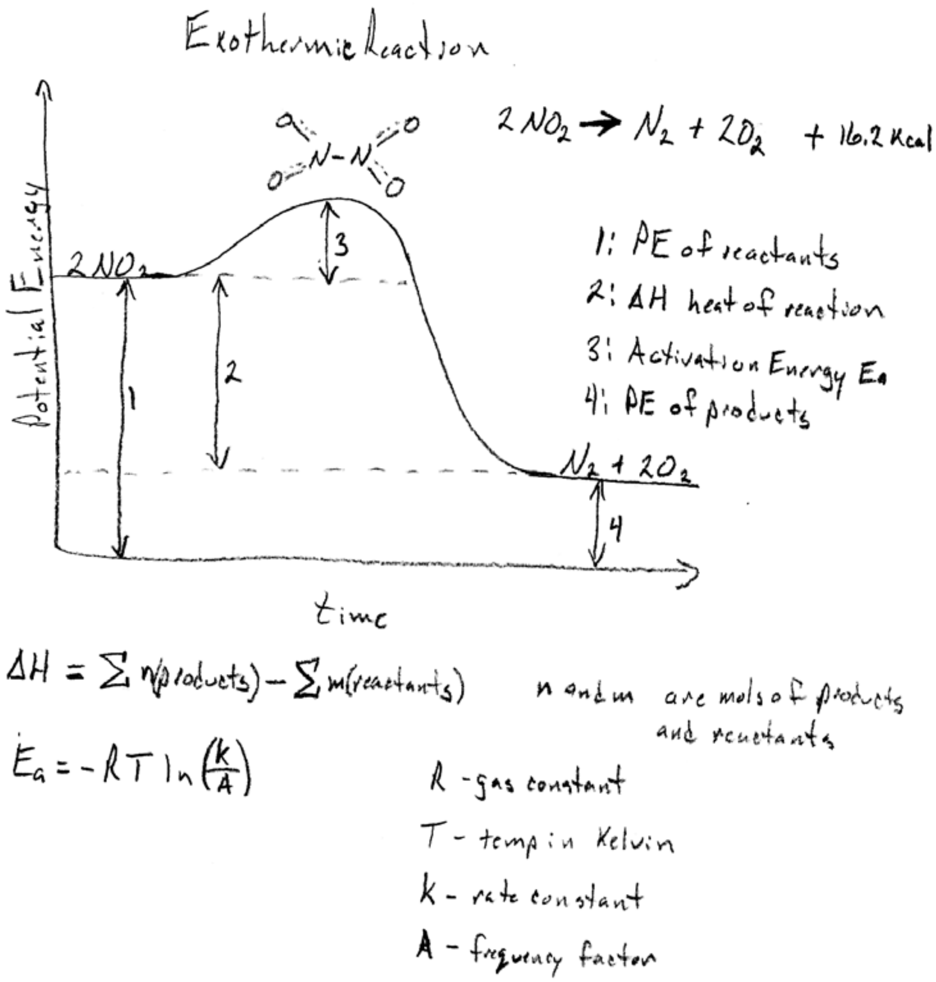


Figure 1. Example of an annotated diagram of an exothermic reaction.

To gain information about the best way to conduct this study, the Attitudes about Types of Problem Solving survey was administered to students from two lab sections with the goal of determining areas of perceived strengths: visual, verbal, or formulaic

(Appendix A). The results indicated that a formulaic mathematical approach was most important to the majority of students in both classes, with visual and verbal methods being somewhat more problematic.

The problem solving attitudes helped to determine four things. The first was students' preferred method of problem solving. Forty-one percent said that they preferred the mathematical method to problem solving, while 31% favored something more visual and hands on (N = 39). The second attitude involved competence. Forty-one percent believed that they were most skilled at solving with equations, while 23% indicated that written problems could be misinterpreted and that consequently an equation with pictures was more informative. The third attitude was related to confidence in results. When it came to which method they believed was most accurate, 62% of students chose mathematical expressions. One student's justification was that "equations explain on a higher level." Another stated, "…equations are the blueprint while pictures and words help understand the equations." The fourth attitude was a reflection of perceived weakness. When asked where they thought they needed the most practice, many left their reasoning blank. However, 23% wanted more guidance as to how equations work and when they should be used, while an almost equal amount, 21%, wanted more help with understanding the written representation of a problem since "an explanation is needed to understand."

The information from the survey guided the purpose and direction of the study and led to the research question: What are the effects of visualization tools on the conceptual understanding of basic chemical processes and changes? As this question was explored, the following subquestions were also developed:

Do student attitudes about problem solving change when visualization tools are used repeatedly?

How does knowledge of basic concepts change with the addition of learning and practice?

CONCEPTUAL FRAMEWORK

It is generally assumed that a dry presentation of facts or rote memorization does not help students learn chemistry. The students in the Chemistry 143 class observed in this study typically begin the course with a high level of mathematical skill; hence, they generally respond well to test questions involving a direct "plug and play" application of formulas. However, telling students just what they have to know does not help them to assimilate the knowledge necessary to work with chemistry in a conceptual environment or practical application situation. Also, over time the teaching of the course has evolved out of the experience that different students have different learning styles, and that at least some students respond better to non-mathematical approaches. These considerations of problem solving and alternate learning styles have led to the use of graphic organizers and annotated diagrams, but the effects of these visualization tools have not previously been measured in this laboratory environment.

Graphic organizers are defined as

> "a visual and graphic display that depicts the relationships between facts, terms, and or ideas within a learning task. Graphic organizers are an alternative way of presenting concepts, ideas and facts that help the students see connections

> between the substituent pieces. Graphic organizers are also sometimes referred to as knowledge maps, concept maps, story maps, cognitive organizers, advance organizers, or concept diagrams" (Hall & Strangman, 2002, p. 1).

One study discovered that students given complete class notes did less well than students given partial notes. The study also found that outlines did not work nearly as well as graphic organizers as demonstrated by the completion of a factual test (Katayman & Robinson, 2000).

It might seem that if rote absorption of facts doesn't work, then graphic organizers are the answer to the teaching problem. However, having students learn-by-doing, giving them access to all sorts of alternative tools just because this is the opposite of methods we assume will not work is not the solution either. The term "extraneous cognitive load" is used to describe the effect on students who are given too many tools without adequate explanation for their use (Stull & Mayer, 2007, p. 1). This term is also used to describe the effect on students who are asked to develop their own tools, in essence like being thrown in a room full of toys and being asked to come up with an understanding of physics. Students become overloaded when asked to spend too much time on process rather than outcome. In other words, it is unwise to become sidetracked by teaching a class on graphic organizers when what we want the students to learn is chemistry (Stull & Mayer, 2007).

Flipping from dry presentation of facts to having students try to learn everything by frenzied random hands-on participation isn't the answer either. For example, not everyone automatically knows how to use a new tool when it is put into his or her hand for the first time. Teacher Margaret Egan (1999) has outlined suggestions toward finding a balanced approach. Discriminatory use of graphic organizers leads to a fine balance between giving instruction and letting students discover and learn on their own (Egan, 1999). Teaching becomes more of a semi-guided exploration, keeping frustration levels to a minimum while maximizing content mastery. A must for effective use of graphic organizers is thoughtful design and critical testing before putting them into use (Egan, 1999). Therefore, a graphic organizer will be taught most effectively to the students if the instructor has practiced with it first. Figure 2 is an example of a useful graphic organizer that compares the important similarities and differences in sleep disorders.

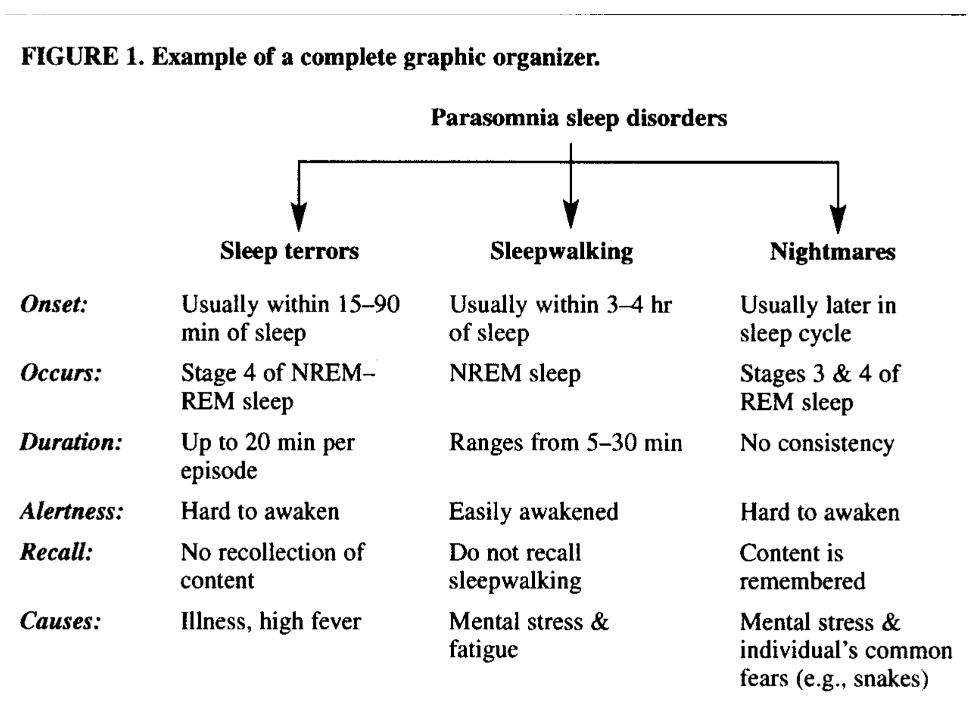


FIGURE 1. Example of a complete graphic organizer.

Parasomnia sleep disorders

	Sleep terrors	**Sleepwalking**	**Nightmares**
Onset:	Usually within 15–90 min of sleep	Usually within 3–4 hr of sleep	Usually later in sleep cycle
Occurs:	Stage 4 of NREM–REM sleep	NREM sleep	Stages 3 & 4 of REM sleep
Duration:	Up to 20 min per episode	Ranges from 5–30 min	No consistency
Alertness:	Hard to awaken	Easily awakened	Hard to awaken
Recall:	No recollection of content	Do not recall sleepwalking	Content is remembered
Causes:	Illness, high fever	Mental stress & fatigue	Mental stress & individual's common fears (e.g., snakes)

Figure 2. Example of a completed graphic organizer (Katayama & Robinson, 2000).

Three very important ways of communicating are written or verbal description, visual art or diagram and symbolic or mathematical notation. These can be combined into an organizational tool called the annotated diagram. The diagram in Figure 3 is an example of an annotated diagram. It is a simple sketch of a process or small sequence of events with a series of explanatory notes and any mathematical relationships that apply.

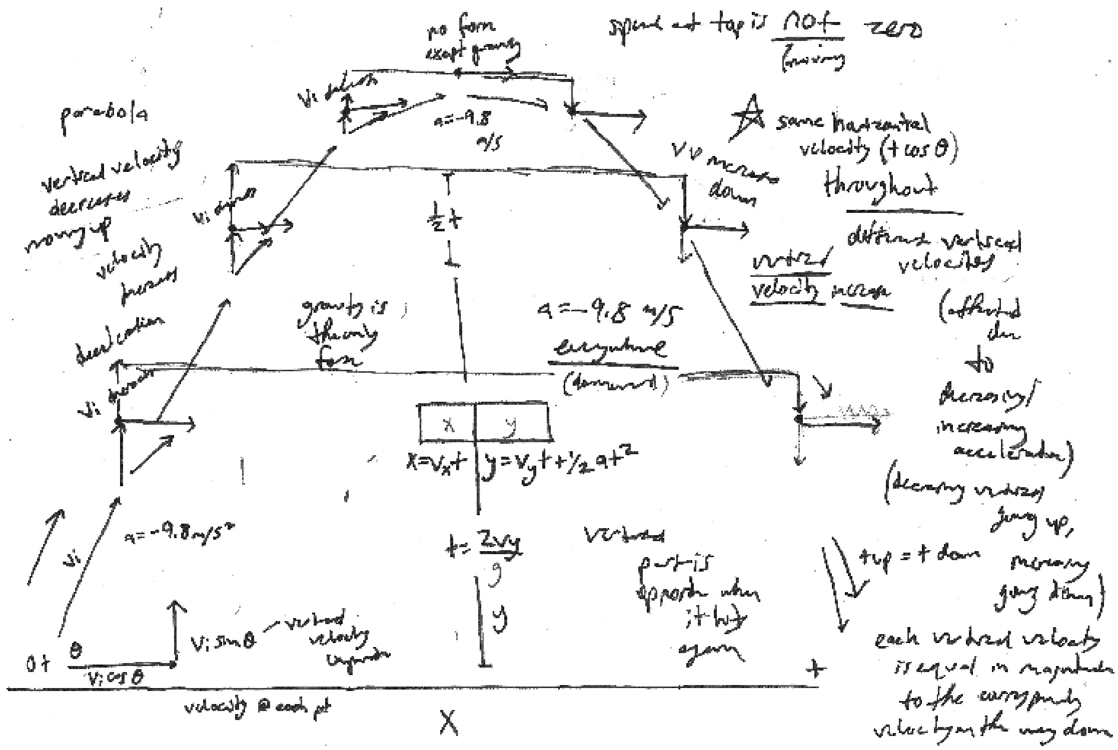


Figure 3. Example of an annotated diagram for projectile motion (Tyree, 2007).

Annotated diagrams enhance student understanding of difficult subject matter but also contain some pitfalls in effective student use. These include not thoroughly presenting the graphic organizer or annotated diagram before setting expectations on its use, as well as lack of teacher rehearsal (Tyree, 2007; Egan, 1999). The goal of combining aspects of graphic organizers and annotated diagrams is for each student to find tools that work best with their own learning style.

METHODOLOGY

Since the objective of this study was to demonstrate improved learning outcomes by use of tools that help students visualize chemical concepts, it was first necessary to analyze test results from a previous year (2010) for the topics that had been most troublesome for a majority of the students. From this information, worksheets for each of the four unit exam tests were created. The worksheets focused on methods to visualize problems and connect them to mathematical statements or processes for solving specific types of questions. Since these worksheets were added to the regular workload of the lab, they were kept as brief and focused as possible.

First, a baseline of chemistry knowledge was established using a Chemistry Concept Inventory consisting of 30 questions (Appendix B). This inventory was pieced together from three different sources. Question numbers 1 thru 15 were taken from JCE Online (“JCE online: CQs and,”). Question numbers 16 thru 22 and 24 thru 28 were taken from the Conceptual Chemistry Questionnaire ("MCI-v5_7-05 [word document],”). Question number 23, 29 and 30 were taken from the Matter Concept Inventory (Warren, n.d.). This inventory was also given at the end of the semester to evaluate how student understanding of the concepts had changed. The method to analyze the data was to take the frequency of scores from each of the unit exams and final for the class as a whole and then separately for the two subject laboratory sections. A percentage for each of the scores was then calculated based on the number of students taking the test. The largest percentage value was identified and used to normalize these results. Finally, graphs were created to compare the class mode to the mode of the two laboratory sections.

In addition to a baseline of chemistry knowledge, a baseline of attitudes was also established through the use of three questionnaires. These included the Attitudes about Types of Problem Solving survey and the Mid-Semester Student Evaluation of the Usefulness of Visualization Tools (Appendices A & C) as well as The Semester End

Attitudes about Types of Problem Solving that was given during the scheduled checkout from the laboratory room (Appendix D). Both of the Attitudes Surveys asked various questions regarding three types of problem solving. The students were to rank each of these types as 1, 2 or 3. This data was then entered into a spreadsheet and the mode of each question was then found to determine an overall ranking. The questionnaire given mid-semester was all written answers. All of these were read over to find general themes and anomalous feedback.

After analysis of the 2010-year's first test, discussion with the class instructor Dr. Broderick indicated that focusing on reaction rates and definitions would be of most benefit not only for this topic, but also as a good foundation for the topics that would be covered as the semester progressed (W. Broderick, personal communication, January 18, 2013). The first developed worksheet, Chemical Reaction Rate (Appendix E), was designed to get students to focus on the word *rate* and how it could be depicted by a graphical representation with units. This worksheet was adapted from the paper written by Kolomuç, A., and Tekin, S. (2011).

The analysis of the 2010-year's second test revealed that the topic of *reaction rates* in the form of dynamic equilibrium in a closed system was still troublesome to many students. The second developed worksheet, LeChatelier's Principle with Graphs (Appendix F), attempted to have students work through a system that was initially at equilibrium and then had various changes imposed upon it. With each of the changes, the students created a section of graph that represented not only the change, but also how it affected the other species involved in the overall reaction. The second part of the worksheet worked in the other direction. A graph was provided with various changes and either a change in concentration or heat was identified.

With the third 2010 test it was discovered that the majority of students had done well calculating values for Gibbs free energy, but had performed poorly on questions regarding the relationships of the variables in the equation. The Gibbs Free Energy, Enthalpy & Entropy worksheet (Appendix G) was developed to employ graphs that related the value of Gibbs free energy (ΔG) to enthalpy (ΔH), temperature (T) and entropy (ΔS). From a linear graph the students were asked to determine the signs of free energy, enthalpy and entropy using the general equation $\Delta G = \Delta H - T\Delta S$. The absolute scale for temperature was used at all times and therefore the sign for T was always positive. The sign of Gibbs free energy (- or +) was then used as a reminder of whether a reaction would be spontaneous or not.

The 2010-year's fourth unit exam led to the development of the last worksheet. Balancing Redox Reactions (Appendix H) was created to tie into the basic concept of stoichiometry. This worksheet had a PowerPoint presentation of the same name that accompanied it (Appendix I) and employed the use of color to streamline the process of keeping track of electrons gained and lost and to minimize the number of times steps needed to be rewritten. The students were given two reactions that needed to be balanced in acidic conditions and two that needed to be balanced in basic conditions.

In addition to each of the worksheets, a PowerPoint presentation was created for each of the ten labs throughout the semester (Appendix J). These were designed to remind students of important concepts, to help explain complex or unfamiliar mathematical expressions, and to provide specific information that had been omitted or changed from the lab manual (Table 1). The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained.

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: 1. What are the effects of visualization tools on the conceptual understanding of basic chemical processes and changes?	Chemistry Concept Inventory taken during lab orientation and lab checkout	Comparison of unit exam and final grades between my lab sections and the rest of the class	Tracking of lab grades throughout the semester
Secondary Questions: 2. Do student attitudes about problem solving change when visualization tools are used repeatedly?	Pretreatment attitude survey	Midway poll of student views of visualization tool use	Posttreatment poll of student attitude about use of visualization tools
3. How does knowledge of basic concepts change with the addition of learning and practice?	Chemical Concept Inventory given as a pretest	Chemical Concept Inventory given as a posttest	

DATA AND ANALYSIS

The Spring Semester began with the survey Attitudes about Types of Problem Solving (Appendix A). This survey asked four questions regarding three approaches to problem solving: written, pictorial and mathematical. The first three questions asked students about their preferred method of problem solving, belief in their own level of skill with each method and the method they thought was most accurate. The majority of students in both laboratory sections chose the use of equations, the mathematical approach, for all three questions, 42%, 58% and 84% respectively. The last question asked which of the three approaches to problem solving was the students' weakest skill. This time the written form of solving came back as most chosen, 47% (n = 36). At the end of the semester not much had changed. The use of mathematical methods was still the top pick for the first three questions, 58%, 69% and 78% respectively. The last question was changed to ask what method they felt had improved the most. In the first laboratory class, 53% (n = 19) said they had the most improvement in the use of equations since as they "needed to use lots of equations for exams we had lots of practice using them." Another student said, "You are very helpful in explaining them and showing how they work. It has made it easier to learn." In the second laboratory class, 47% (n = 17) of students stated that they had improved most in the use of written methods because the "lab reports strengthened both writing skills and understanding equations." In both labs, the students ranked pictorial problem solving below mathematical and written methods. A few of the students commented that they had come to recognize the value of visual representation stating that "equations solve better but pictures are more helpful," and "I didn't think pictures were as helpful as they've proven to be this semester." One had "learned to transfer (information) from written to pictures and equations."

The Chemical Concept Inventory was presented to both of the large lecture classes to take if they so chose and was broken down to five categories: basic ideas and concepts, energy, stoichiometry, polarity and dilution (Appendix B). Figure 4 shows that students averaged 59% correct on questions related to basic ideas, 54% on questions related to energy, 29% on questions related to stoichiometry, 56% on questions regarding polarity and 69% on questions about dilution on the pretest in blue (*n* = 52). There was very little change in these averages on the posttest in red.

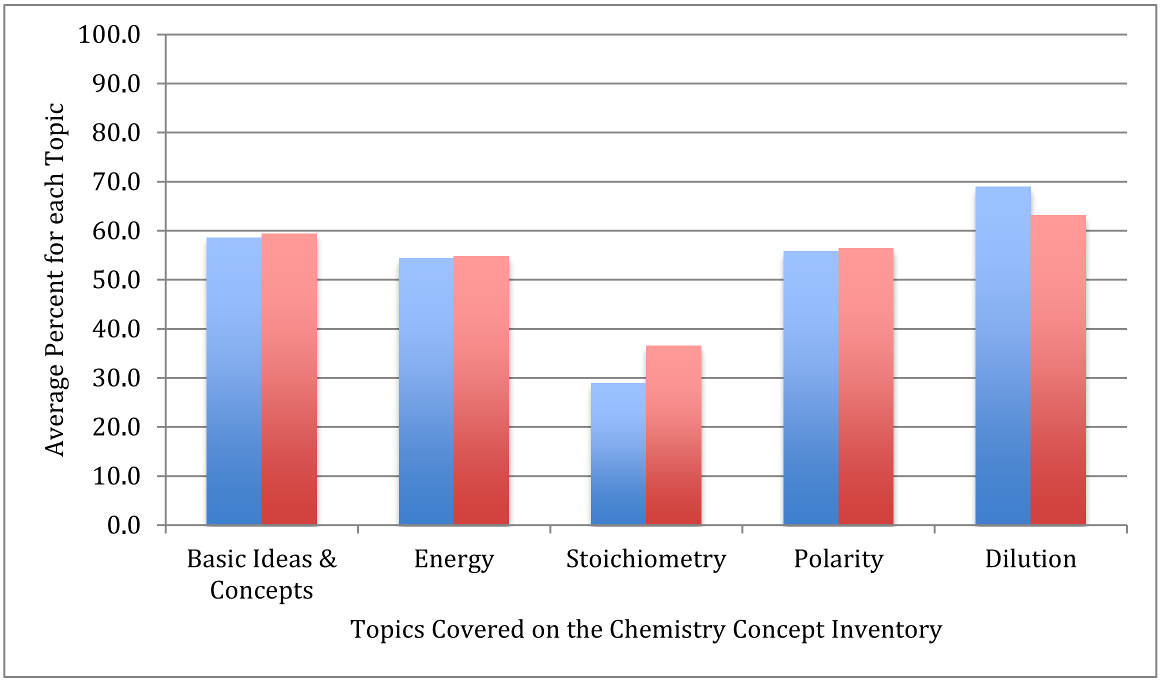


Figure 4. Averages for each of the five topics from the Chemistry Concept Inventory (Appendix B), (*n* = 52).

As can be seen in Figure 5, the answers to the topic of basic ideas were quite varied. Two of the questions within this topic were categorized as everyday observations and preconceptions. The idea of what forms bubbles in boiling water was less understood by 19% than was the concept of change in mass as solid iron oxidizes and forms rust (Questions 2 and 12). Students scored lower when asked about counting in the millions or billions before something is observable to the naked eye (Question 3). This question also required ideas of molar mass and the metric system in order to answer correctly. Some of the students did not answer correctly when asked what happened to the mass of evaporated iodine that had been sealed in a vial (Question 5) but still knew that mass had to be conserved (Question 6). The second to last question in this topic regarding the molecular distribution of a gas in a closed container as it was cooled down but remained in the gas phase was the most missed in the pretest (Question 26). The most common wrong answer involved molecules clumping together in the center of the container. For this same question 6% of the students on the pretest and 8% on the posttest selected the answer where the molecules would stay distributed throughout the container but would shrink in size.

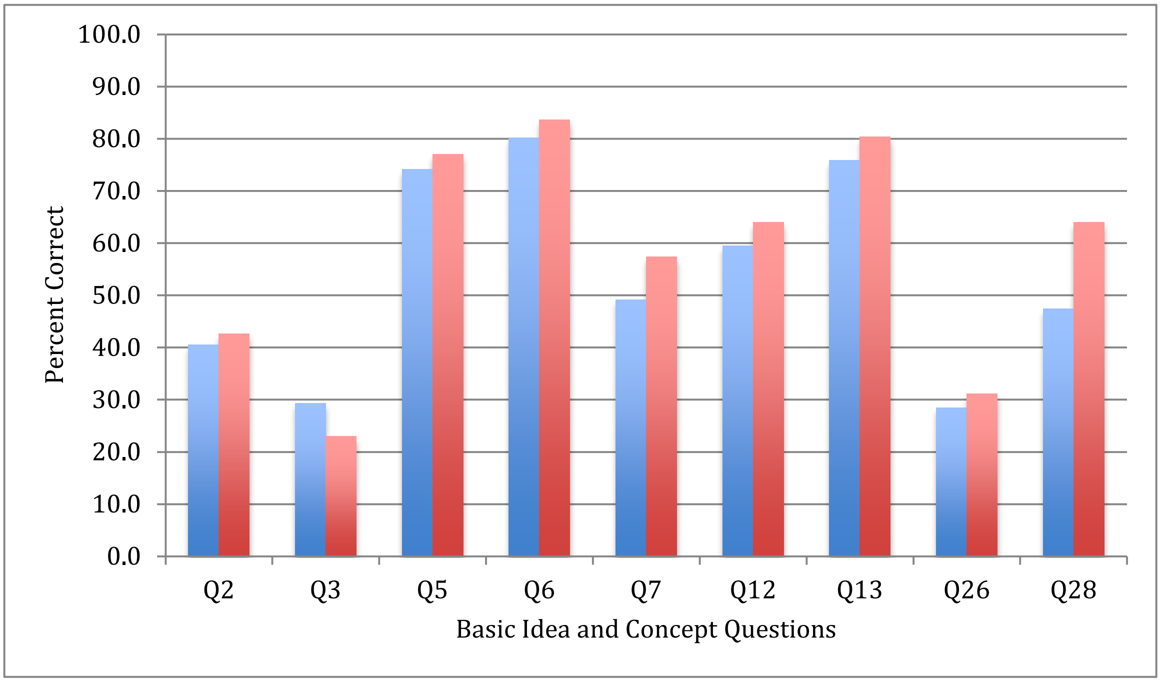


Figure 5. Basic ideas and concepts questions from the Chemistry Concept Inventory, (n = 52).

Key:
Question 2: Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?
Question 3: What is the approximate number of carbon atoms it would take placed next to each other to make a line that would cross this dot: ▪
Question 5: A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams. The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:
Question 6: What is the reason for your answer to question 5?
Question 7: The circle on the left shows a magnified view of a very small portion of liquid water in a closed container. What would the magnified view show after the water

evaporates?
Question 12: Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:
Question 13: What is the reason for your answer to question 12?
Question 26: The following diagram represents a snapshot in time of a cross-sectional area of a steel tank filled with oxygen gas at room temperature. (The dots represent the distribution of oxygen molecules). Which of the following diagrams illustrate a snapshot of the distribution of the contents of the steel tank if the temperature is lowered? (The oxygen remains in the gas phase).
Question 28: What is there between the particles inside the flask in figure A below?

In general, energy is not covered in depth in the prerequisite first semester class and so students scored poorly on three of the four questions on energy. Those questions were included to see how the second semester's emphasis would affect the answers. As can be seen there was little or no change in the percentages of correct answers (Figure 6). The last question in this section was answered correctly by 83% of the students on the pretest. The question asked for the temperature of a mug of tea that had ice added but was no longer melting the ice. When asked about the heat released in the formation of water fewer than half the students answered it correctly on the pretest (Question 8). This number dropped slightly on the posttest. Less than half the students understood the second question in this topic (Question 10). The solution involved the reason why heating two different substances at the same rate to the same temperature required different times. The percentage of correct answers to the reasoning behind the difference in time (Question 11) for the two substances did not change.

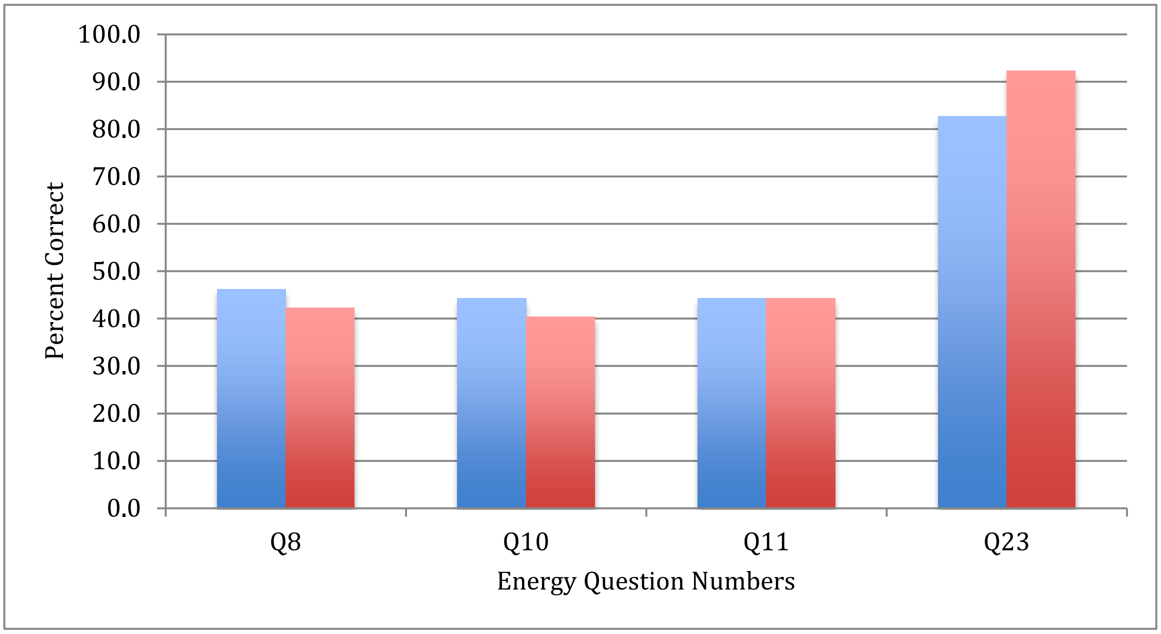


Figure 6. Energy questions from the Chemistry Concept Inventory, (*n* = 52).
Key:
Question 8: Heat is given off when hydrogen burns in air according to the equation, $2H_2 + O_2 \rightarrow 2H_2O$. Which of the following is responsible for the heat?
Question 10: 100 mL of water at 25°C and 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50°C. Two minutes later the temperature of the water is 50°C. Which liquid received more heat as it warmed to 50°C?
Question 11:What is the reason for your answer to question 10?
Question 23: You add several ice cubes to a mug of hot tea. After ten minutes, you notice that half of the ice remains and the ice is no longer melting. The temperature of the tea now is:

Of the questions that involved stoichiometry, the first one asked students to identify what was the same before and after a reaction (Question 1) and was the only problem that had more than one possible correct answer depending on how an instructor preferred to teach the relationship between mass and energy (Figure 7). Many of the topics covered in the second semester of chemistry relied on the use of stoichiometry and yet these questions as a group were the most missed of all the topics in the inventory. Question 1 had the largest gain but was still answered correctly by only 39% of the students on the posttest. The next two questions were similar in that they represented elements as different shaped objects (Questions 4 and 16). The difference was that the second one gave a balanced stoichiometric equation and asked what it would look like in pictorial form while the third one gave the equation in pictorial form and asked for the equation in numeric and symbolic form.

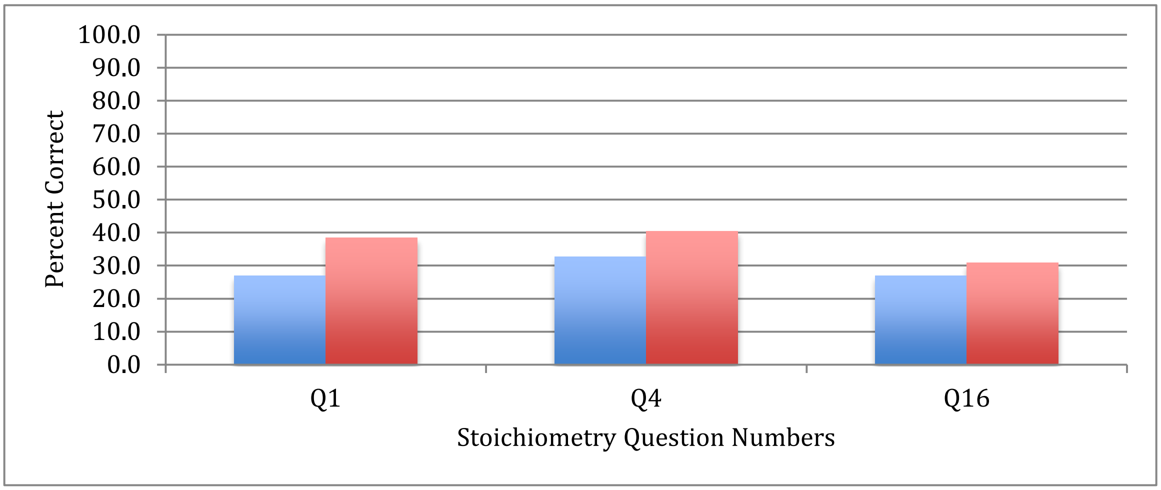


Figure 7. Stoichiometry questions from the Chemistry Concept Inventory, (n = 52).
Key:
Question 1: Which of the following must be the same before and after a chemical reaction?
Question 4: The diagram represents a mixture of S atoms and O_2 molecules in a closed container. Which diagram shows the results after the mixture reacts as completely as possible according to the equation: $2S + 3O_2 \rightarrow 2SO_3$
Question 16: The reaction of element X with element Y is represented in the following diagram. Which equation describes this reaction?

Most of the questions in the polarity section of the inventory were answered correctly by about half the students who participated (Figure 8). The questions in this section came as pairs. The second of each pairing asked for the reasoning behind the answer for the previous question. The first question asked about the positioning of the bonding electron pair that is shared between hydrogen and fluorine. A basic grasp of the trend in electronegativity on the periodic table was an essential idea for student understanding when asked about the position of a shared electron pair between a group one element and a group seven element (Question 17). On the third question, a working model of bonding and non-bonding electron pairs and the shapes created when forming a molecule was required knowledge when a group number was referenced (Question 19). When asked to identify a polar molecule (Question 21) many of the students answered successfully but failed to choose the correct reasoning behind the answer (Question 22). On the pretest more than a third of students chose the reason that mentioned non-bonding pairs of electrons and failed to pick up on the lack of symmetry in two dimensions. On the posttest, 31% still picked the same incorrect answer.

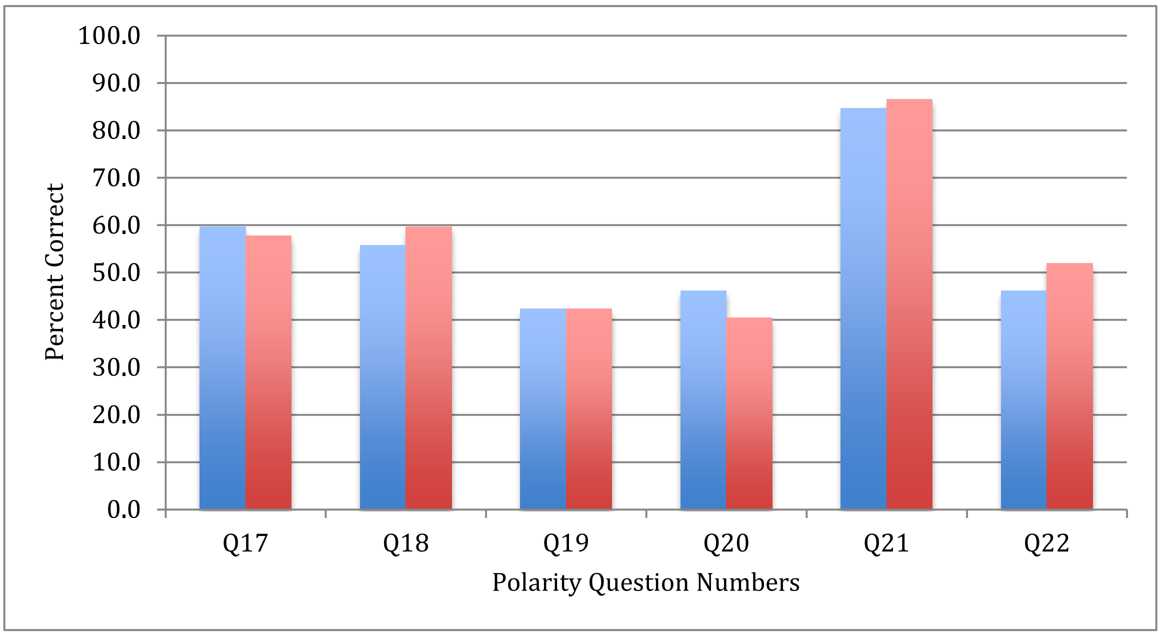


Figure 8. Polarity questions from the Chemistry Concept Inventory, (n = 52).
Key:
Question 17: Hydrogen is a group 1 element, while fluorine is a group 7 element. Which of the following best represents the position of the shared electron pair in the HF molecule?
Question 18: What is the reason for your answer to question 17?
Question 19: Nitrogen (a group 5 element) combines with bromine (a group 7 element) to form a molecule. This molecule is likely to have the following shape:
Question 20: What is the reason for your answer to question 19?
Question 21: Which of the following molecules is polar?
Question 22: What is the reason for your answer to question 21?

The subject of dilution was understood by the majority of the students except for the second and third questions of this group (Figure 9). The second question in this group asked students about the concentration of a saturated solution after half the liquid had been allowed to evaporate (Question 14). The majority said that the concentration would increase, reasoning that there would be the same amount of salt in less water. These students failed to recognize what is implied when a solution is stirred until no more salt will dissolve. There was a marked decrease in understanding displayed by students from the pretest to the posttest when asked to pick a molecular diagram that indicated a change in concentration (Question 9). This question asked about the distribution of sugar molecules in a solution that started out at a volume of one liter and was diluted to two liters. There was no complimentary question to this one for students to choose their best reasoning.

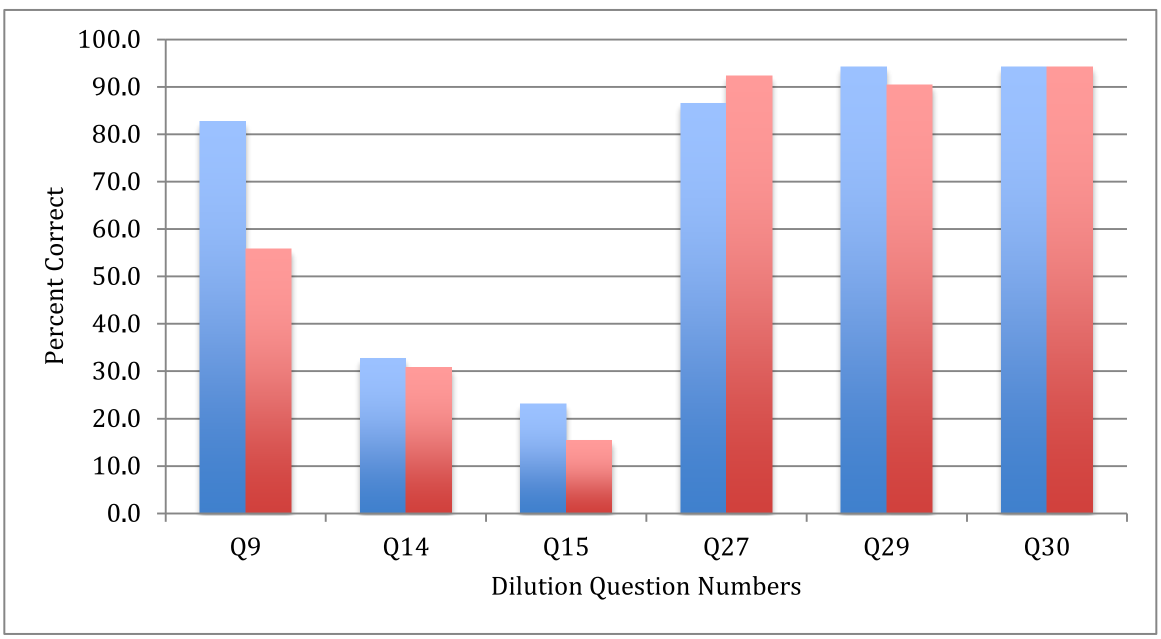


Figure 9. Dilution questions from the Chemistry Concept Inventory, (n = 52).
Key:
Question 9: Figure 1 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram,

the water molecules have not been shown. Which response represents the view after 1.0 L of water was added (Figure 2).
Question 14: Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if water evaporates until the volume of the solution is half the original volume? (Assume that the temperature of the solution remains constant.) The concentration
Question 15: What is the reason for your answer to question 14?
Question 27: The following sets of drawings represent "snapshots" of a stoppered flask containing air particles before and after some of the particles were removed. Choose the best drawings of air before and after some was removed from the flask.
Question 29: You decide to share some sugar-sweetened fruit juice with your friend. You divide the fruit juice equally into two glasses. You then add an equal volume of water to Glass B. Which glass contains the sweeter tasting drink?
Question 30: Which glass contains more sugar?

Chemical Reaction Rate was the first worksheet to be handed out to the laboratory sections (Appendix E). Only 31 students filled out and returned this sheet. The first question required the students to mediate an argument between two other fictional students discussing what the term "reaction rate" meant. Nearly every answer was some slight variation of "The rate of reaction is the change in concentration of a reactant or product per unit of time." The second half of this question focused on how the rate changes as the reaction proceeds over time. Again, most responses were similar to "It slows as the reaction continues because there are less molecules, reducing the frequency of collisions, which reduces the number of reactions." The second page required students to create a graph of a reaction rate vs. time after having been given a graph of concentration vs. time for a generic reactant. The two fictional students also created graphs but it was not indicated whether these were correct or not. No one thought either of the two fictional students was correct but created one of three basic shapes as seen in the figures below. The split was nearly a third for each, 36% for the first two graphs below and 23% for the third graph. The first two graphs would be read as the concentration vs. time for products and reactants respectively. Only two students drew graphs that interpreted the slope correctly (Figure 13).

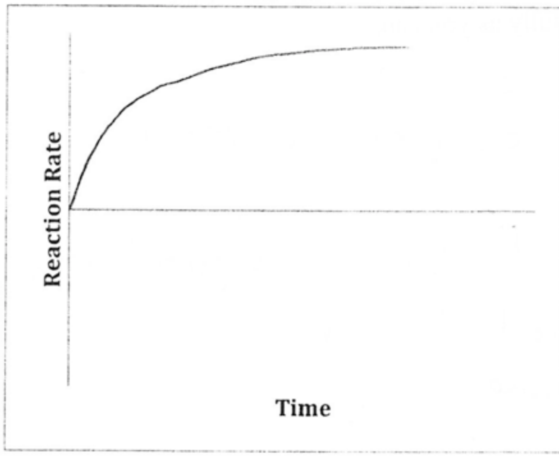


Figure 10. First example of an incorrect Reaction Rate vs. Time graph, (n = 31).

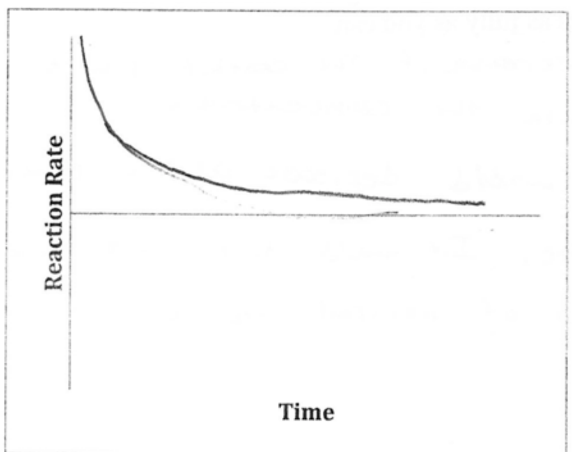


Figure 11. Second example of an incorrect Reaction Rate vs. Time graph, (n = 31).

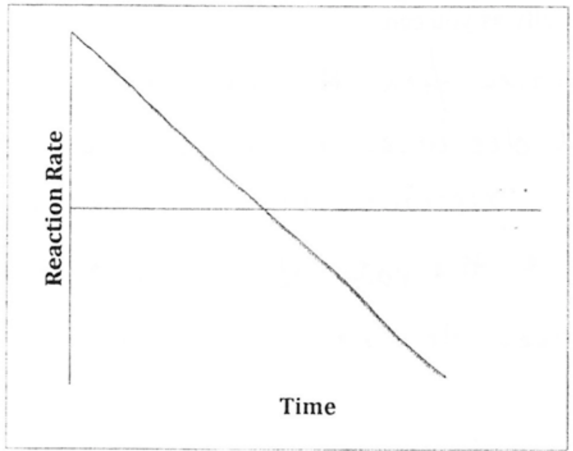


Figure 12. Third example of an incorrect Reaction Rate vs. Time graph, (n = 31).

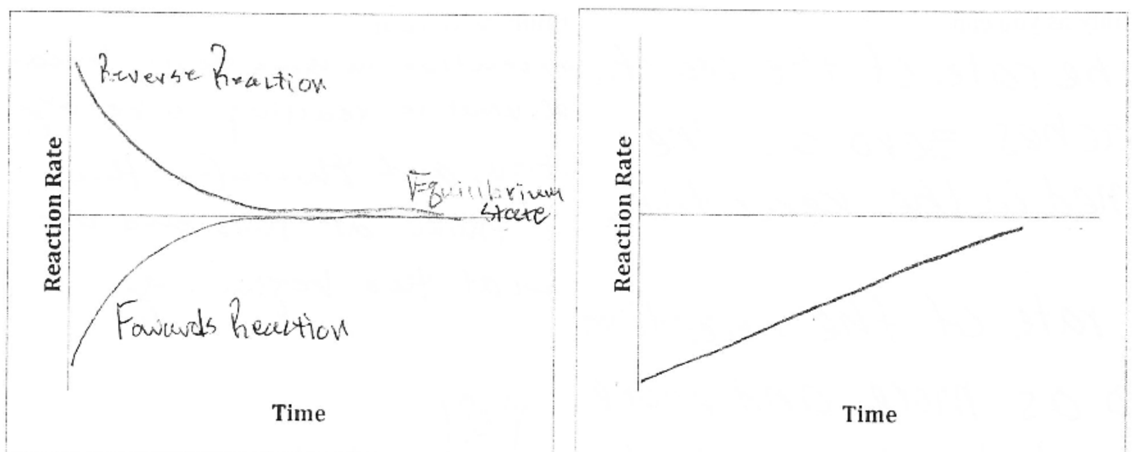


Figure 13. Two correct interpretations of Reaction Rate vs. Time, (n = 31).

With a greater number of students for the class as a whole the blue graph in Figure 14 has the general bell curve shape centered, overall, on the mode score of 72.2%. The graph of the scores for the laboratory sections in red doesn’t have the same bell curve shape since the number of students is quite a bit less but does show a mode score that is higher than the class mode by two questions. The spread of scores for the laboratory sections is also narrower compared to the rest of the class. In each of the unit exams and the final exam there is one question built in for extra credit.

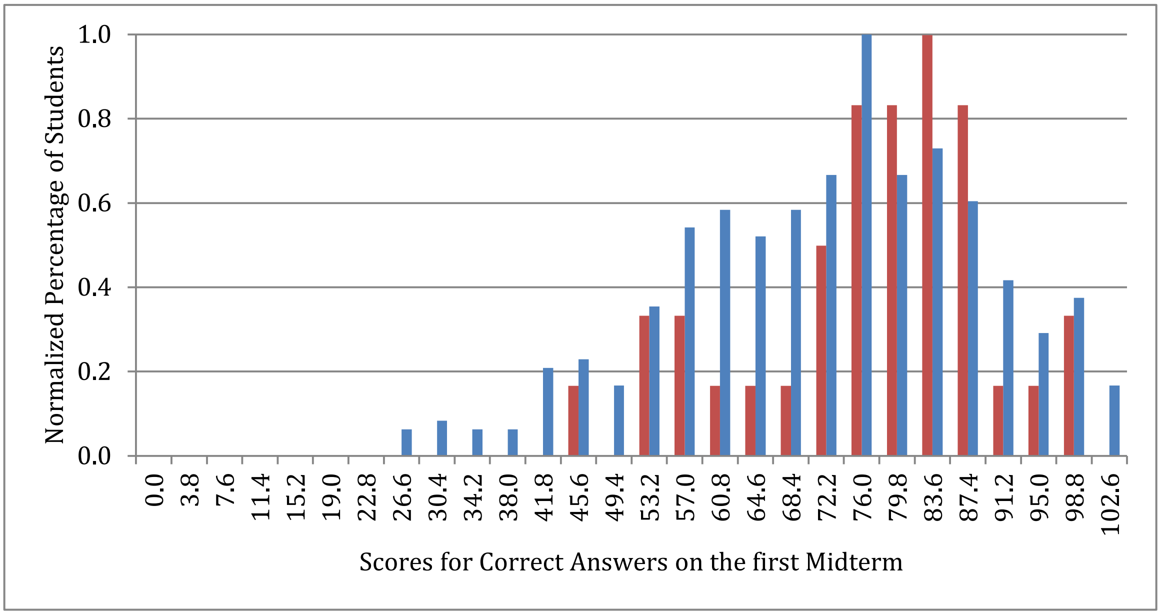


Figure 14. Normalized percentage of scores for the class, (n = 402) and the two lab sections on the first unit exam, (n = 36). Each number on the x-axis represents the score a student would get for a number of correct answers on the test. For example, a score of 49.4% on the unit exam would equate to thirteen correct answers and a score of 102.6% would be twenty-seven correct answers out of twenty-seven questions.

The second worksheet dealt with LeChatelier's Principle and employed the use of graphs to help with the understanding of this idea (Appendix F). Less than half of the students in the two laboratory sections decided to participate on this worksheet. The first question was written in several parts, each one designed to impose a change on a system in equilibrium. The students then needed to decide what would happen to the system to regain a new equilibrium. Nearly everyone was able to determine what would happen and the creation of graphs of this change went very well as noted in Figure 15. About mid-semester a questionnaire was given to the students to evaluate the usefulness of the two worksheets taught at that point (Appendix C). The questionnaire revealed deficiencies in the LeChatelier's Principle worksheet. Many students from the two laboratory sections indicated that the worksheet was poorly written and was confusing to follow although one student commented, “The worksheet used for the LeChatelier’s lab was very helpful, I enjoyed working through the questions and understood it the most.”

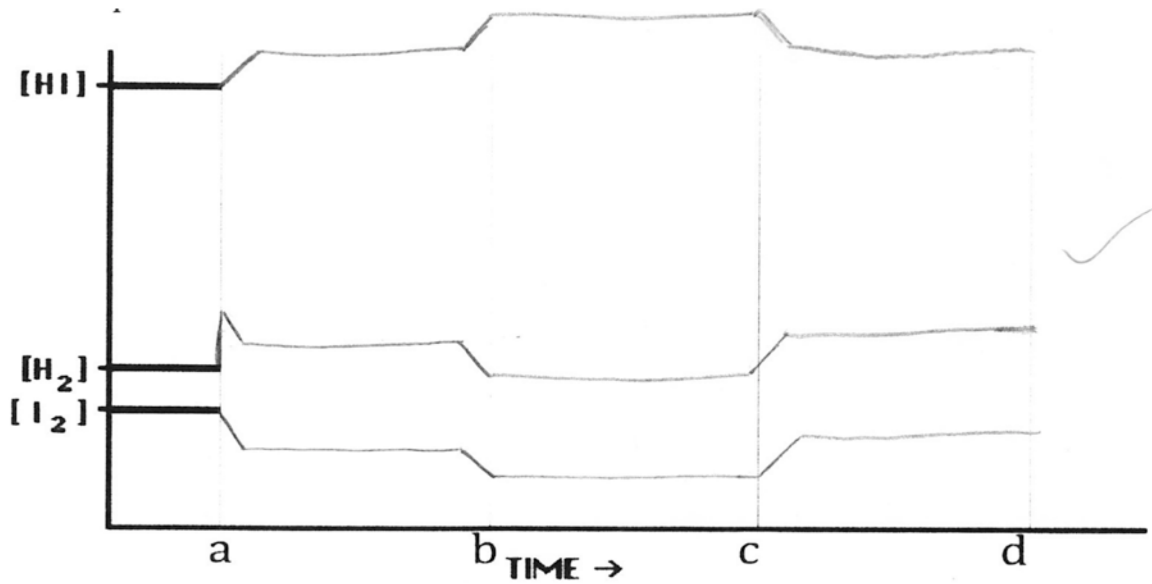


Figure 15. Example of student graph for LeChatelier's Principle worksheet, (n = 18).

The second question gave them a graph with several changes along with a generic equation for the reaction and an enthalpy value that was used to determine the effect of temperature changes on the system. Nearly everyone could identify the changes in concentration from the graph but several were not able to properly use the information supplied with the enthalpy value. The removal and addition of heat to the system were reversed in their answers.

A second unit exam comparison was made in a fashion similar to the first. This time the mode for the class was an 87.4%. Figure 16 shows a shift towards the upper end of the grade scale compared to the first test but fewer perfect scores. When the data were gathered four students had not taken this unit exam. The mode for the laboratory sections was lower than the class on this test by two questions. The spread of scores for the two laboratory classes is quite a bit narrower than the rest of the class with the majority of laboratory students above 68.4%.

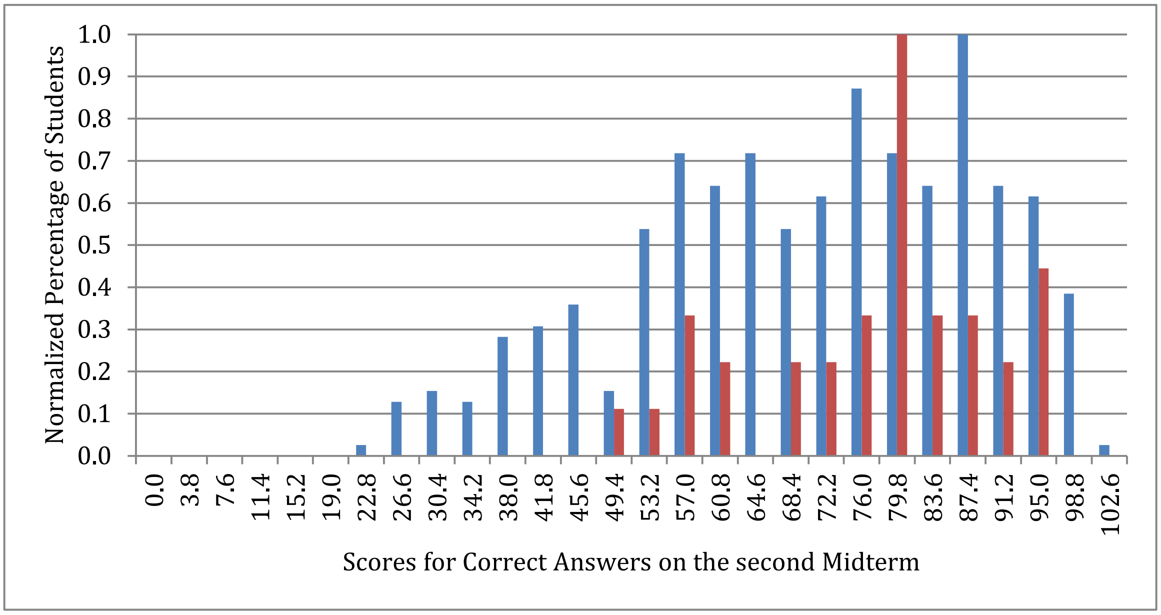


Figure 16. Normalized percentage of scores for the class, (n = 398) and two lab sections on the second unit exam, (n = 36).

The third worksheet on Gibb's free energy gave students practice in reading signs (+ or -) from four different graphs of ΔG vs. T (Appendix G). All of the graphs were linear and started at a temperature of absolute zero so that the y-intercept could be read for the enthalpy (ΔH) value. Most were able to answer what the signs were but then a few mixed up what the sign of ΔG meant for the spontaneity of the reaction. This worksheet was due the same day as the test that included this topic and a few stated after the test that it had helped them quite a bit. A total of 29 students participated by turning this worksheet in.

The mode for the class on the third unit exam was slightly lower than the second one at 79.8% but still on the high end of the scale (Figure 17). The scores trail off quite a bit more towards the low end as well. This was also the last unit exam before the final date to drop the class. Seventeen students who had taken the second test did not take this unit exam. At this point three students in the labs had dropped the class but only one of them had stopped attending the laboratory section. Once again the mode for the laboratory sections is only slightly higher. As with the second unit exam, the majority of the students from the two laboratory sections were grouped above 68.4%.

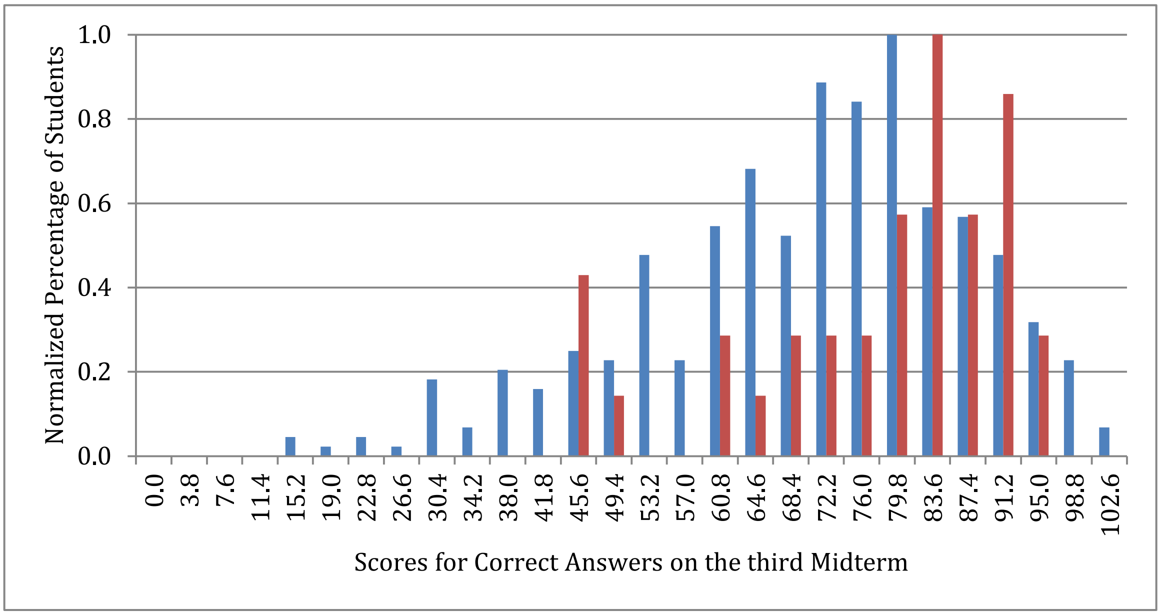


Figure 17. Normalized percentage of scores for the class, (*n* = 381) and two lab sections on the third unit exam, (*n* = 36).

The final worksheet, Balancing Redox Reactions, returned to the basic skill of stoichiometry but added the counting of electrons transferred (Appendix H). Balancing in either an acidic or basic solution to keep track of total charge on either side of the equation added to the complexity. Nearly two thirds of the class participated and turned in this sheet (*n* = 21). In addition to this worksheet, a PowerPoint presentation with an alternate method of balancing was prepared and emailed to the students (Appendix I). This method employed the use of different colors to connect the two sides of the reaction together. One color connected the element that had lost electrons and a second color identified the element that had gained them. By the time the students started working on the practice sheet they had already been using the half-reaction method presented in class and used heavily in the online homework modules. Analysis of the worksheet that had been turned in revealed that 100% had used the half-reaction method. The method outlined in the PowerPoint presentation received mixed reviews. On the positive side one student stated, “Yes, the steps walking through it and working it out slowly was very helpful.” Another made an especially useful suggestion for the future by saying “A voice capture with the slides would have been extremely helpful. The steps outlined in the PowerPoint was helpful even though the method was new.” Not all thought it was useful, however, and said “It was a little jumbled” and another “very confusing.” Again, this worksheet was due in lab on the day of the test and several in each section stayed after the laboratory experiment was completed to ask questions regarding the processes of balancing.

Sixteen more students from the entire class did not take the fourth test (Figure 18). The mode on this was slightly higher then the last one, 83.6%, which equates to one more correct answer, but most of the class was grouped above 64.6%. The mode for the laboratory sections was only one question higher then the mode for the class as a whole. Once again the spread for the two laboratory sections is narrower than the class as a whole.

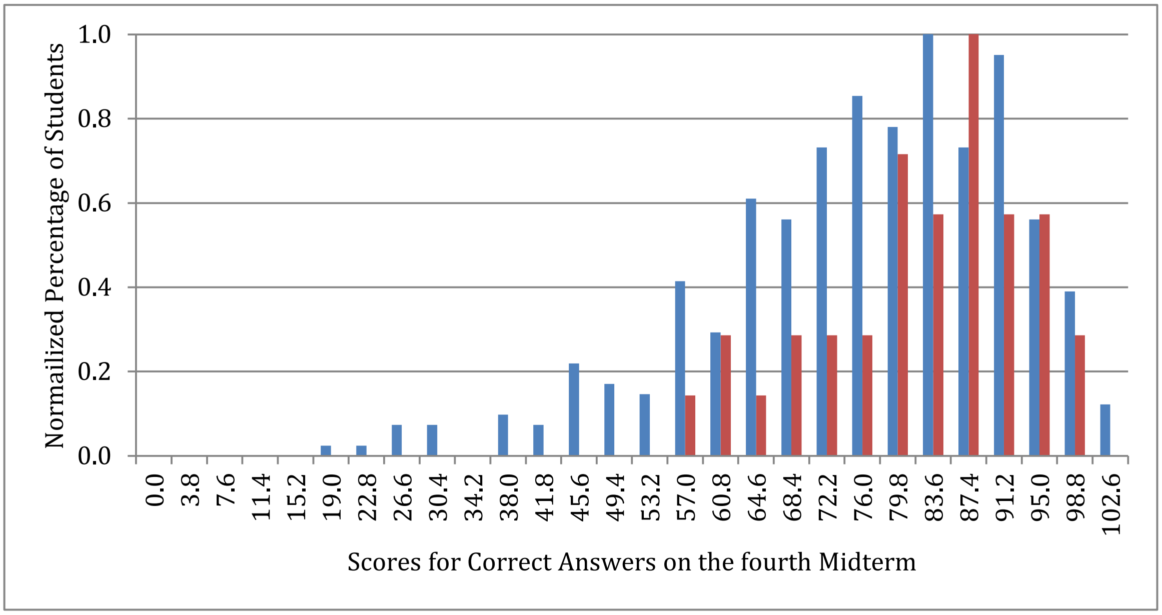


Figure 18. Normalized percentage of scores for the class, (*n* = 365) and two lab sections on the fourth unit exam, (*n* = 36).

Figures 19 and 20 compare the numbers of students in four groupings of percentile ranges for each of the four unit exams. In Figure 19 for the whole class fluctuated a little but overall didn't change much. The two laboratory sections in Figure 20 show an increase in the number of students in the 25 to 50th percentile range on the second test in red which was the test covering the poorly written worksheet on LeChatelier's Principle. The trend after that, however, is towards the higher percentile ranges with all students ranking in the highest two groups by the fourth test (in purple).

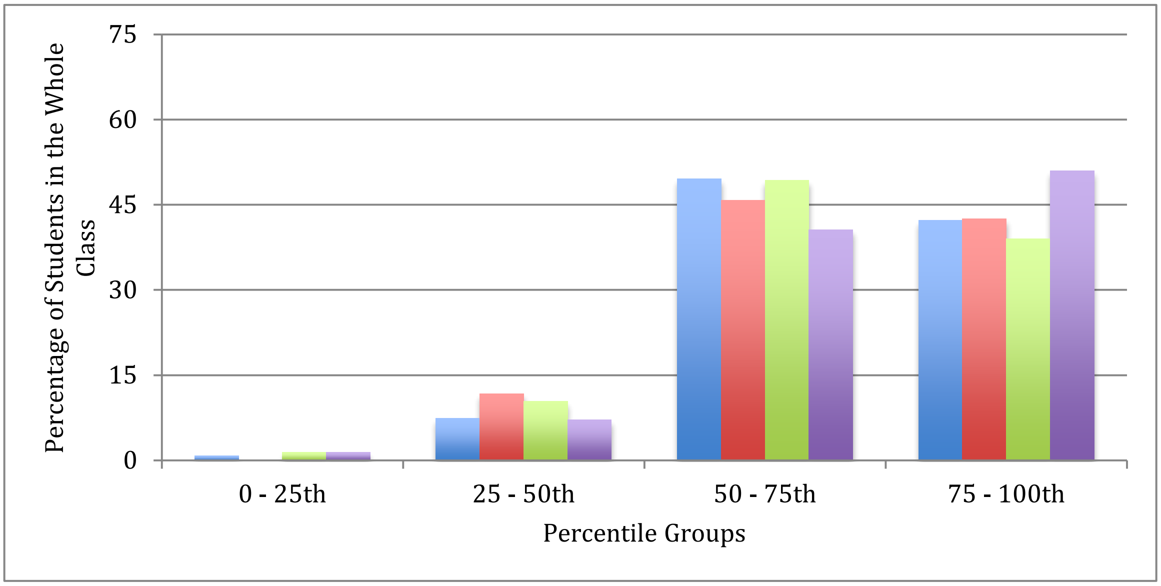


Figure 19. Percentage of students from the whole class on each of the four unit exams grouped into four percentile ranges, (n = 367).

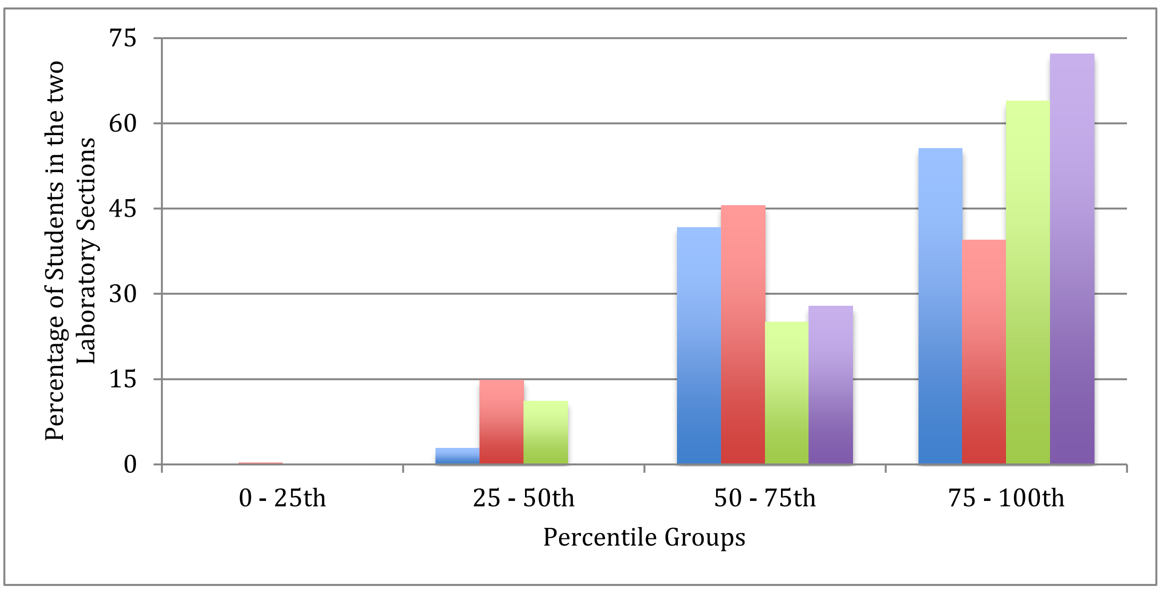


Figure 20. Percentage of students from two lab sections on each of the four unit exams grouped into four percentile ranges, (n = 36).

On the final exam there was a large separation in the mode for the class, in blue, and the mode for the two laboratory sections, in red (Figure 21). This equates to nine more questions correct. There were 41 questions on the final and each was worth 5 points. As with the unit exams, there was one question for extra credit.

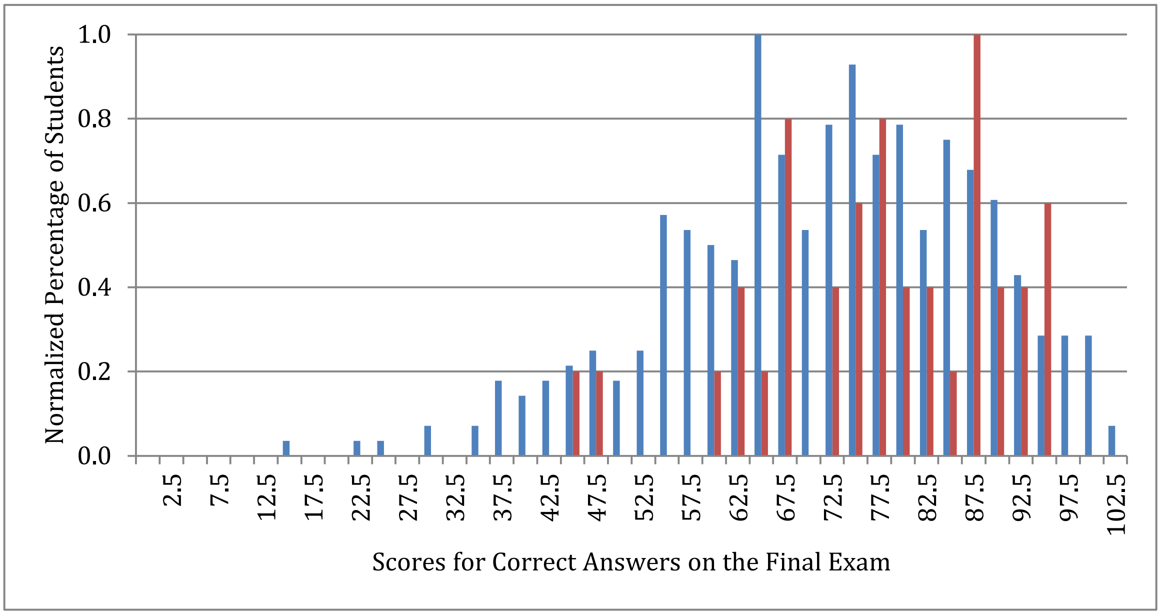


Figure 21. Normalized percentage of scores for the class, (n = 367) and two lab sections on the final, (n = 36).

In Figure 22 the normalized percentages for the class as a whole, in blue, have been compared to the two laboratory sections, in red. The whole class followed the trend set in the four unit exams with the numbers in the 50 to 75th percentile slightly dominating. The trend set by the unit exams for the two laboratory sections also followed here on the final with no students in the lowest group and the graph then climbing progressively from the second to the fourth group.

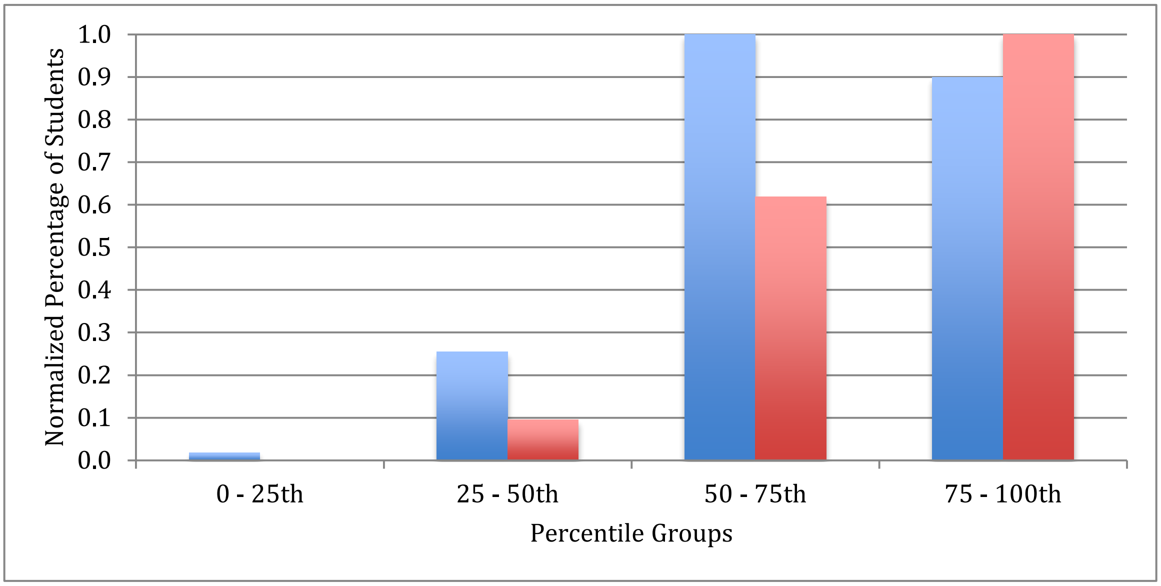


Figure 22. Normalized percentage of students from the class, (*n* = 367) and two lab sections, (*n* = 36), on the final exam grouped into four percentile ranges.

A comparison of average lab scores for both laboratory sections throughout the semester showed that they were fairly well matched in their abilities (Figure 23). The project for the fourth laboratory activity was a handout covering LeChatelier's Principle. The only things that were recorded were their observations for each of the three sections and a brief conclusion summarizing those observations. Since there was no formal report written for this activity, scores tended to be a little better than the rest.

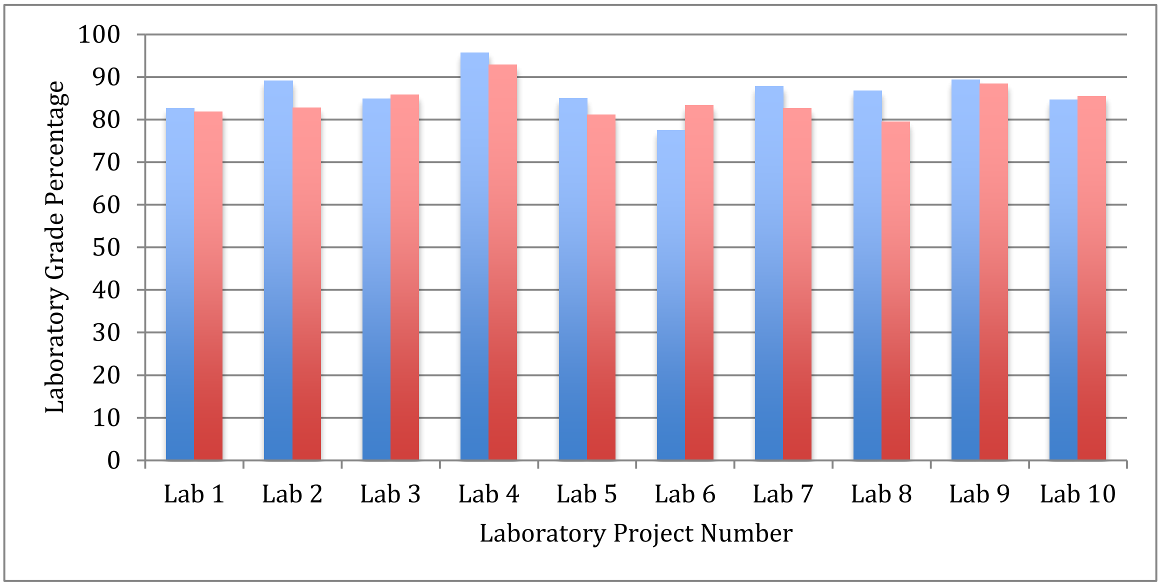


Figure 23. Comparison of average laboratory scores for section 009 in blue, (n = 19) and section 007 in red, (n = 20).

INTERPRETATION AND CONCLUSION

I have been a tutor and teacher at the college level for several years, working with both traditional and non-traditional students. I also taught at private high school for two years but have since returned to the college venue. I was trained to ask leading questions that would draw out the experience that students already had and direct them to a place of new knowledge. By not giving out answers I had to become creative in forming leading questions that approached problems from different angles. I also responded to nonverbal cues and adapted and changed tactics to cater to varied learning styles.

I looked inward as well to see what had worked for me as a non-traditional student with a slight learning disorder. As a student working with fellow students in study partnerships or small groups, I began sharing the visual tools that I had created for myself when I saw that some students could work on a problem mathematically but lacked the ability to transfer the formula to different problems. I developed a reputation of success with small groups and individuals and while this continued to be a specialty, I continued to use and improve these tools when I became a TA and teacher in recent years.

When I began this capstone research project I developed the idea of using these same tools in a larger, more generalized classroom or laboratory setting. The question that grew was whether these devices could be made specific enough to help students that needed different problem solving tools but general enough to be used in groups larger than five composed at least in part by students who were comfortable with conventional approaches. Because the students in the two laboratory sections were randomly selected, it is apparent that they were representative of an average grouping. By the fourth unit exam, the two sections scored in the upper two groups of results. Since the laboratory sections were representative of the whole class, it is safe to assume that these tools can be successfully applied to a larger group.

Collected data were analyzed to answer my primary focus question on the effects of visualization tools on the understanding of basic processes and concepts in chemistry. That test scores for the two laboratory sections subjected to this study shifted from lower to higher percentile groups is evident. What remains somewhat unclear is whether the score shift was a direct result of the use of the visualization tools or if the extra attention and practice involved as a result of introducing the tools had an effect as well. Although this question remains for further examination, the before and after attitude surveys and formal quantification of test results led to several useful conclusions.

The Attitudes about Types of Problem Solving survey at the beginning of the course and its follow-up companion at the end of the semester demonstrated that attitudes toward different approaches to problem solving are difficult to affect. From the final attitude survey, it seems that students able to find answers using traditional formulaic mathematical methods still preferred to use them. However, it also appears that students needing help seeing concepts in a chemistry problem solving setting were able to appreciate new strategies that were introduced as visual tools.

Evaluation of the data suggest that the effects of these tools are greater in the long term than the short term as evidenced by comparing the final exam of the semester to the four unit exams. Also, it appears as a result of introducing the specific subject worksheets that more students than normal came to ask questions about class work; in other words, the learning process better engaged students when it involved visual tools. Because everyone in the lecture class had generally the same learning experience, and because the laboratory projects covered only a very small percentage of the topics discussed in class or examined as homework, the data and final test results support the conclusion that the visual tools introduced to two lab sections had a positive impact on the test results for those two sections.

In answer to the secondary questions of the triangulation matrix, attitudes that students held toward types of problem solving were difficult to change. It would also seem that while the basic processes tested in the class had improved as evidenced by the spread of nine questions on the final, overall understanding of concepts did not change. The averages of correct answers on the Chemical Concept Inventory did not change from the beginning of the semester to the end.

In the Chemical Concept Inventory when students were asked about dilution on the molecular level the number that chose the correct answer decreased by nearly 33% from the pre-test to the post-test (Question 9). One possible explanation for this is that they may have understood the question to imply the solution was saturated and in equilibrium with a solid since the second most chosen answer was that the concentration of the solution would not change when pure water was added. Better wording of the question or a follow up question asking about reasoning for their answers should be written.

VALUE

This action research project has given me valuable experience in developing and writing tools that help students to see ideas from different perspectives. As a result of this project I will continue to quantify improvements when developing tools in the future, especially with reference to test results researched from previous years. I will also explore different techniques for improved classroom assessment. Feedback from the classroom has proven to be absolutely necessary in the development of tools that maximize effect and positively impact the most students. I plan to develop better surveys in general, and specifically after the use of visualization tools, to determine exactly what works.

Working with individuals or small groups has always been a large part of my teaching duties and will continue to be important to me. I will continue to use tools tailored to these situations as student feedback is immediate and it is both a challenge and a source of satisfaction to react spontaneously to specific learning needs. My project has given me a foundation based on research to be even more responsive in individual and small group settings.

In studying the application of visual aids to larger audiences, I have come to realize that there are still topics that I need to explore in order to make more effective visualization tools that have general application over mixed learning styles. As a teacher my own learning will be focused on seeing new ideas from different points of view and in different formats. I have also developed the ability to self-improve by experimenting with new approaches and validating the results with data.

Another positive outcome of this project was that the level of communication improved, even if this was not directly connected to a relationship between visual learning tools and improved test results. At the beginning of every semester of teaching any type of lab I have supplied several ways for the students to contact me in addition to supplying the location of my office. The majority of students have never used this information. This past spring semester, however, was different. By emailing the presentations from each of the laboratory meetings and sending out messages with clarifications, I apparently opened lines of communication in a virtual “space” that was easy and comfortable for the class. Students emailed or sent text messages of questions regarding lab reports as well as offering suggestions on how new information could best be presented. These exchanges occurred with greater frequency than I have experienced in the past and, as a result, I will explore more proactive methods of interacting with students. In the fall semester of 2012 I received a total of 154 email messages from the 27 students in the two lab sections that I taught. During this project I received 346 email messages from the 38 students in both lab sections. This was not only a 225% increase in total messages but also an increase of 160% in the average number of messages for each student, from 5.7 messages per student to 9.1 messages per student.

REFERENCES CITED

Area Chamber of Commerce: Home. (n.d.). Retrieved March 25, 2013, from http://www.bozemanchamber.com/

Egan, M., (1999). Reflections on effective use of graphic organizers. *Journal of Adolescent & Adult Literacy, 42(8),* 641-645.

Katayama, A. D., & Robinson, D. H., (2000). Getting students 'partially' involved in note-taking using graphic organizers. *Journal of Experimental Education 68 (2),* 119-133.

Hall, T., & Strangman, N. (2002). *Graphic organizers.* Wakefield, MA: National Center on Accessing the General Curriculum. Retrieved March 1, 2013 from http://aim.cast.org/learn/historyarchive/backgroundpapers/graphic_organizers

JCE Online:CQs and ChPs: CQs: Chemical Concepts Inventory. (n.d.). Retrieved November 12, 2012 from http://www.jce.divched.org/JCEDLib/QBank/collection/CQandChP/CQs/ConceptsInventory/CCIIntro.html

Kolomuç, A., & Tekin, S., (2011). Chemistry Teachers' Misconceptions Concerning Concept of Chemical Reaction Rate. *Eurasian Journal of Physics and Chemistry Education 3(2),* 84-101.

MCI-v5_7-05 [Word document]. (n.d.) Retrieved November 15, 2012 from http://modeling.asu.edu/MNS/MatterConceptsInv/MCI-v5_7-05.doc

Montana State University - Quick facts. (n.d.). Retrieved March 25, 2013 from http://www.montana.edu/opa/facts/quick.htm

Montana State University - Undergraduate areas of study. (n.d.). Retrieved February 20, 2013, from http://www.montana.edu/academics/majors/

Stull, A. T., & Mayer, R. E., (2007). Learning by doing versus learning by viewing: Three experimental comparisons of learner-generated versus author-provided graphic organizers. *Journal of Educational Psychology 99(4),* 808-820.

Tyree, E., (2007). *The effect of annotated diagrams on student understanding and perception of physics.* Unpublished professional paper, *Montana State University-Bozeman.*

Warren, S. (n.d.). SPECK-8 - Chemical Concept Inventory v4.doc - Detail. Retrieved November 12, 2012 from http://speck-8.wikispaces.com/file/detail/Chemical Concept Inventory v4.doc

APPENDICES

APPENDIX A

ATTITUDES ABOUT TYPES OF PROBLEM SOLVING

Rank the methods you prefer to use for solving problems 1 = most preferred, 3 = least preferred.

___ using words (written form).

___ using pictures (pictorial representation).

___ using equations (mathematical form).

Use this space to briefly explain why.

Rank the following statements regarding your skill at solving problems 1 = good, 3 = poor.

___ solving problems in written form.

___ solving problems using pictorial form.

___ solving problems using equations.

Use this space to briefly explain why.

Rank the following in the order that you believe solves problems most accurately 1 = most accurately, 3 = least accurately.

___ using words (written form).

___ using pictures (pictorial representation).

___ using equations (mathematical form).

Use this space to briefly explain why.

Please rank your response 1= most help needed, 3 = least help needed.

___ I could use more practice/help/training for solving problems in written form.

___ I could use more practice/help/training for solving problems using pictorial representation.

___ I could use more practice/help/training for solving problems using equations.

Use this space to briefly explain why.

APPENDIX B

CHEMICAL CONCEPTS INVENTORY

Chemical Concepts Inventory

Please **do not** write on this packet. You will indicate your answers on a scan-tron sheet.

Do not put your name or on the scantron sheet. Enter the following digits into the first eight bubbles of the ID Number box on the scan-tron: The month and day of your birthday, in the form mmdd, followed by the last four digits of your CatCard ID#. For example, if Julie's birthday is **March** *8* and her CatCard ID# is -00105489, she would bubble in **03***08*5489. Please fill in M or F under sex.

Do not put any other identifying information on your scan-tron.

This inventory consists of 30 questions. Carefully consider each question and indicate the one best answer for each. Several of the questions are paired. In these cases, the first question asks about a chemical or physical effect. The second question then asks for the reason for the observed effect.

1. Which of the following must be the same before and after a chemical reaction?

   a. The sum of the masses of all substances involved.
   b. The number of molecules of all substances involved.
   c. The number of atoms of each type involved.
   d. Both (a) and (c) must be the same.
   e. Each of the answers (a), (b), and (c) must be the same.

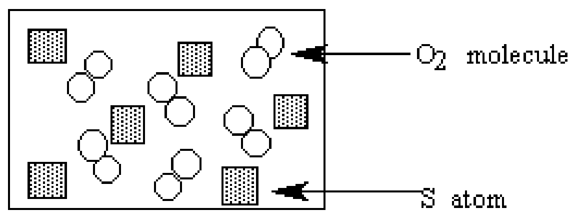
2. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?

   a. Air.
   b. Oxygen gas and hydrogen gas.
   c. Oxygen.
   d. Water vapor.
   e. Heat.

3. What is the approximate number of carbon atoms it would take placed next to each other to make a line that would cross this dot: ▪

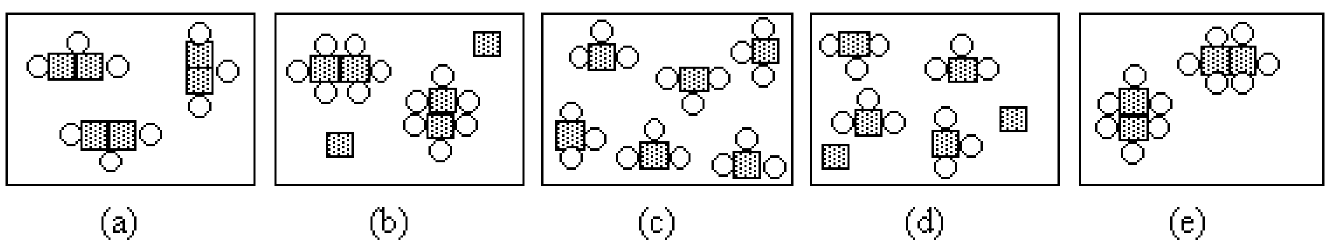
a. 4
b. 200
c. 30,000,000
d. 6.02×10^{23}

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

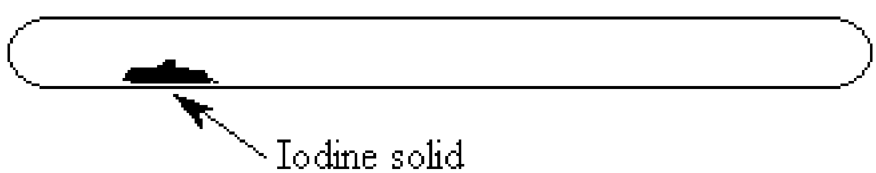


Which diagram shows the results after the mixture reacts as completely as possible according to the equation:

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



5. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27.0 grams.



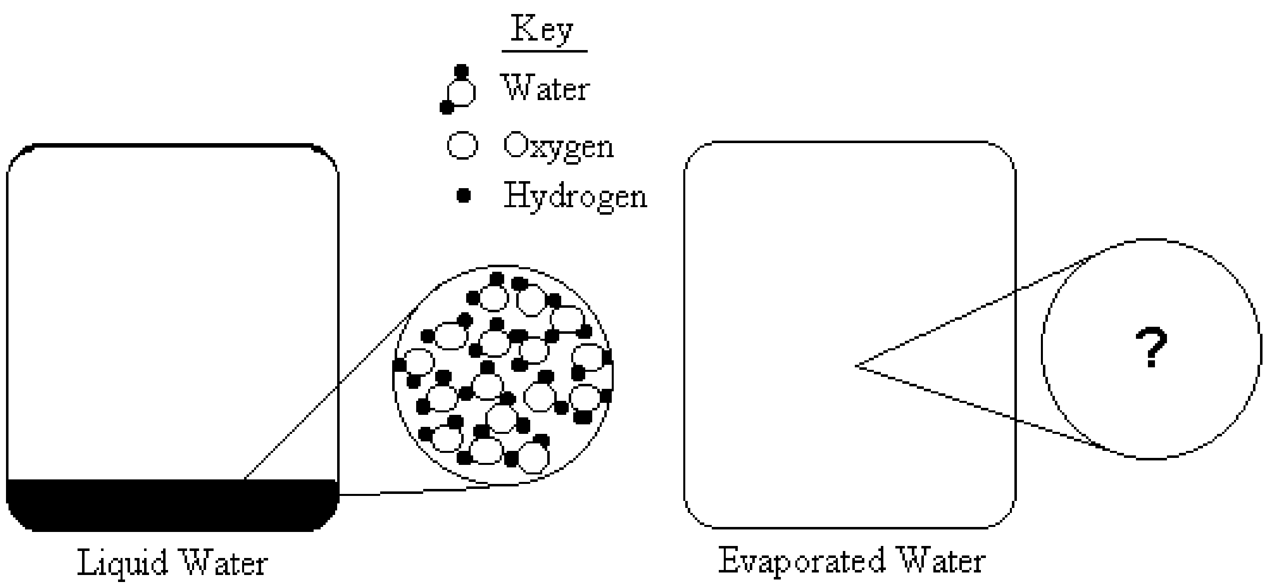
The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

a. less than 26.0 grams.
b. 26.0 grams.
c. 27.0 grams.
d. 28.0 grams.
e. more than 28.0 grams.

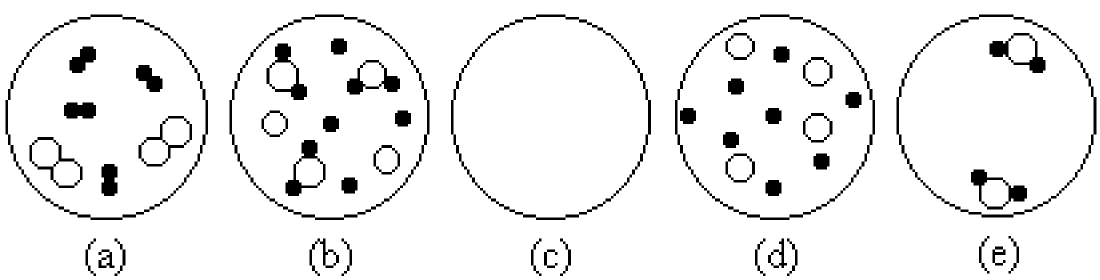
6. What is the reason for your answer to question 5?

a. A gas weighs less than a solid.
b. Mass is conserved.
c. Iodine gas is less dense than solid iodine.
d. Gasses rise.
e. Iodine gas is lighter than air.

7. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.



What would the magnified view show after the water evaporates?



8. Heat is given off when hydrogen burns in air according to the equation

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Which of the following is responsible for the heat?

a. Breaking hydrogen bonds gives off energy.
b. Breaking oxygen bonds gives off energy.
c. Forming hydrogen-oxygen bonds gives off energy.
d. Both (a) and (b) are responsible.
e. (a), (b), and (c) are responsible.

9. Figure 1 represents a 1.0 L solution of sugar dissolved in water. The dots in the magnification circle represent the sugar molecules. In order to simplify the diagram, the water molecules have not been shown.

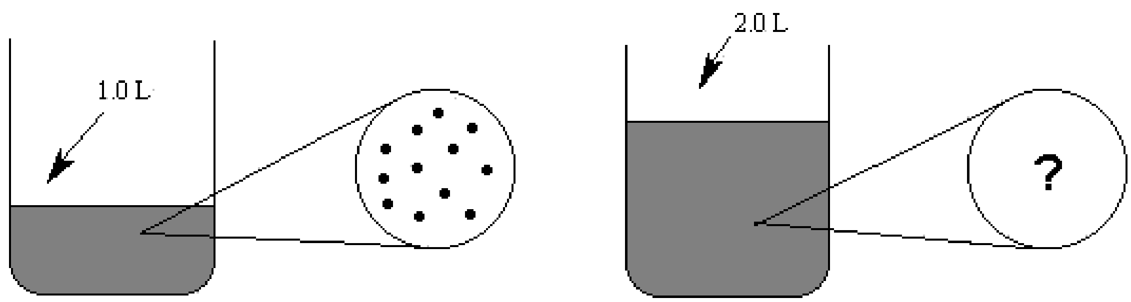
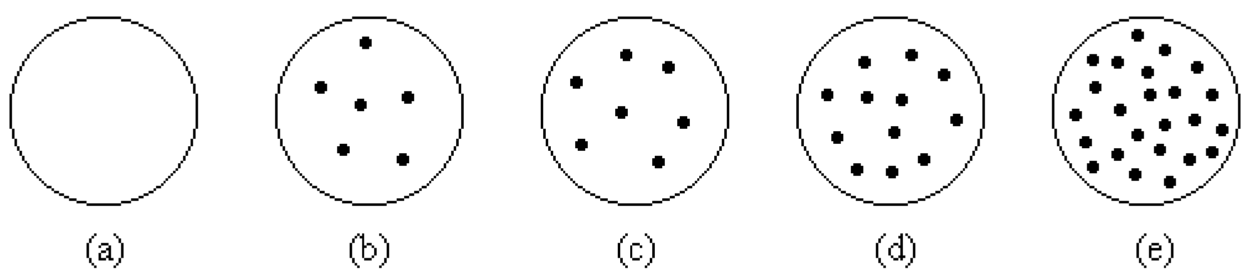


Figure 1 **Figure 2**

Which response represents the view after 1.0 L of water was added (Figure 2).



10. 100 mL of water at 25°C and 100 mL of alcohol at 25°C are both heated at the same rate under identical conditions. After 3 minutes the temperature of the alcohol is 50°C. Two minutes later the temperature of the water is 50°C. Which liquid received more heat as it warmed to 50°C?

a. The water.
b. The alcohol.
c. Both received the same amount of heat.
d. It is impossible to tell from the information given.

11. What is the reason for your answer to question 10?

a. Water has a higher boiling point then the alcohol.
b. Water takes longer to change its temperature than the alcohol.
c. Both increased their temperatures 25°C.
d. Alcohol has a lower density and vapor pressure.
e. Alcohol has a higher specific heat so it heats faster.

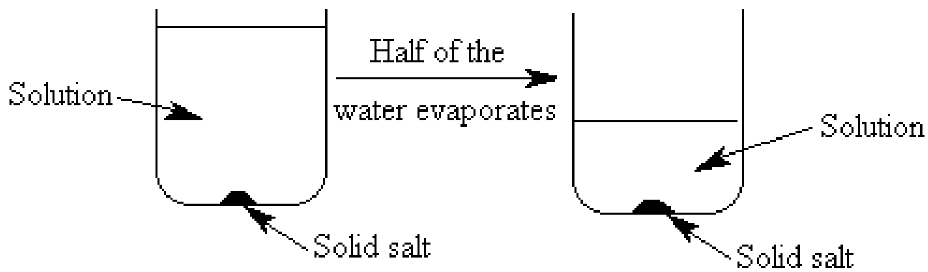
12. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

a. less than the nail it came from.
b. the same as the nail it came from.
c. more than the nail it came from.
d. It is impossible to predict.

13. What is the reason for your answer to question 12?

a. Rusting makes the nail lighter.
b. Rust contains iron and oxygen.
c. The nail flakes away.
d. The iron from the nail is destroyed.
e. The flaky rust weighs less than iron.

14. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if water evaporates until the volume of the solution is half the original volume? (Assume that the temperature of the solution remains constant.)



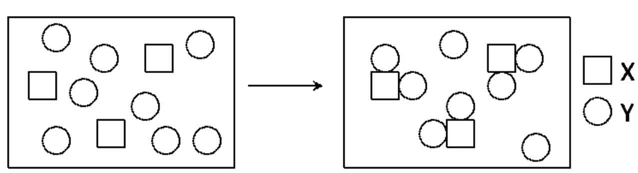
The concentration

a. increases.
b. decreases.
c. stays the same.

15. What is the reason for your answer to question 14?

a. There is the same amount of salt in less water.
b. More solid salt forms.
c. Salt does not evaporate and is left in solution.
d. There is less water.

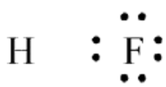
16. The reaction of element X with element Y is represented in the following diagram.

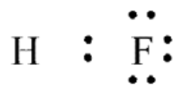


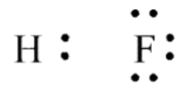
Which equation describes this reaction?

a. $3X + 8Y \rightarrow X_3Y_8$
b. $3X + 6Y \rightarrow X_3Y_8$
c. $X + 2Y \rightarrow XY_2$
d. $3X + 8Y \rightarrow 3XY_2 + 2Y$
e. $X + 4Y \rightarrow XY_2$

17. Hydrogen is a group 1 element, while fluorine is a group 7 element. Which of the following best represents the position of the shared electron pair in the HF molecule?

a. 

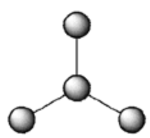
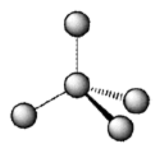
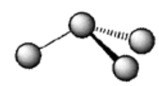
b. 

c. 

18. What is the reason for your answer to question 17?

a. Non-bonding electrons influence the position of the bonding or shared electron pair.
b. As hydrogen and fluorine form a covalent bond the electron pair must be centrally located.
c. Fluorine has a stronger attraction for the shared electron pair.
d. Fluorine is the larger of the two atoms and hence exerts greater control over the shared electron pair.

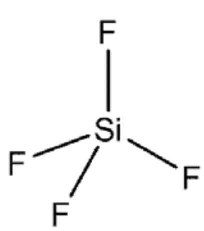
19. Nitrogen (a group 5 element) combines with bromine (a group 7 element) to form a molecule. This molecule is likely to have the following shape:

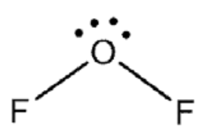
a. 
b. 
c. 

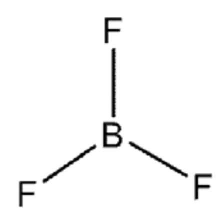
20. What is the reason for your answer to question 19?

a. Nitrogen forms three bonds which equally repel each other.
b. The arrangement of the bonding and non-bonding electron pairs around nitrogen results in the shape of the molecule.
c. The polarity of the nitrogen-bromine bonds determines the shape of the molecule.
d. The difference in electronegativity values for bromine and nitrogen determine the shape of the molecule.

21. Which of the following molecules is polar?

a. 

b. 

c. 

22. What is the reason for your answer to question 21?

a. The polarity of the molecule is due to the high electronegativity of fluorine.
b. Non-symmetrical molecules containing different atoms are polar.
c. Non-bonding electrons on an atom in the molecule produce a dipole and hence a polar molecule.
d. A large difference in the electronegativities of the atoms in bonding results in a polar molecule.

23. You add several ice cubes to a mug of hot tea. After ten minutes, you notice that half of the ice remains and the ice is no longer melting. The temperature of the tea now is

a. higher than the temperature of the ice.
b. lower than that of the ice.
c. the same as that of the ice.
d. It is impossible to tell.

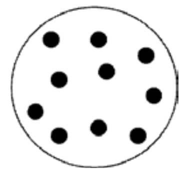
24. Water (H_2O) and hydrogen sulfide (H_2S) have similar chemical formulae and have V-shaped structures. At room temperature, water is a liquid and hydrogen sulfide a gas. The difference in state between water and hydrogen sulfide is due to:

a. Stronger intermolecular bonds between H_2O molecules than between H_2S molecules.
b. Stronger chemical (intramolecular) bonds between O and H than between S and H.
c. Slower moving H_2O molecules compared to H_2S molecules.

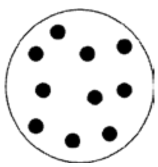
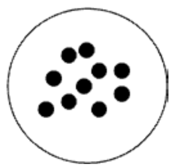
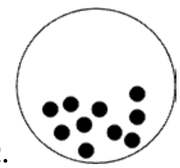
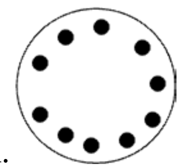
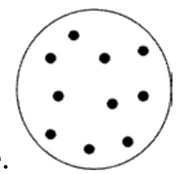
25. What is the reason for your answer to question 24?

a. The small particles in gases move faster than the small particles in liquids.
b. The bonds within each molecule of H_2S are easily broken, whereas those within H_2O molecules are not.
c. The two molecules have different polarities.
d. H_2O is a polar molecule, whereas H_2S is a non-polar molecule.

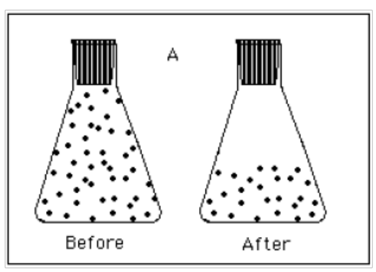
26. The following diagram represents a snapshot in time of a cross-sectional area of a steel tank filled with oxygen gas at room temperature. (The dots represent the distribution of oxygen molecules).

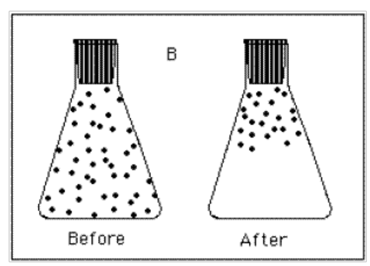


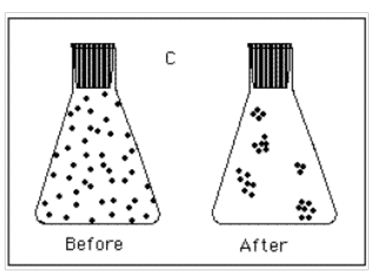
Which of the following diagrams illustrate a snapshot of the distribution of the contents of the steel tank if the temperature is lowered? (The oxygen remains in the gas phase).

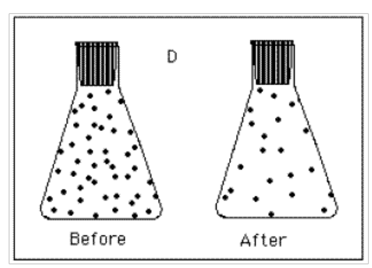
a.  b.  c.  d.  e. 

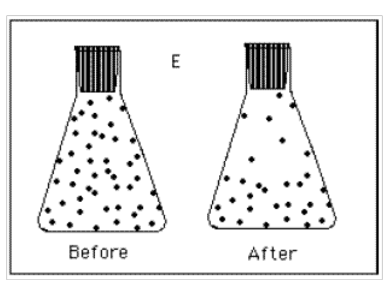
27. The following sets of drawings represent “snapshots” of a stoppered flask containing air particles before and after some of the particles were removed. Choose the best drawings of air before and after some was removed from the flask.



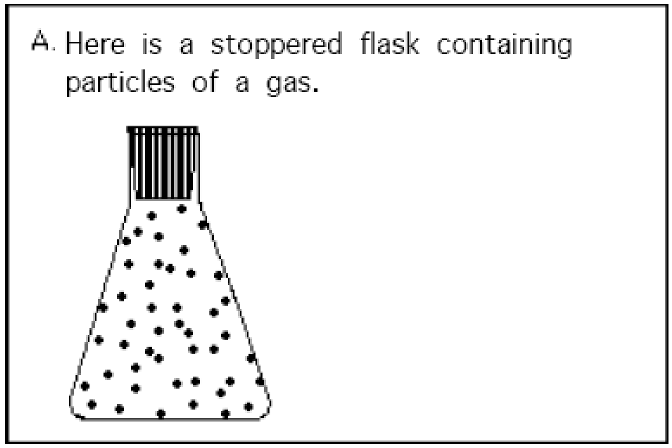








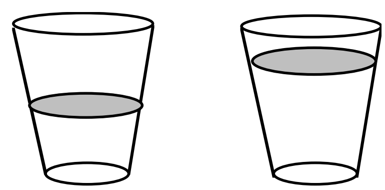
28. What is there between the particles inside the flask in figure A below?



a. Air
b. No material
c. Vapor
d. Oxygen
e. Pollutant

For questions 29 & 30 refer to the following:

You decide to share some sugar-sweetened fruit juice with your friend. You divide the fruit juice equally into two glasses. You then add an equal volume of water to Glass B.



Glass A Glass B

29. Which glass contains the sweeter tasting drink?

a. Glass A
b. Glass B
c. Glass A and Glass B contain drinks that are equally sweet.
d. There is not enough information to tell.

30. Which glass contains more sugar?

a. Glass A
b. Glass B
c. Both glasses contain equal amounts of sugar.
d. There is not enough information to tell.

Chemical Concepts Inventory: Answers

1. d (Note: Some instructors who teach that a change in internal energy reflects a change in mass prefer c)
2. d
3. c
4. d
5. c
6. b
7. e
8. c
9. b
10. a
11. b
12. c
13. b
14. c
15. b
16. c
17. a
18. c
19. c
20. b
21. b
22. b
23. c
24. a
25. c
26. a
27. d
28. b
29. a
30. c

APPENDIX C

MID-SEMESTER STUDENT EVALUATION OF THE USEFULNESS OF VISUALIZATION TOOLS

1) How has your attitude changed toward problem solving since using the worksheets handed out in lab?

2) Describe how your approach to solving problems has changed.

3) Do you feel that you have benefited from the use of the worksheets? Explain.

4) If you were to make a change to the handouts what would it be and why?

5) Do you feel like you are becoming more successful at solving problems? Explain.

6) Is there anything else that you feel would help you to become more successful in this class?

APPENDIX D

SEMESTER END ATTITUDES ABOUT TYPES OF PROBLEM SOLVING

Rank the methods you prefer to use for solving problems 1 = most preferred, 3 = least preferred.

___ using words (written form).

___ using pictures (pictorial representation).

___ using equations (mathematical form).

Use this space to briefly explain why.

Rank the following statements regarding your skill at solving problems 1 = good, 3 = poor.

___ solving problems in written form.

___ solving problems using pictorial form.

___ solving problems using equations.

Use this space to briefly explain why.

Rank the following in the order that you believe solves problems most accurately 1 = most accurately, 3 = least accurately.

___ using words (written form).

___ using pictures (pictorial representation).

___ using equations (mathematical form).

Use this space to briefly explain why.

Please rank your response 1 = most improved, 3 = least improved.

___ I believe that I have improved most when solving problems in written form.

___ I believe that I have improved most when solving problems using pictorial representation.

___ I believe that I have improved most when solving problems using equations.

Use this space to briefly explain why.

APPENDIX E

CHEMICAL REACTION RATE

Name: ____________________________________

Lab Section Number (circle one): 007 or 009

Reaction Rate:

Question 1. Consider a reaction where chemicals ‘A’ and ‘B’ react to form ‘C’

$$A + B \rightarrow C$$

Two students discuss the reaction:

Student 1: “The reaction rate is the rate of formation of ‘C’ and it is increasing with time.”

Student 2: “No, the rate of reaction shows the period of time that is required for a reaction to occur.”

Both students are having trouble defining the term ‘reaction rate’. Answer questions (a) and (b) below and help these students to correct their thinking on this topic.

a) Explain in your own words what you understand by the term ‘rate of reaction’.

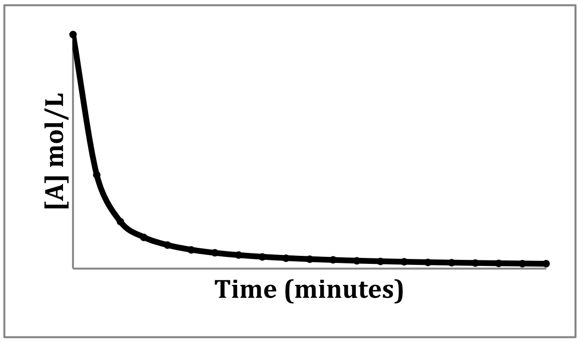
b) How does the rate of reaction change from the beginning until the end of the reaction? Please explain your answers as fully as you can.

Reaction Rate-Time:

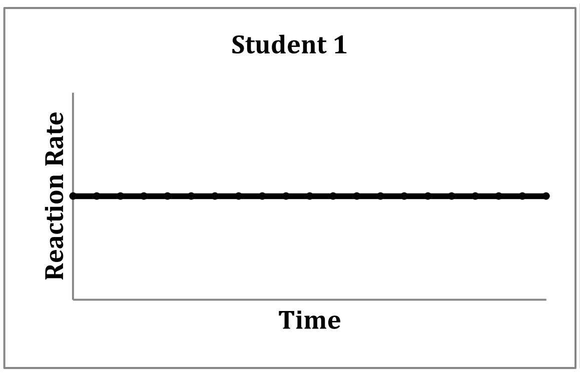
Question 2. Consider a reaction where two chemicals 'A' and 'B' react to form 'C'

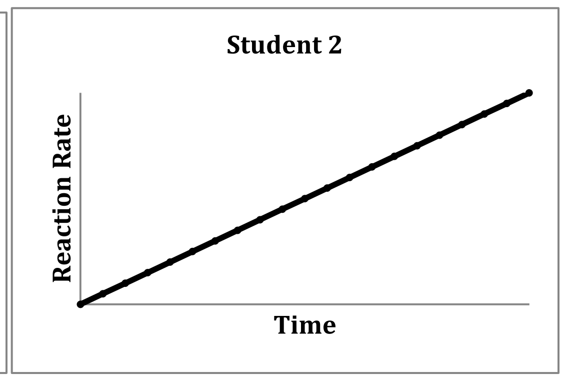
$$A_{(aq)} + B_{(aq)} \rightarrow C_{(aq)}$$

The graph below shows how the concentration of A changes with time.



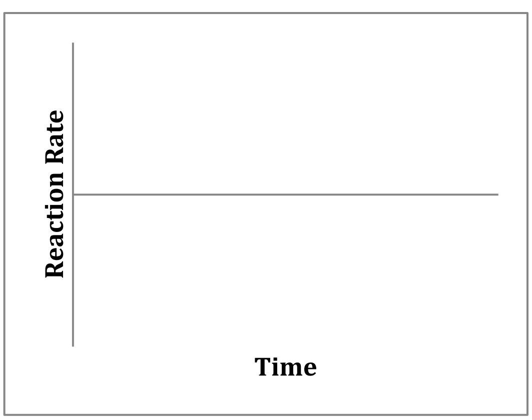
Two students use this information to draw graphs for the reaction rate against time.





a) What is your opinion? Make a drawing to show the rate of reaction against time.

b) What would you say to convince these students that your answer is correct? Use the space at the right of the graph and give as much detail as you can.



APPENDIX F

LECHATELIER’S PRINCIPLE WITH GRAPHS

Name: ___________________________________

Lab Section Number (circle one): 007 or 009

1. Consider the following reaction at equilibrium:

$$H_{2(g)} + I_{2(g)} \Leftrightarrow 2HI_{(g)}$$

Predict the ***direction of equilibrium shift*** by each of the following imposed changes:

a) Addition of more H_2 gas to the container will do what to the rate of the forward reaction?

left no change right

b) If, for a while, the rate of the *forward* reaction is ***greater than*** the rate of the *reverse* reaction, what will happen to the [HI]? left no change right

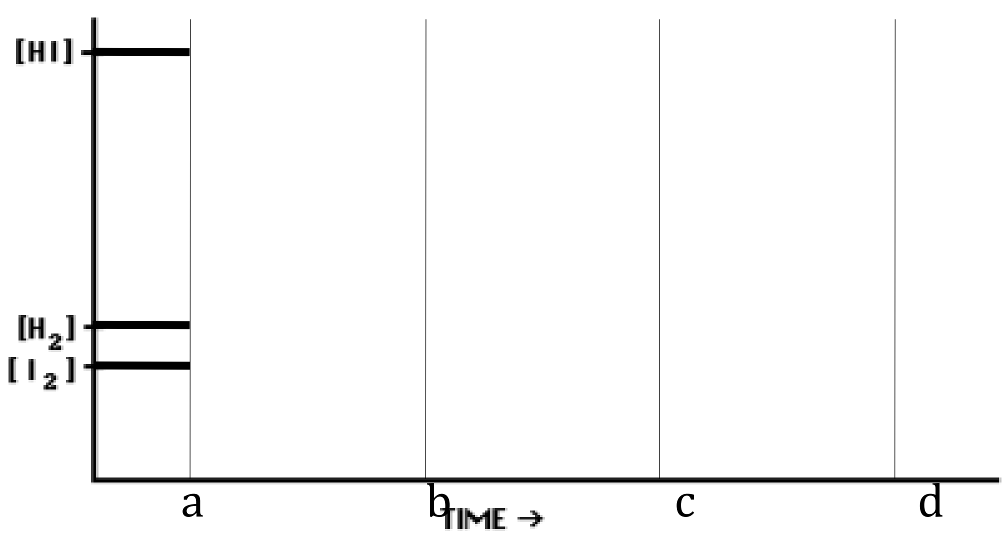
c) As the [HI] is increased, what will happen to the rate of the *reverse* reaction?

left no change right

d) When the rate of the *reverse* reaction once again becomes ***equal*** to the rate of the *forward* reaction, a new ________________________________ has been reached.

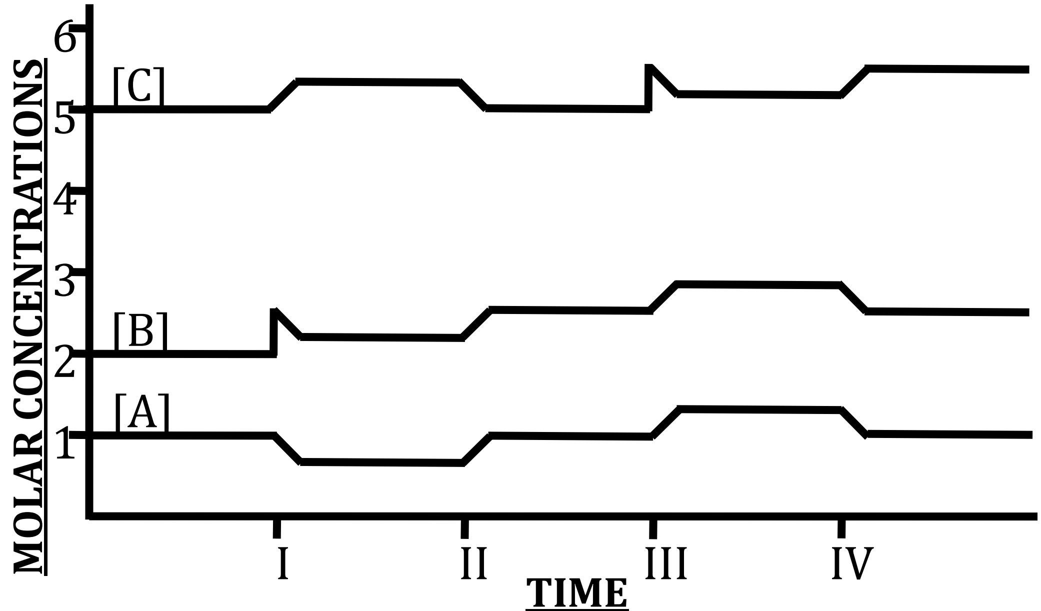
e) Since the rate of the *forward* reaction was, for a while (part b), greater than the rate of the *reverse* reaction, a new equilibrium will have slightly higher concentration(s) of ________________ and slightly lower concentration(s) of ________________.

Sketch a graph of the relative concentrations of each species as the process outlined in a-e of this question is carried out.



2. Given the following graph showing the concentrations of species A, B and C, state what changes in **temperature** or **concentration** are responsible for each of the shifts shown on the graph. The equilibrium equation is:

$$A_{(g)} + B_{(g)} \Leftrightarrow C_{(g)} \qquad \Delta H = -65\ kJ$$



a) At time I, the

____.

b) At time II, the

____.

c) At time III, the

____.

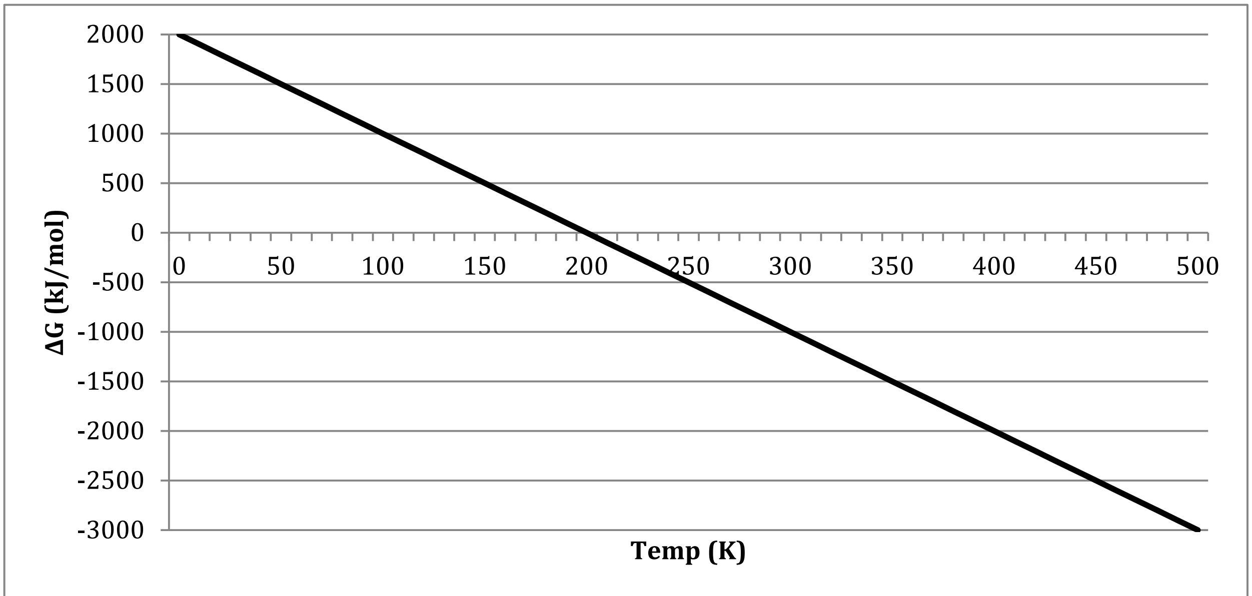
d) At time IV, the

____.

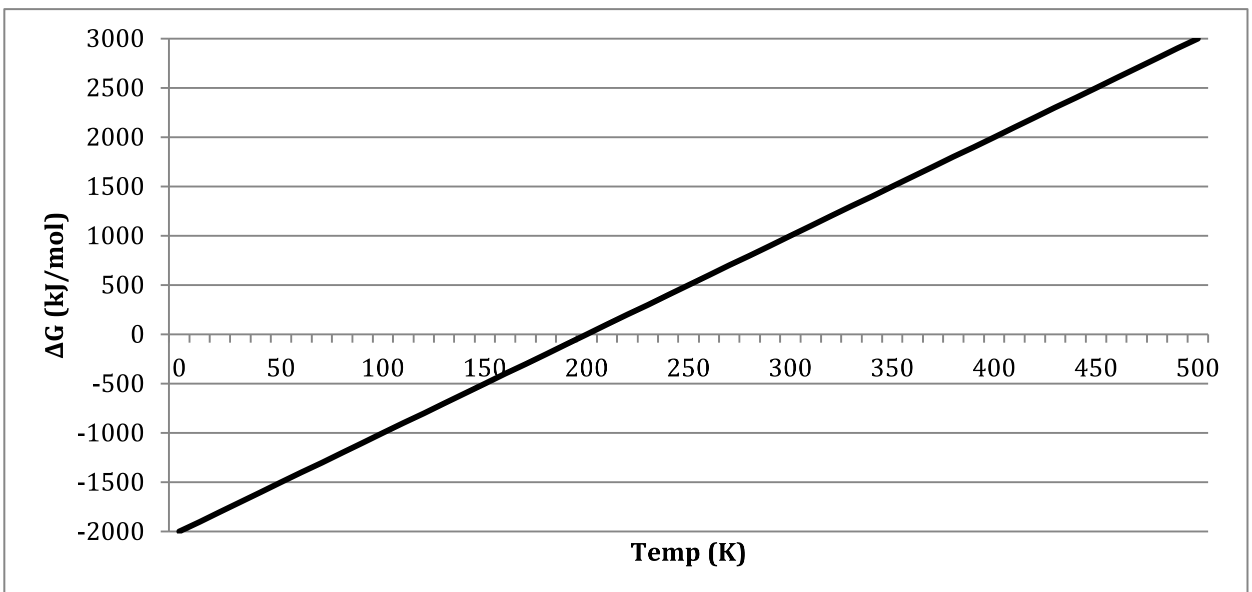
APPENDIX G

GIBBS FREE ENERGY, ENTHALPY & ENTROPY

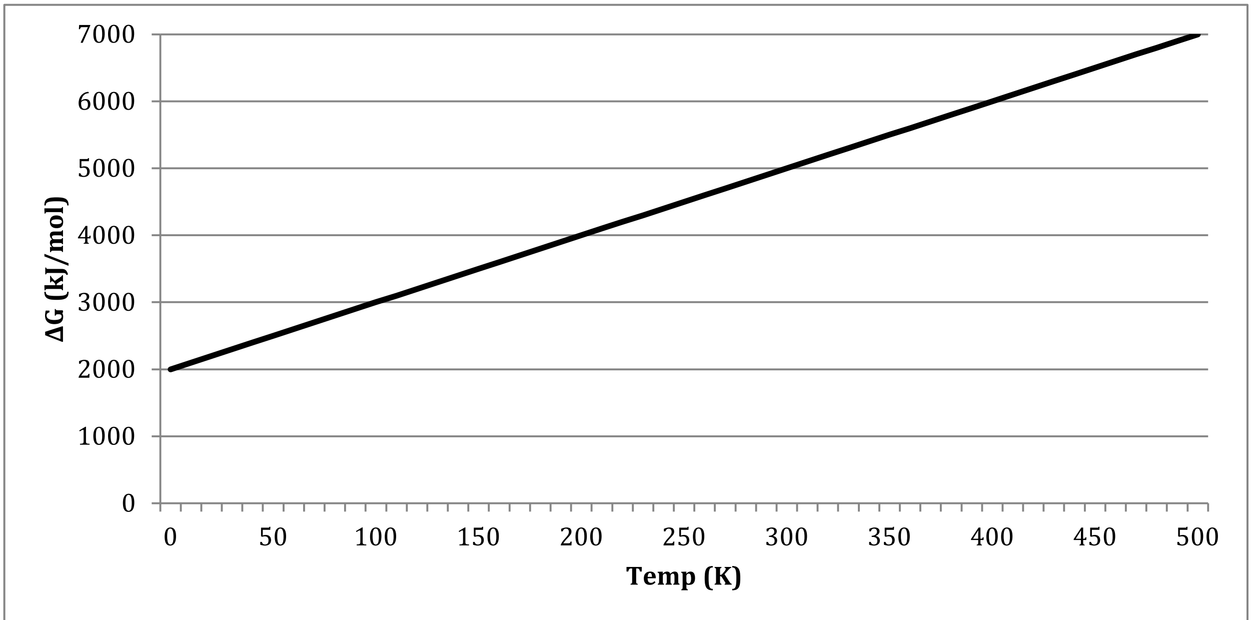
The following are graphs of ΔG vs. temperature for constant values of ΔH and ΔS. For each one, determine the signs indicated and the spontaneity.



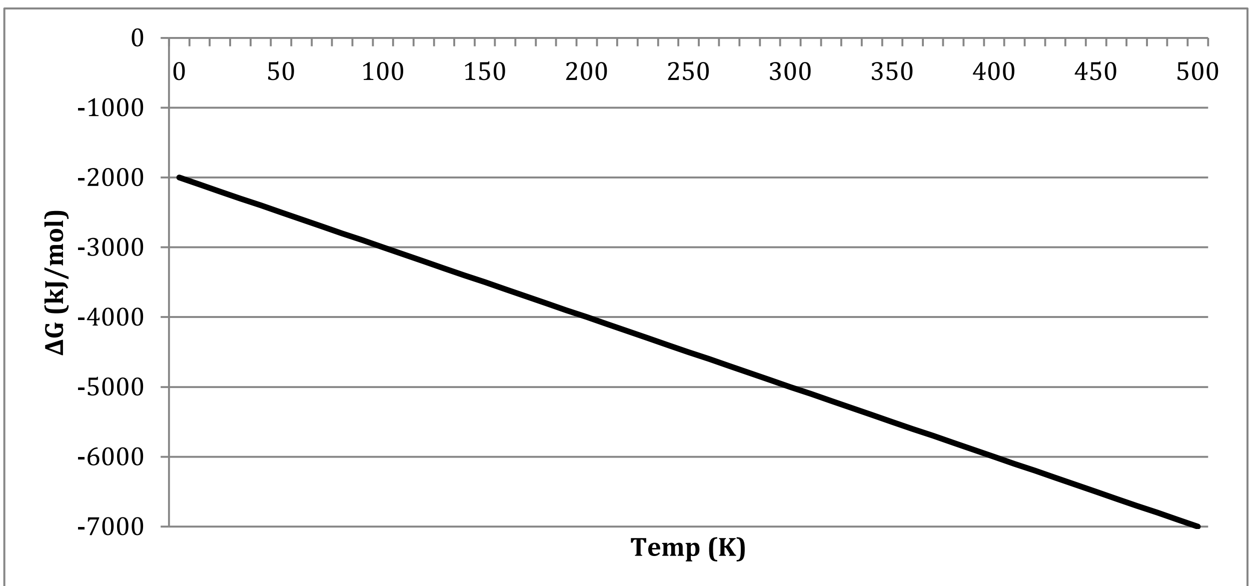
Sign of $\Delta H°$	Sign of $\Delta S°_{system}$	$\Delta_r G°$		Spontaneity
		Sign @ low T	Sign @ high T	
				never low T high T always



Sign of $\Delta H°$	Sign of $\Delta S°_{system}$	$\Delta_r G°$		Spontaneity
		Sign @ low T	Sign @ high T	
				never low T high T always



Sign of $\Delta H°$	Sign of $\Delta S°_{system}$	$\Delta_r G°$		Spontaneity
		Sign @ low T	Sign @ high T	
				never low T high T always



Sign of $\Delta H°$	Sign of $\Delta S°_{system}$	$\Delta_r G°$		Spontaneity
		Sign @ low T	Sign @ high T	
				never low T high T always

APPENDIX H

BALANCING REDOX REACTIONS

Name: ____

Lab Section Number (circle one): 007 or 009

Review the balancing processes in the PowerPoint that was sent to your email. Just looking at the slides may not be of much help since items on each slide have been added in a chronological order.

Balance the following reactions:
Reactions in Acid:

Balance the following reactions in acid.

$$Na_2C_2O_4 + \quad MnO_4^- \Rightarrow \quad CO_2 + \quad Mn^{2+} + \quad Na^+$$

$$Sn^{2+} + \quad IO_3^- \Rightarrow \quad Sn^{4+} + \quad I^-$$

Reactions in base:

Balance the following reactions in a base.

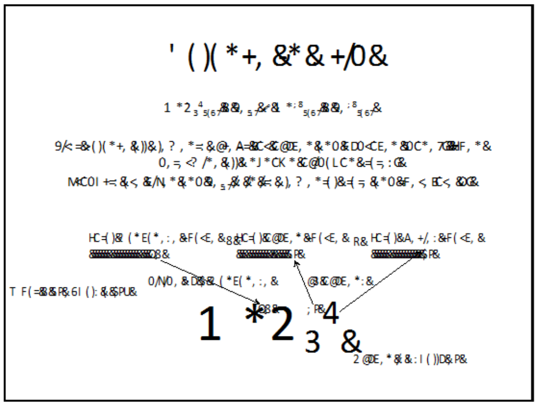
$$Cu(NH_3)_4^{2+} + S_2O_4^{2-} \Rightarrow SO_3^{2-} + Cu + NH_3$$

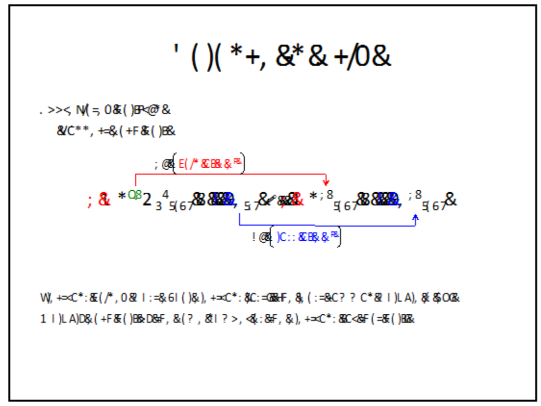
$$Zn + NO_3^{-} \Rightarrow Zn(OH)_4^{2-} + NH_3$$

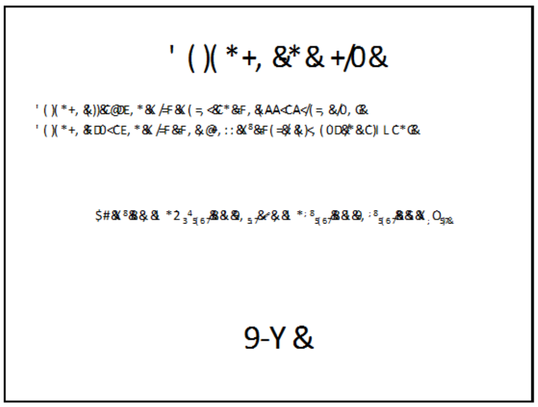
Did you find the method outlined in the PowerPoint helpful? Please briefly explain why or why not.

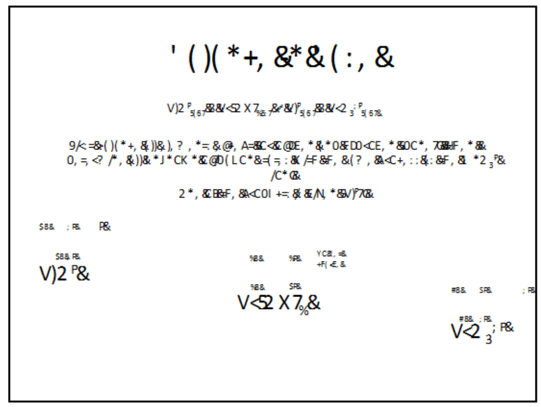
APPENDIX I

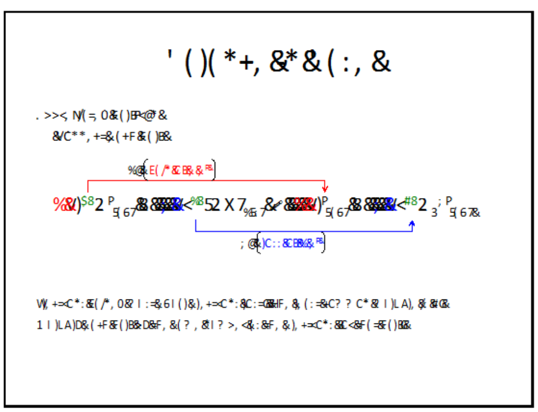
BALANCING REDOX REACTIONS POWERPOINT SLIDES

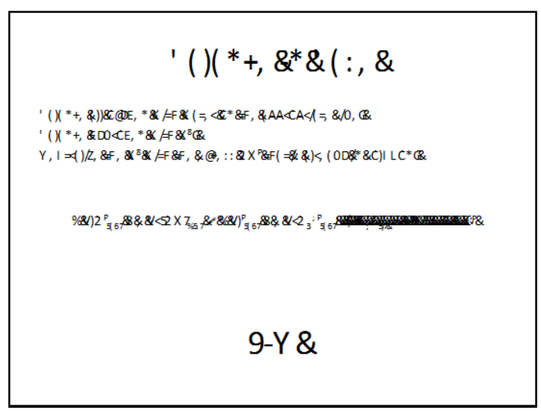






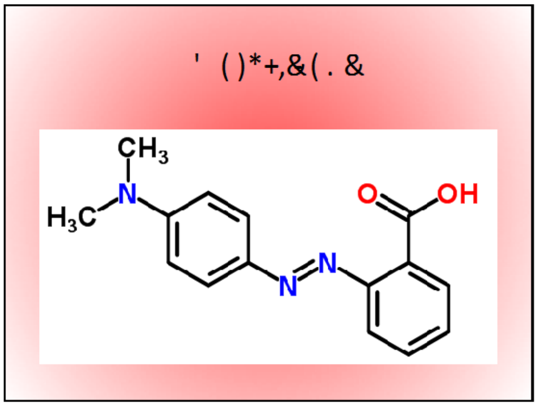


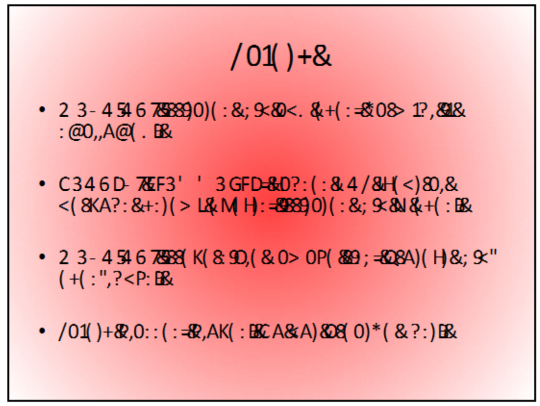


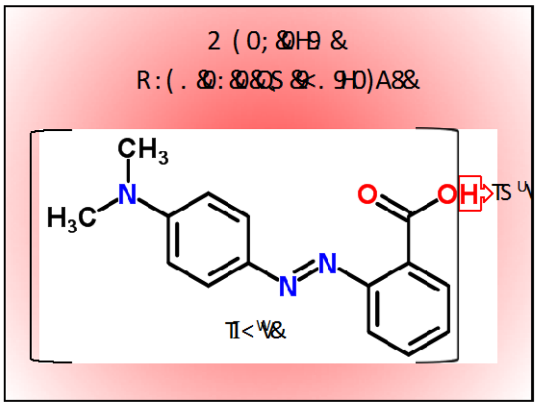


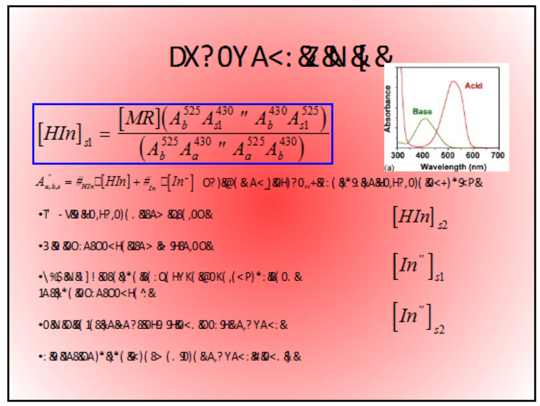
APPENDIX J

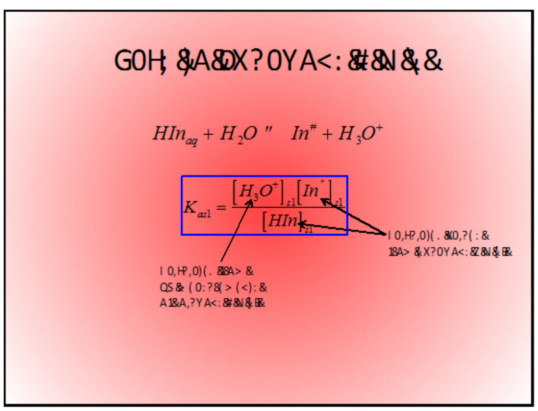
EXAMPLE OF LABORATORY POWERPOINT PRESENTATION


CH3
N
H3C
O
OH
N
N

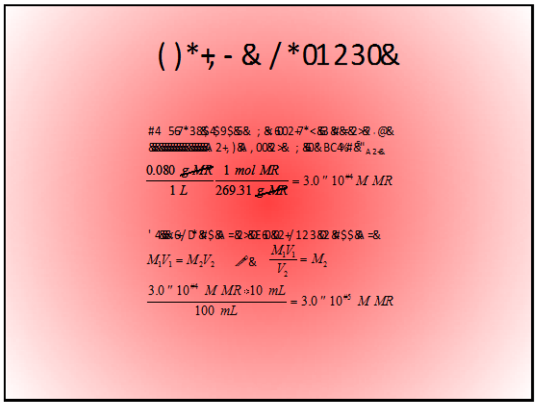


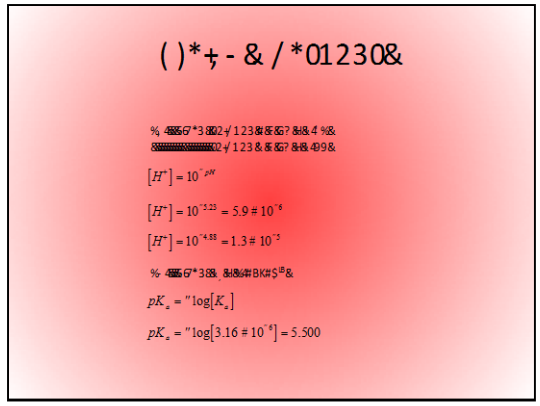

CH3
N
H3C
O
OH
N
N


$[HIn]_{s1} = \frac{[MR](A_b^{525}A_{s1}^{430} - A_b^{430}A_{s1}^{525})}{(A_b^{525}A_a^{430} - A_a^{525}A_b^{430})}$
Acid
Base
Absorbance
300
400
500
600
700
(a)
Wavelength (nm)
$[HIn]_{s2}$
$[In^-]_{s1}$
$[In^-]_{s2}$


$HIn_{aq} + H_2O \rightleftharpoons In^- + H_3O^+$
$K_{as1} = \frac{[H_3O^+]_{s1}[In^-]_{s1}}{[HIn]_{s1}}$


Methyl red indicator color
below pH 4.4
between pH 4.4 & 6.2
above pH 6.2
H3C
N
CH3
N
N
COOH


$\frac{0.080\ \cancel{g\ MR}}{1\ L}\ \frac{1\ mol\ MR}{269.31\ \cancel{g\ MR}} = 3.0 \times 10^{-4}\ M\ MR$
$M_1V_1 = M_2V_2$ $\frac{M_1V_1}{V_2} = M_2$
$\frac{3.0 \times 10^{-4}\ M\ MR \cdot 10\ mL}{100\ mL} = 3.0 \times 10^{-5}\ M\ MR$


$[H^+] = 10^{-pH}$
$[H^+] = 10^{-5.23} = 5.9 \times 10^{-6}$
$[H^+] = 10^{-4.88} = 1.3 \times 10^{-5}$
$pK_a = -\log[K_a]$
$pK_a = -\log[3.16 \times 10^{-6}] = 5.500$