THE EFFECT OF COMPUTER SIMULATIONS ON THE CONCEPTUAL UNDERSTANDING IN GENERAL CHEMISTRY LAB

by

Stephen David Mohr

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In presenting this professional paper in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the MSSE Program shall make it available to borrowers under rules of the program.

Stephen David Mohr

July 2014

DEDICATION

I dedicate this paper to my wife Lynne who has been very supportive and encouraging through this whole process and has given me the best gift in the world, our two beautiful daughters Joy Lyric and Quinn Skylar.

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ABSTRACT

Computer simulations provide an interactive and visual environment that promote and support conceptual change in chemistry education. They are tools that enable students to become actively engaged in their learning and encourage concept exploration and assist in developing their inquiry skills. It is through the implementation of a series of inquiry based student activities that these simulations will be evaluated for their effectiveness in improving conceptual understanding. The results of this study revealed that traditional instruction supplemented with computer simulations helped students perform better on short term conceptual assessments. The use of computer simulations improved student achievement and had a positive influence on student's attitudes to learning conceptual chemistry concepts.

INTRODUCTION AND BACKGROUND

For the last four years I have been teaching General Chemistry class at Jackson-Milton High School in North Jackson, Ohio about 17 miles west of Youngstown, Ohio. As a science teacher at the high school level, I have found that my students in my General Chemistry classes appear to have a limited ability to apply conceptual concepts learned in class to lab settings and vice versa. I suspect that this is a result of students lacking the skills needed to perform the required lab along with their being anxious about manipulating lab equipment. I want all students to be able to apply the concepts they learn in their assignments and to have low anxiety in performing lab. To accomplish this, I looked at the effectiveness of computer based simulated labs in a Chemistry class. In regards to Ohio's New Learning Standards state mandates I looked to improve student learning and understanding of concepts in the areas of electrical configuration, chemical bonding and molecular structure.

School Demographics

Jackson-Milton High school is a rural school district of about three hundred students in ninth through twelfth grade coming mostly from the communities of North Jackson and Lake Milton; there are a few students that do come in on open enrollment from other surrounding communities. The community population for the school is approximately 5600 people. The school diversity is 99% White and 1% Black; about 63% of our students are on free or reduced lunch program and a high percentage come from single parent homes. Our special education student population is 17% of our students. On the last (2013) Ohio State School Report Card the high school achieved a rating of “B”.

Focus Questions

This action research study required the study of two groups. I compared my two General Chemistry classes. One class did only the traditional hands-on laboratory investigations, while the other class did a computer simulated laboratory activity before the hands on version. I focused on the following questions:

- What are the effects of computer simulations on students’ conceptual understanding of electron configuration, chemical bonding and molecular structure?
- How do computer simulations influence student attitudes towards active inquiry and problem solving in Chemistry?

CONCEPTUAL FRAMEWORK

The use of computer simulations is changing the very nature of scientific investigation (Casti, 1998) and providing unique insights into the way the world works (Wolfram, 2002). In an effort to engage students in the authentic making of science, many science educators have begun using models and simulations in classrooms as well (Feurzeig & Roberts, 1999; Friedman & diSessa, 1999). Past studies provide lots of empirical evidence that people learn from simulations, and that simulations therefore have great teaching value. For example, NASA's training puts astronauts through simulated events before missions. Our military and police forces use simulation training to develop ways to clear a building during combat situations. Airlines and even our military have pilots go directly from many hours in a simulator to the cockpit of an airplane. Medical students can learn the physical relationships of body parts and how systems work together and then have progressed from learning on cadavers to working with onscreen simulators (Prensky, 2007**)**. So, if a prospective doctor can learn about a complex piece of anatomy or a difficult procedure from a simulator as do our top airline pilots, certainly high school students can learn in the same manor. Students can now experiment in a virtual world of complex, dynamic systems in a way that was impossible just years ago.

To be effective in today's world, science needs to focus on how scientists do real science according to the 1996 National science education standards The Ohio State Board of Education has adopted the more rigorous Ohio Revised Science Content Standards as part of Ohio's New 2015 Learning Standards for academic learning that list the following demands for scientific inquiry:

- Design and conduct scientific investigations
- Use technology and mathematics to improve investigations and communications
- Formulate and revise explanations and models using logic and evidence
- Recognize and analyze explanations and models

As a result of these state mandates teachers are looking to improve student learning and understanding of concepts. One method to improve student learning and understanding of concepts is through the use of computer simulations as outlined in the article *Examining the combination of physical and virtual experiments in inquiry science classroom* (Smith, & Puntambekar 2011). This investigation was done with pulley systems in the simple machine curriculum of a sixth grade middle school setting. The study was designed to look at two different groups of students; ones doing a physical "hands-on" lab then a virtual lab experiment, and the other group did a virtual lab experiment than the physical "hands-on" lab, the main goal was to see what sequence was the most effective. The authors concluded that the sequences of the lab experience were very important. Students who conducted the virtual lab after performing the physical "hands-on" lab outperformed those who conducted it in reverse order. Furthermore the results also suggested that combining of physical virtual activities can improve conceptual understanding and the sequence can have important effects on learning.

Research has shown that computer-based manipulatives are even more effective than ones involving physical objects. Some of the reasons for this increased effectiveness are outlined in pages 270-279 of Clements & McMillen (1996):

- *Computer manipulatives link the concrete and the symbolic by means of feedback.*

  For example, a major advantage of the computer is the ability to associate active experience with manipulatives to symbolic representations. The computer connects manipulatives that students make, move, and change with numbers and words. Many students fail to relate their actions on manipulatives with the notation system used to describe these actions. The computer links the two.
- *Computer manipulatives dynamically link multiple representations*. Such computer links can help students connect many types of representations,

such as pictures, tables, graphs, and equations…[allowing] students to see immediately the changes in a graph as they change data in a table. These links can also be dynamic. Students might stretch a computer geoboard's rectangle and see the measures of the sides, perimeter, and area change with their actions.

- *Computers change the very nature of the manipulative*. Students can do things [using computer-based manipulatives] that they cannot do with physical manipulatives.

Computer simulations make these types of interactive, authentic, meaningful learning opportunities possible. Learners can observe, explore, recreate, and receive immediate feedback about real objects, phenomena, and processes that would otherwise be too complex, time-consuming, or dangerous (Bell and Smetana, 2008). Broadly defined, computer simulations are computer-generated dynamic models that present theoretical or simplified models of real-world components, phenomena, or processes. They can include animations, visualizations, and interactive laboratory experiences.

Geelen and Mukherjee (2011) looked at the use of visualizations (i.e. animations, short moving gifs, etc) in the classroom. The study was conducted in physics and chemistry classes, using internet based visualizations in the areas of Le Chatelier’s Principles, Intermolecular Forces and Thermochemistry, and a class setting that used no visualizations. Students’ learning was measured using a pre and post chemistry conceptual inventory test (CCI) but the results were inconclusive. The only significant difference was on the performance of male to females, males did better after the use of visualizations than did females. An additional finding was that with visualizations there was an increase in students' enjoyment of learning and engagement with science.

Tatli and Ayas (2012) carried out their study in a 9th grade chemistry class by examining both the instructional techniques used by the teacher along with the students' use of Virtual Chemistry Lab (VCL) in order to determine the impact on student learning. The results of the study showed that VCL software was as effective as the "hands-on" approach and it positively affected the constructivist learning environment by allowing students to freely interact with their virtual environment. It showed that the virtual laboratory aided in creating a constructivist learning environment. A constructivist learning environment is created when students' actively construct their knowledge by thinking, doing, and interacting with their environment. Tatli and Ayas also found that students who did the virtual chemistry labs performed the labs as precisely as the "hands-on" approach; they felt safe during the experiment; and could readily relate the virtual experiments to something that they would do in daily life. With virtual labs being flexible and easy to change; it allowed abstract concepts to become more concrete, students' daily experiences can become experiments, and students have the ability to move at their own pace and needs. With the flexibility of the virtual world, interactions between instructor and learner become independent of time and place making it relevant in the real world (Tatli & Ayas, 2012).

Computer simulations can be used in conjunction with hands-on labs and activities that also address the concepts targeted by the simulation to support student learning. Simulations should not be used as a sole replacement for labs in the classroom as found by the study done by Bell and Smetana (2008). This study found that simulations used in isolation were ineffective when proceeding to a hands-on activity. A simulation may familiarize students with a concept under a focused environment. Bell and Smetana (2008) suggest that lessons involving computer simulations should remain student-centered and inquiry-based to ensure that learning is focused on meaningful understandings, not rote memorization. Simulations are often simplified models of reality. Therefore, it is necessary for students to accept the simulated environment as an intelligible and plausible representation of reality. In addition, it is critical that students realize the differences between the simulation and reality. Without understanding a model's limitations, students may form misconceptions.

In their study on learning with computer simulations, Eckhardt et al (2012) tested and measured the factual, conceptual and procedure knowledge attained by students by means of pretest and post-test assessments along with homework in a predict-observe-explain format. Eckhardt et al (2012) stated that it is important to be able to look at how the previous procedural knowledge on how to do laboratory investigations effects the student ability to perform both the physical and virtual labs.

My review and analysis of the literature revealed many studies that showed the usefulness of computers in science education as an interactive communication tool allowing access to all kinds of information; as a tool for problem solving; as an apparatus for carrying out simulations of chemical phenomena and experiments; and as a tool to measure and monitor laboratory experiments. While some of the more recent research studies focus on evaluations of the effectiveness of scientific visualizations for learning concepts, a number of studies relate more to students' self-reports of their enjoyment and engagement when using visualizations.

METHODOLOGY

In order to determine the affect of computer simulations on student achievement and conceptual understanding, I have collected both qualitative and quantitative data from a variety of sources. Several articles I have reviewed detailed the use of pretest and post-test assessments. Both Basaraba (2012) and, Zacharia & Anderson (2003), used pre and post-assessments to compare student learning. They also did student interviews to judge students attitudes towards their respective science classes as well as student attitudes/feelings towards their experience with the simulations. I have used a similar approach.

Traditionally my students have been taught concepts of electron configuration, ionic and covalent bonding and molecular structure with the teacher researcher providing conceptual examples and problem solving techniques in a lecture-based instructional model and the students doing hands on labs to reinforce them. The main goals of this study were to supplement the hands on approach to inquiry activities using computer simulations in order to evaluate the use of these simulations on student conceptual understanding, as well as their attitude toward lab and chemistry class.

In this action research study I compared my two General Chemistry classes, consisting of a total of thirty- one eleventh-grade students and two twelfth grade students. The student population included thirty-two Caucasian students and one Filipino student; four students out of the thirty-three were on free and reduced lunch program. The classes were a period apart from one another and shared a common lab period between them I saw one class during lab period while the other class was in a study hall with another teacher.

This intervention lasted ten weeks in early January to mid March. I had to extend the time period due to the weather. We covered the units of electron configuration, chemical bonding, and molecular shapes. In order to verify whether these two groups were comparable a common non-intervention exam focused on skills necessary for success in Chemistry developed by the American Chemical Society in 2011 called the CCI (Conceptual Chemistry Inventory) was given (Appendix A). 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.

Comparison Group

The first class period as the control group in the study had seventeen students with eleven males and six females, sixteen were in eleventh grade and one in twelfth grade. This class did not use computer simulated laboratory activities and performed only traditional hands-on labs.

Treatment Group

The second chemistry class had sixteen students with eight males and eight females, fifteen were in eleventh grade and one in twelfth grade. They completed computer simulated laboratory activities before performing traditional hands-on laboratory activities. The treatment group used simulated laboratory activities found on

Explorelearning.com, including the following laboratory activities found in appendix B: Electron Configuration, Ionic Bonds, and Covalent Bonds along with one found at the PhET group website Building and Naming Compounds. They performed each activity during their respective scheduled laboratory period; on the next scheduled laboratory period they completed a hands-on version laboratory activity that was the same as the non-treatment class. Student interviews (Appendix C) were conducted after the completion of each simulation to determine their attitudes towards and evaluate the effectiveness of the simulations.

At the end of each laboratory period both classes completed a five question exit slip (example in appendix D) on the concepts covered in the laboratory activity. The day after each hands-on laboratory activity was completed, to gauge its effectiveness on learning the concepts covered in the unit, a multiple choice with one extended response question conceptual quiz was given (example in appendix E). At the end of the each unit on electrons and bonding a multiple choice exam (example in appendix F) with a few extended response type questions was given and another exam was given after the molecular structure unit. My data collection is summarized in Table 1.

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: 1. What are the effects of computer simulations on students' conceptual understanding of Chemical Bonding and Molecular Structure?	Common quiz assessments (Chem 2nd Period compared to Chem 4th Period)	Common summative unit assessment (Chem 2nd Period compared to Chem 4th Period)	Interviews
Secondary Questions: 2. How do computer simulations influence student attitudes towards active inquiry and problem solving in Chemistry	Interviews/Surveys		

DATA AND ANALYSIS

In order to determine the effect that computer simulations had on student achievement, conceptual understanding, and student attitudes towards chemistry this study collected qualitative and quantitative data from a variety of sources. These sources included pre and post treatment student surveys, summative quizzes and summative exams scores. The data sets were collected from two general chemistry classes. One class, the comparison class was taught traditionally through lecture and traditional hands-on labs. The second, treatment class, was also taught through lecture and traditional hands-on labs but completed computer laboratory activities before they did a traditional hands-on lab. In total there were thirty-three participants in this study. The researcher determined the statistical significance using the statistical analysis software R to conduct *t* tests, and to measure variability and tendencies.

CCI Pretest for Comparison

In order to determine that the two chemistry classes comparable and similar, a common exam developed by the American Chemical Society in 2011 called the CCI (Conceptual Chemistry Inventory) was given the week before the use of computer simulations began by the treatment group. The comparison group had a Mean score of 44.41% and a Standard Deviation of 16.67. The treatment group had a Mean score of 43.65% and a Standard Deviation of 13.61. The difference between the two groups was not significant $t(33) = 0.1465$, $p = 0.8845$. It can be concluded that these two groups were comparable when determining the effect of computer simulations.

Impact of Computer Simulations on Student Learning

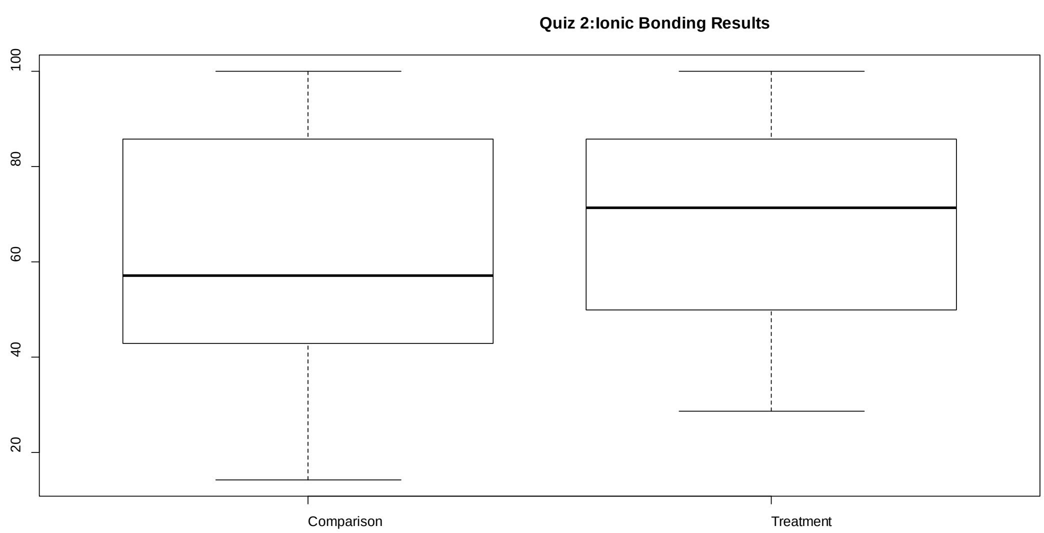
I compared the treatment and comparison group scores on four quizzes. These quizzes were completed the day after each hands-on lab was performed. The quizzes can be found in the appendices and include:

- Lab 1: Student Exploration: Electron Configuration
- Lab 2: Student Exploration: Ionic Bonds
- Lab 3: Student Exploration: Covalent Bonds
- Lab 4: Building and Naming Compounds

I also compared the results on two exams taken by the treatment and comparison groups after instruction.

The first quiz focused on electron configuration. The treatment class used a computer simulation found on explorelearning.com before completing the same hands on lab as the comparison group on, in example, The Chemistry of Fireworks. The comparison group had a Mean score of 65.06% and a Standard Deviation of 16.39. The treatment group had a Mean score of 77.68% and a Standard Deviation of 15.62. The difference between these two groups was statistically significant, $t(33) = -2.2959$, $p = 0.02842$.

The next set of data analysis concerned the concepts of ionic bonding. The comparison group had a Mean score of 57.98% and a Standard Deviation of 25.49. The treatment group had a Mean score of 68.75% and a Standard Deviation of 22.86. The difference between these two groups was not statistically significant, $t(33) = -1.2787$, $p = 0.2105$. With the data shown in *Figure 1* when plotted in a Box and Whisker format on can see, there is clearly a difference in the range of scores and in the median.



Fig

Figure 1. Box-and-Whisker Plot of Quiz #2 Ionic Bonding of comparison and treatment group. Boxes represent the inter-quartile range (25th to 75th percentile), and whiskers indicate the minimum and maximum values. The statistical median is represented by the dark black line in the box, (*N*=33).

The third laboratory and quiz focused on covalent bonds. The treatment class completed a computer simulation found on explorelearning.com on covalent bonds before completing the same hands on lab as the comparison group on comparing ionic and covalent compounds. The comparison group had a Mean score of 47.90% and a Standard Deviation of 25.72. The treatment group had a Mean score of 69.64% and a Standard Deviation of 20.12. The difference between these two groups was statistically significant, $t(33) = -2.7134$, p= 0.01092.

The final laboratory and quiz focused on molecular shapes. The treatment class used a computer simulation PhET group website Building and Naming Compounds. The quiz was of four multiple choice questions with two extended response on identifying the polarity of molecules and drawing the Lewis structure of a compound. The comparison group had a Mean score of 65.06% and a Standard Deviation of 16.39. The treatment group had a Mean score of 77.68% and a Standard Deviation of 15.62. The difference between these two groups was statistically significant, $t(33)= -2.2959$, p = 0.02842.

I compared the results of the two summative exams that both the comparison and treatment groups took at the end of the units on electron configuration and bonding and then with molecular shapes.

On summative exam one, the comparison group had a Mean score of 80.20% with a Standard Deviation of 14.30. The treatment group had a Mean score of 85.01% with a Standard Deviation of 11.69. The difference between the two groups on exam one were not statistically different $t(33)= = 1.0613$, p = 0.2969. *Figure 2* shows summative exam one results plotted in a Box and Whisker format demonstrating that on can see there is a difference in the range of scores was smaller and the biggest difference was in the lowest and highest scores were higher between the two groups.

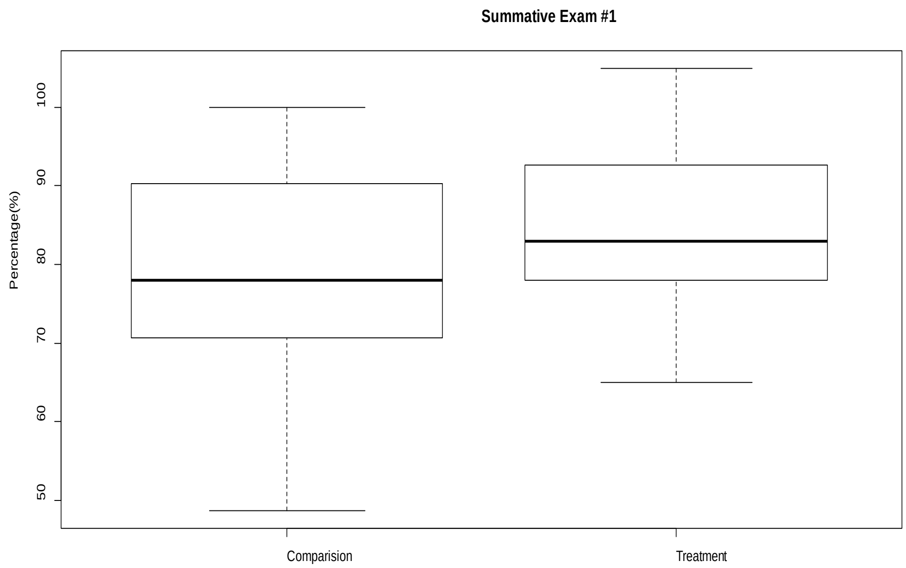


Figure 2: Box-and-Whisker Plot of Summative Exam #1of comparison and treatment group. Boxes represent the inter-quartile range (25th to 75th percentile), and whiskers indicate the minimum and maximum values. The statistical median is represented by the dark black line in the box, (*N*=33).

On summative exam two, the comparison group had a Mean score of 69.80% and a Standard Deviation of 19.75. The treatment group had a Mean score of 72.59% and Standard Deviation of 12.56. The difference between the two groups on summative exam two, was not statistically different *t*(33) t = -0.4849, p-value = 0.6316. In *Figure 3*, shows summative exam one results plotted in a Box and Whisker format demonstrating clearly there is a difference in the range of scores and in the median between the two groups.

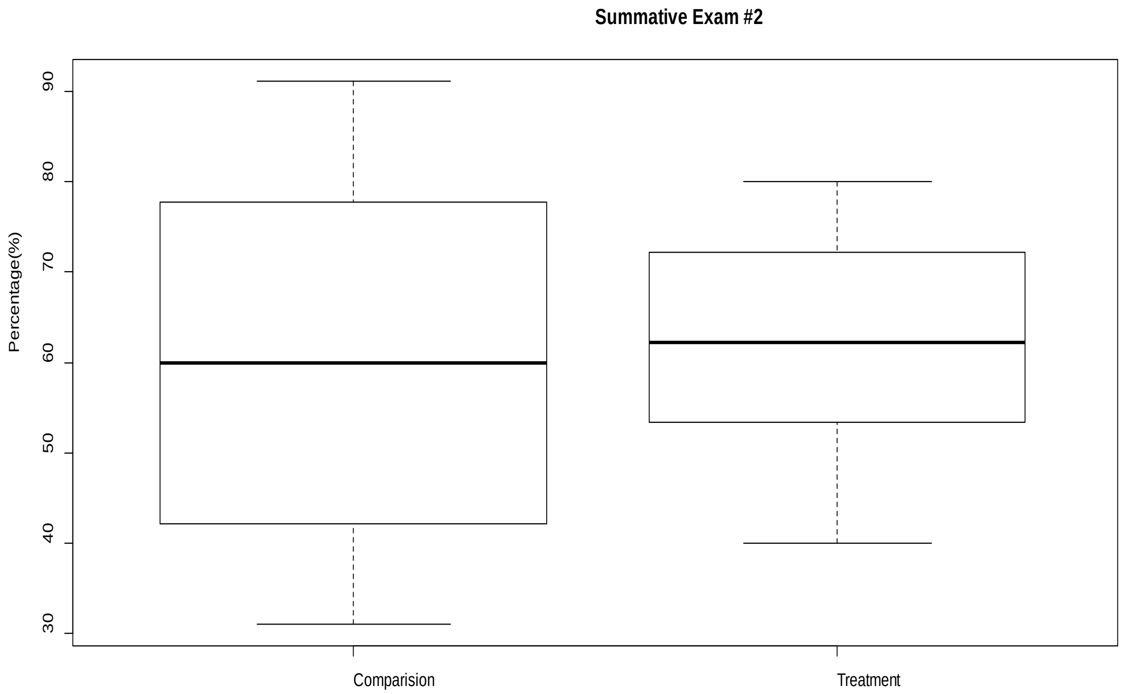


Figure 3: Box-and-Whisker Plot of Summative Exam #2 of comparison and treatment group. Boxes represent the inter-quartile range (25th to 75th percentile), and whiskers indicate the minimum and maximum values. The statistical median is represented by the dark black line in the box, (*N*=33).

Student Perception on the Use of Computer Simulations

To evaluate student perspectives on the use of computer simulations student interviews were conducted after they had performed the virtual simulated laboratory activity. The two groups were given the CLASS-Chemistry (Colorado Learning Attitudes about Science Survey) (Appendix G) along with additional attitudinal survey on laboratory (Appendix H) pre and post treatment.

I randomly selected four students from the treatment group after each simulation, for a total of sixteen students to participate in student interviews. Three out of the eleven interview questions dealt with how the simulation aided in conceptual understanding of chemistry and the concepts emphasized in laboratory activity. Out of the thirteen students that responded 77% of the individuals indicated that the simulations helped their understanding. For example, one student stated "by showing things that could not be seen in lab, easier to understand" and another "it helped in getting a better understanding". The next question concerned how simulations affect their conceptual understand of chemistry. Out of the thirteen respondents, all of them agreed that the simulations improved their understanding of the concepts. Most stated that "it broke it down into a step by step process" and that simulations allowed for "better visualization of sometimes hard concepts to actually be seen". When asked to elaborate further in why the simulations helped, most if not all said "because it was easier to see". The last question that dealt specifically with the use of the simulation with chemical bonding and molecular structure, of the eight students picked for the chemical bond simulation interview, all eight agreed the simulation was useful in that it showed what electrons were used in the bond. The four students that were chosen for the molecular structure simulation interview agreed that it was very easy to see how that unshared pair of electrons dictated the overall shape.

Three out of the eleven interview questions dealt with students views towards the actual use of the simulations and if they want to use them more to do laboratory activities. The first question was about using the computer simulations outside of class. Out the thirteen respondents 27% said that they would "sometimes they get stuck on homework and they might help". The other 36 % stated that "they would not work on their computer" and the last 37 % stated that "YouTube is easier to find help". Out of the respondents that did not like the computer simulations, it was asked why, 60% indicated that "they were not as cool as hands on labs", and "they got very repetitive". The last question dealing with the use of computer simulations, it was asked if they would to do more computer simulated labs. Out of the twelve respondents, 58% stated that they would because "it was easier to setup and do than hands-on labs", "it was easier to understand how the parts went together".

The post-treatment CLASS Survey did not show any statistically significant changes between the pre-survey and post-survey. Their attitude about chemistry stayed the same. The attitudinal survey did reveal some major changes in the treatment group views towards the use of computers and laboratory investigations. Students were more likely to perceive that they had a better understanding of the concepts underlying the lab experiment, the relationship between the experiment and course content, and relationship between different course concepts. In addition, students felt that computer based materials could help them learn. The results of those questions are summarized in Table 2.

Table 2
Attitudinal Survey Statements of responses pre- and post-treatment (N=16)

Attitudinal Survey Statements	Percentage of Responses Pre- Intervention		Percentage of Responses Post- Intervention	
#1 Often in lab I didn't understand the concept behind the lab experiment	SA	12.5%	SA	0%
	A	43.75%	A	18.75%
	N	0%	N	12.5%
	D	**25%**	**D**	**43.75%**
	SD	**18.75%**	**SD**	**12.5%**
#4 It was clear how the lab experiments fit into this course	**SA**	**43.75%**	**SA**	**62.5%**
	A	**31.25%**	**A**	**31.25%**
	N	18.75%	N	6.25%
	D	0%	D	0%
	SD	6.25%	SD	0%
#9 Assuming that all the following activities are equally well-implemented **I learn by:** using computer-based materials.	**SA**	**6.25%**	**SA**	**12.5%**
	A	**25%**	**A**	**56.25%**
	N	25%	N	12.5%
	D	18.75%	D	12.5%
	SD	12.5%	SD	6.25%
#21 **I know I understand when** I can see how concepts relate to one another	**SA**	**31.25%**	**SA**	**37.5%**
	A	**37.5%**	**A**	**43.75%**
	N	25%	N	12.5%
	D	6.25%	D	6.25%
	SD	0%	SD	0%

INTERPRETATION AND CONCLUSION

According to the quantitative data collected the use of computer simulations appeared to have a positive effect on student understanding and achievement. When considering the electron configuration simulation and the flame test hands on lab, the results demonstrated that there was an increase in conceptual knowledge over the control group. In the ionic and covalent bonds experience there was once again, based on the quiz scores a gain in conceptual knowledge. The results of the molecular structures could be ruled inconclusive because of the similarities in the simulation and the hands-on version, but the results of the t-test showed that there was a statistical difference in the quiz scores.

Computer simulations can promote student learning by giving them a visual aid into the sometimes invisible, complex conceptual world of chemistry as found in my literature review. This action research project found that traditional instruction supplemented with computer simulations helped students to perform better on short term conceptual assessments. More analysis will have to be done to determine why the performance on the summative exams did not yield the same results.

The use of computer simulations did not have a dramatic impact on the pacing of the treatment group as it took only took three days longer to complete all of the work. This could be because of the unique situation of having a separate lab period to do the laboratory investigating in.

There is still value in the hands-on experience that cannot be duplicated in the virtual world as of yet. I believe one such value would be the smells associated with certain chemicals; another would be the learned safety issues that are associated with handling dangerous chemicals in the laboratory setting.

Bell and Smetana (2008) suggest that lessons involving computer simulations should remain student-centered and inquiry-based to ensure that learning is focused on meaningful understandings, not rote memorization. As a result of this project, I will consider the following factors when determining if a particular simulation would be beneficial for my students:

- A believable representation that enhances scientific understanding through imagery and visualization, so that students will believe be it could be real. But let them know the limitation of the simulation.
- That further develops their knowledge and conceptual understanding of the content.
- That facilitates data collection and analysis that they can do that analysis in real time or later for more in depth analysis One that provides engaging exploration so the students do not develop boredom and then disconnect.
- That will confront their misconceptions and not add to them.

VALUE

This action research project had a profound impact on me and my classroom. It has introduced me to another leaning environment that is highly effective in engaging and challenging students in a very accessible way. As a result of this project I intend to incorporate a visual simulation that is either during instructional lecture periods or as an inquiry based laboratory activity to start the unit. I also plan to continue to using simulations as a precursor to the hands-on laboratory activities, and have encouraged my colleagues in the science department to implement them as well. I have presented the value of virtual simulations to the mathematics department, in hopes that they can find them as beneficial as I did.

This project has provided a means to show necessary visualization of concepts of subject matter that is very abstract. Although a majority of students like and learned through the use of computers, there were some that preferred the hands-on laboratory activities. Those should not be abandoned completely, but should be a complement to the virtual simulations. Through this project it has made me become a more reflective instructor, especially in how and in which order I present the material.

This project showed that there was a positive effect of computer simulations on student achievement, but it did lead to further research questions. One such area would be the identification of pitfalls of using simulations without laboratory activity. Another study to investigate would be the proper sequence for using computer simulations, if they should be used as an inquiry introduction activity to a concept, as a replacement for real-life experience, or in supplemental activity to a hands-on laboratory activity.

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APPENDICES

APPENDEX A

CHEMICAL CONCEPT INVENTORY

Conceptual Questions (CQs): Chemical Concepts Inventory

This inventory consists of 22 multiple choice 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. (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. A glass of cold milk sometimes forms a coat of water on the outside of the glass (Often referred to as 'sweat'). How does most of the water get there?

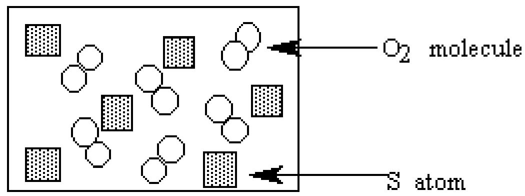
    a. Water evaporates from the milk and condenses on the outside of the glass.
    b. The glass acts like a semi-permeable membrane and allows the water to pass, but not the milk.
    c. Water vapor condenses from the air.
    d. The coldness causes oxygen and hydrogen from the air combine on the glass forming water.

4. What is the mass of the solution when 1 pound of salt is dissolved in 20 pounds of water?

    a. 19 Pounds.
    b. 20 Pounds.
    c. Between 20 and 21 pounds.
    d. 21 pounds.

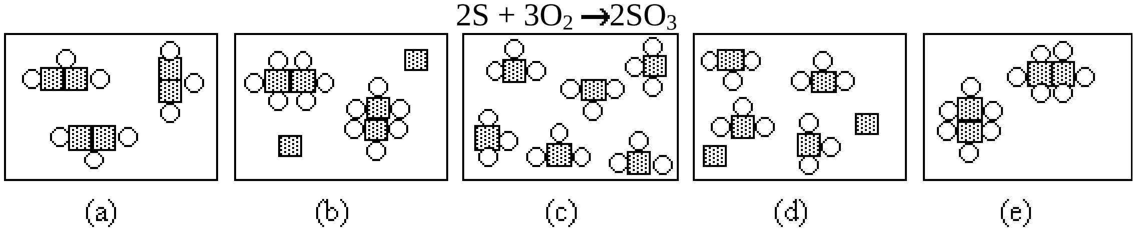
e. More than 21 pounds.

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

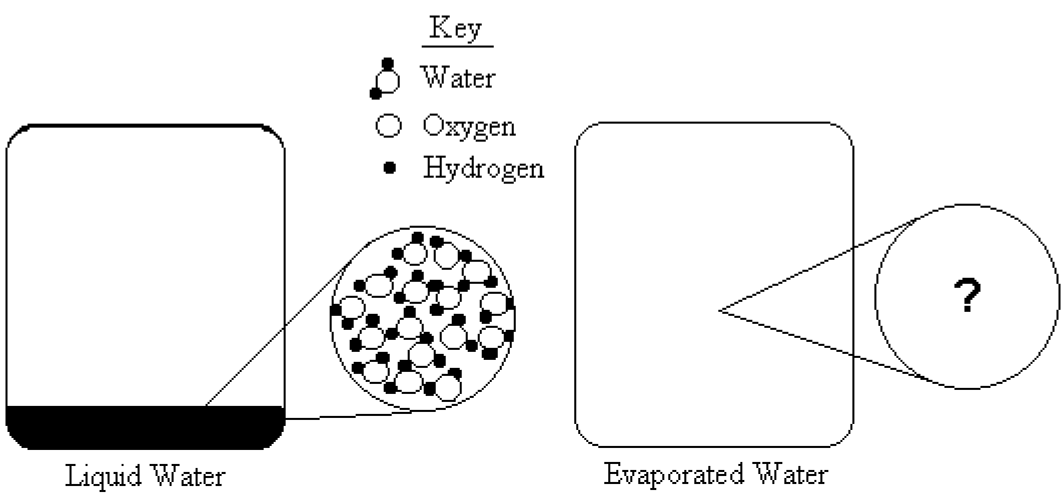


Which diagram shows the results after the mixture reacts as completely as possible according to the equation:

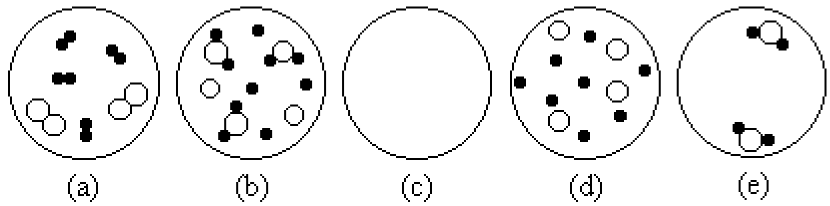
$$2S + 3O_2 \rightarrow 2SO_3$$



6. 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?



7. True or False? When a match burns, some matter is destroyed.

a. True
b. False

8. What is the reason for your answer to question 7?

a. This chemical reaction destroys matter.
b. Matter is consumed by the flame.
c. The mass of ash is less than the match it came from.
d. The atoms are not destroyed, they are only rearranged.
e. The match weighs less after burning.

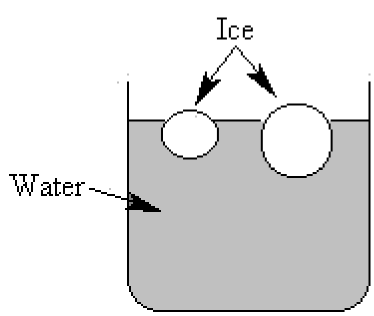
9. Heat is given off when hydrogen burns in air according to the equation

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

Which of the following is responsible for the heat?

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.

10. Two ice cubes are floating in water:



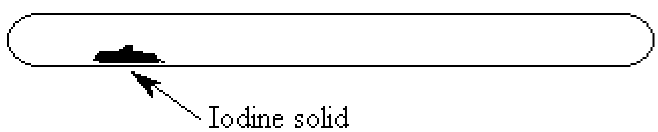
After the ice melts, will the water level be:

a. higher?
b. lower?
c. the same?

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

a. The weight of water displaced is equal to the weight of the ice.
b. Water is more dense in its solid form (ice).
c. Water molecules displace more volume than ice molecules.
d. The water from the ice melting changes the water level.
e. When ice melts, its molecules expand.

12. 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.

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

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.

14. 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}

15. 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.

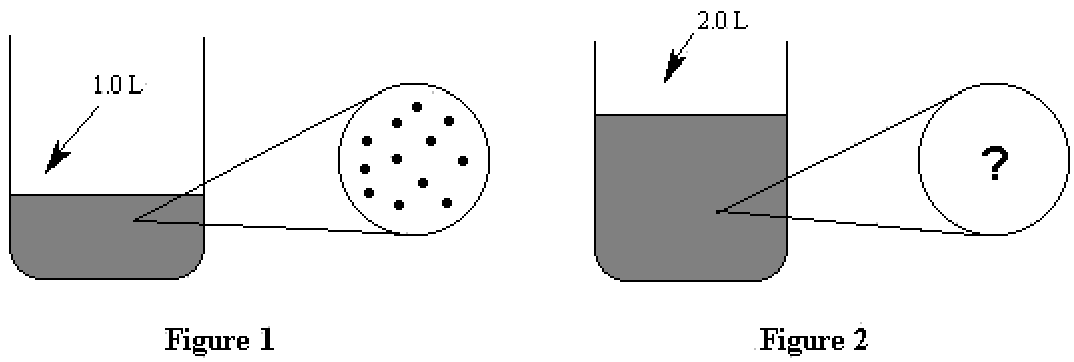


Figure 1

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

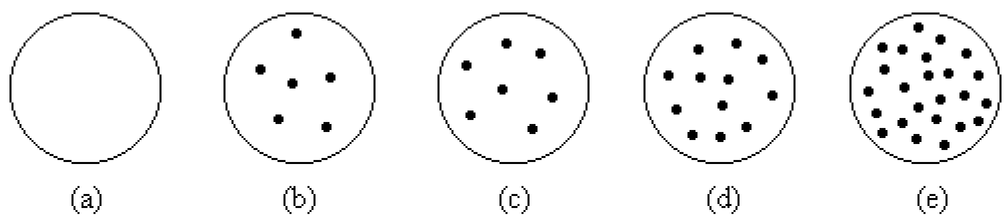


Figure 2

16. 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.

17. What is the reason for your answer to question 16?

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.

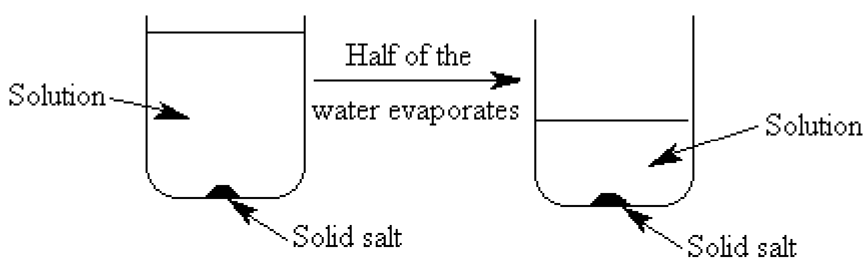
18. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

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.

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

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.

20. 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 temperature remains constant.)



The concentration

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

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

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.

22. Following is a list of properties of a sample of solid sulfur:

i. Brittle, crystalline solid.
ii. Melting point of 113^{o}C.
iii. Density of 2.1 g/cm3.
iv. Combines with oxygen to form sulfur dioxide

Which, if any, of these properties would be the same for one single atom of sulfur obtained from the sample?

a. i and ii only.
b. iii and iv only.
c. iv only.
d. All of these properties would be the same.
e. None of these properties would be the same.

APPENDIX B:

SIMULATED LAB ACTIVITIES

Simulated Lab Activities found on explorelearning.com

Electron Configuration:
http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=513&ClassID=2439914#

Ionic Bonding:
http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=514&ClassID=2439914#

Covalent Bonding:
http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=512&ClassID=2439914

Simulated Lab Activities found on PHET

Molecular Shapes: http://phet.colorado.edu/en/simulation/molecule-shapes

APPENDIX C

POST UNIT INTERVENTION STUDENT INTERVIEWS

POST UNIT INTERVENTION STUDENT INTERVIEWS

Instructions

The following questions are to be asked of the student subjects after completion of the unit objectives.
The following statements are to be read to student subjects prior to commencing the interview:
Participation in this interview is voluntary and you can choose to not answer any question that you so not want to answer, and you can stop at any time.
Your participation or non-participation will not affect your grade or class standing.

Questions

1. Do you enjoy chemistry? Why or why not?

2. Do you find chemistry a difficult subject? Why or why not?

3. Did you enjoy learning the chemistry concepts of this unit using the computer simulations? Why or Why not?

4. Can you evaluate the simulations we have used this unit. In other words, is there simulation you thought were better than the others? Provide some reasons why.

5. Did the simulations help you visualize the ideas and concepts of Chemical Bonding/Molecular Structure? Explain how.

6. Would you use other computer simulations to help you understand and solve chemistry concepts and problems outside of class (i.e. when doing homework)? Explain how.

7. What did you like about using the simulations? Explain

8. What did you not like about using the simulations? Explain.

9. Would you like to do more labs using the computer simulations? Why or why not.

10. How did the computer simulations affect your understanding of the chemistry concepts? Explain.

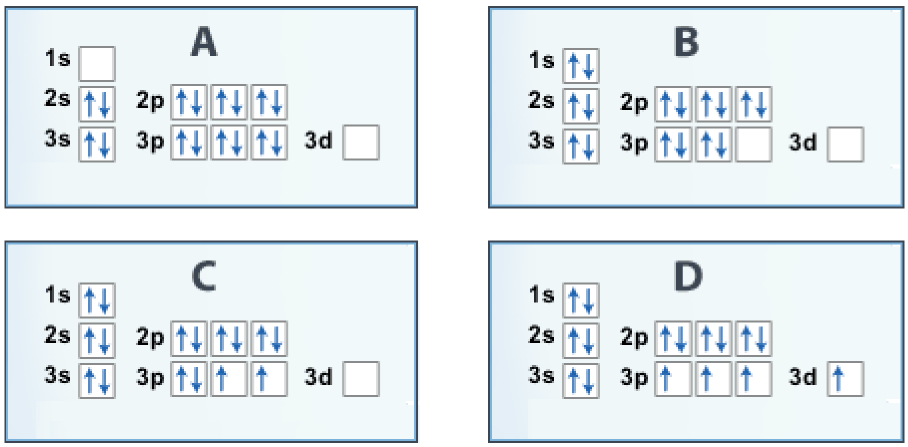
11. Anything else you want to tell me regarding the use of computer simulations for learning chemistry concepts?

APPENDIX D:

EXAMPLE EXIT SLIP

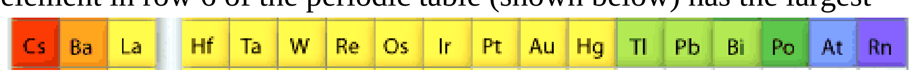
Exit Slip #1: Electron Configuration

1. Which of the following diagrams correctly shows the electron configuration of Sulfur, z= 16?



2. What is the maximum number of electrons that can occupy the 3rd electron shell?
   a. 2
   b. 6
   c. 10
   d. 18

3. Which element in row 6 of the periodic table (shown below) has the largest radius?



   a. Cs
   b. Os
   c. Hg
   d. Rn

4. Calcium has an atomic number of 20. A stable calcium atom has an electronic configuration of
   a. $1s^2 2s^2 2p^6 3s^2 3p^6 4s$
   b. $1s^2 1p^6 1d^{10} 1f^2$
   c. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2$
   d. $1s^2 2s^2 2p^6 3s^2 3p^6$

e. $1s^2 1p^6 2s^2 2p^6 3s^2 3p^2$

5. The electrons with principle energy level n = 2 of a stable atom of Boron (atomic number = 5) draw the electron arrangement of neutral Boron.

APPENDIX E

EXAMPLE CONCEPTUAL QUIZZ

Quiz #1 Electron Configuration

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____1. An element with three valence electrons is used to dope a semiconductor. What type of semiconductor is formed?

a.	*N*	c.	*npn*
b.	*P*	d.	*pnp*

____2. Electron 1 falls from energy level four to energy level two. Electron 2 falls from energy level three to energy level two. Which electron is more likely to emit red light?

a. 1
b. 2
c. Neither electron could emit red light.
d. Both electrons emit red light.

____3. Which is a possible last sublevel for an element found in Group 18?

a.	$3p^6$	c.	$4p^3$
b.	$4s^2$	d.	$4d^8$

____4. What are the valence electrons in the electron configuration of tin, $[Kr]4d^{10}5s^25p^2$?

a.	[Kr]	c.	$5s^25p^2$
b.	$4d^{10}$	d.	$5p^2$

5. Draw what electron dot structure tat shows a bromine atom that has lost an electron to become an ion. __________________________

..
$[:Br:]^-$

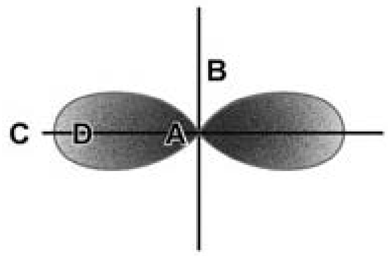
APPENDIX F:

UNIT ONE SUMMATIVE EXAM

Exam Unit 1

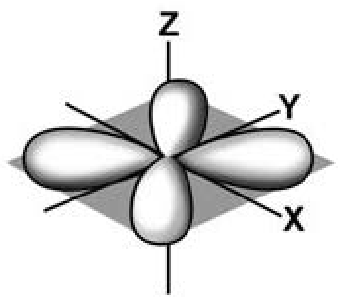
Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. Which is the most probable location for an electron in this orbital?



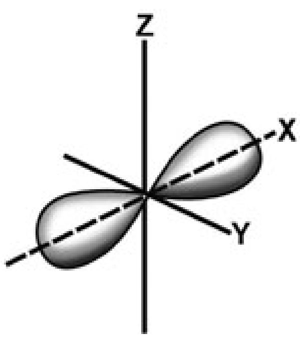
a. A
b. B
c. C
d. D

____ 2. Which type of orbital is shown?



a. s
b. p
c. d
d. f

____ 3. Which type of orbital is shown?



a. s
b. p
c. d
d. f

____ 4. Which element has the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$?

a. Titanium (Ti)
b. Chromium (Cr)
c. Sulfur (S)
d. Selenium (Se)

____ 5. Which is the correct electron configuration for the element Molybdenum (Mo)?

a. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^4$
b. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^6$
c. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4d^{10} 4p^6 5s^2 5d^4$
d. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^4$

____ 6. Which is the correct electron dot diagram for the element Silicon (Si)?

a. 

b. 

c. 

d. 

____ 7. Which is the correct electron dot structure for the element Fluorine (F)?

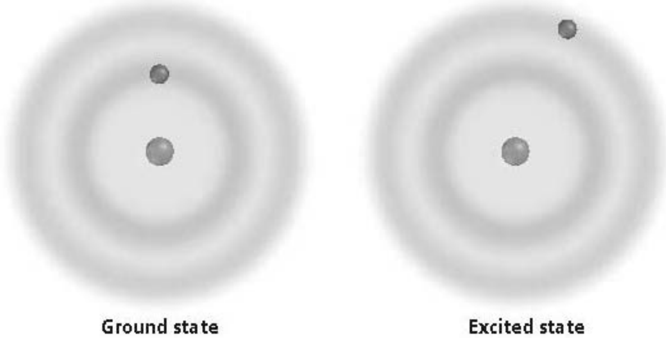
a. 

b. 

c. 

d. 

____ 8. The difference between the atom on the left and the atom on the right is that the electron has been



a. ejected.
b. electrified.
c. excited.
d. grounded.

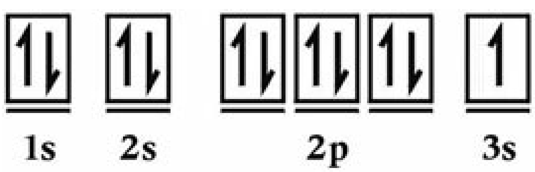
____ 9. Using the table below, determine how many valence electrons are in an atom of neon gas.

Electron Configurations and Dot Structures

Element	Atomic Number	Electron Configuration
Lithium	3	$1s^2 2s^1$
Beryllium	4	$1s^2 2s^2$
Boron	5	$1s^2 2s^2 2p^1$
Carbon	6	$1s^2 2s^2 2p^2$
Nitrogen	7	$1s^2 2s^2 2p^3$
Oxygen	8	$1s^2 2s^2 2p^4$
Fluorine	9	$1s^2 2s^2 2p^5$
Neon	10	$1s^2 2s^2 2p^6$

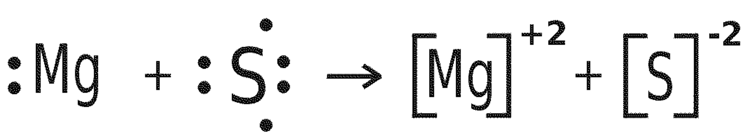
a. 2
b. 4
c. 6
d. 8

____ 10. Which ion is this atom most likely to form?



a. Na^+
b. Na^-
c. Ne^-
d. Mg^+

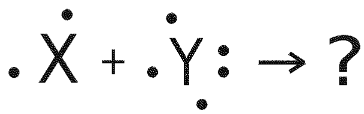
____ 11. In the equation for the formation of magnesium sulfide shown, which atom gains electrons?



A B C D

a. A
b. B
c. C
d. D

____ 12. Which is the correct formula for the ionic compound that results from these two atoms?



a. X_2Y_5 c. X_2Y_3
b. X_5Y_2 d. X_3Y_2

____ 13. Which is described as the force holding two atoms together?
a. cation c. formula unit
b. chemical bond d. lattice

____ 14. Which is a property of substances that exhibit metallic bonding?
a. high boiling points c. low melting points
b. rigid and brittle d. poor conductors of electricity

____ 15. Which is the correct formula for the compound formed between beryllium and nitrogen?
a. BeN c. Be_3N_2
b. Be_3N d. Be_2N_3

____ 16. Which combination of bonds is present in this molecule?

O = O

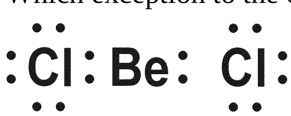
a. 1 sigma bond only c. 2 pi bonds
b. 1 sigma bond and 1 pi bond d. 1 sigma bond and 2 pi bonds

A) F−F b) N≡N c) O=O

____ 17. Which is true of the bond length of these covalent molecules?
a. The bonds in A are longer than the bonds in B or C
b. The bonds in C are the same length as the bonds in B
c. The bonds in B are longer than the bonds in A or C
d. The relative bond length of these compounds cannot be determined

____ 18. Which covalent molecule has the strongest bond?
a. A c. C
b. B d. They are all equally strong

____ 19. Which exception to the octet rule is shown by this molecule?

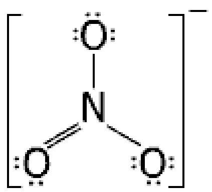


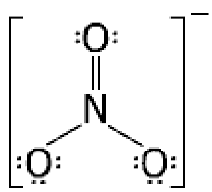
a. uneven number of valence electrons
b. suboctet
c. expanded octet
d. coordinate covalent bond

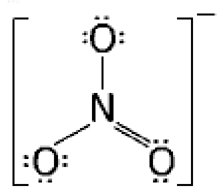
____ 20. Which type of bond has one pair of electrons shared between atoms?

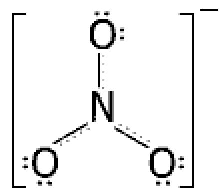
a. single covalent
b. coordinate covalent
c. double covalent
d. metallic

____ 21. Identify the correct structure of NO_3^-.

a.


b.


c.


d.


____ 22. A compound $BeCl_2$ uses sp hybrid orbitals of Be atom. Which of the following is the correct bond angle in the compound?

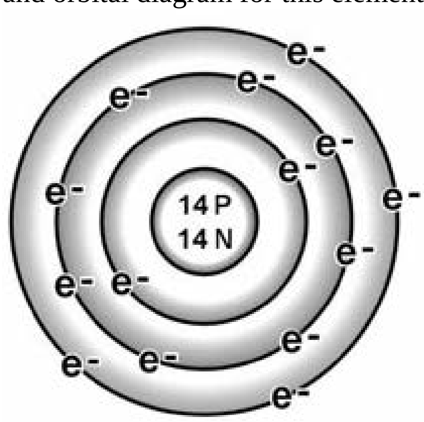
a. 104.5°
b. 109.5°
c. 120°
d. 180°

Short Answer

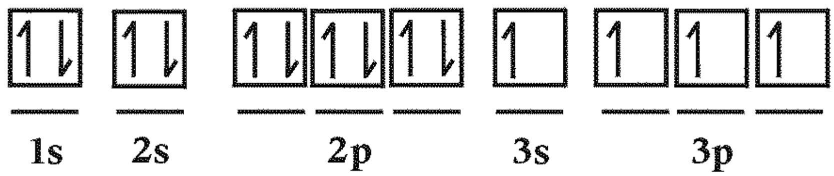
1. A student records the following electron configuration for the element Arsenic (As). Evaluate this student's answer.
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4d^{10} 4p^3$

2. Explain why it is only possible for two electrons to exist in the same orbital.

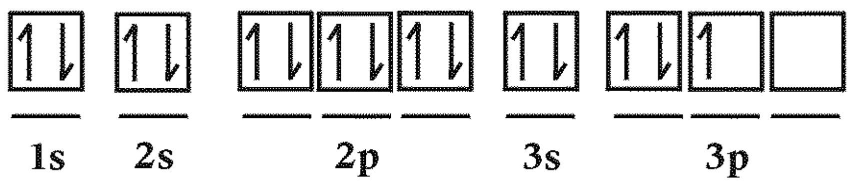
3. Use the model of the atom shown to identify the correct element. Write the electron configuration and orbital diagram for this element.



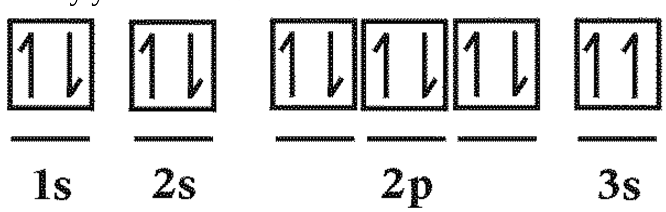
4. Which rule for filling of orbitals by electrons in the element Silicon is being violated in the orbital diagram shown? Justify your answer.



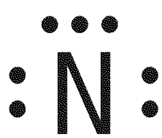
5. Which rule for the filling of orbitals in the element Phosphorus is being violated in the orbital diagram shown? Justify your answer.



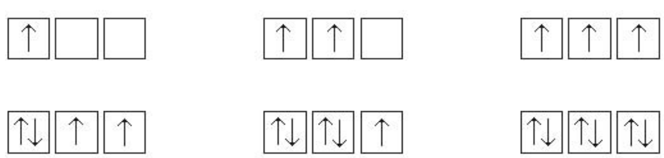
6. Which rule for the filling of orbitals by electrons in the element Magnesium is being violated? Justify your answer.



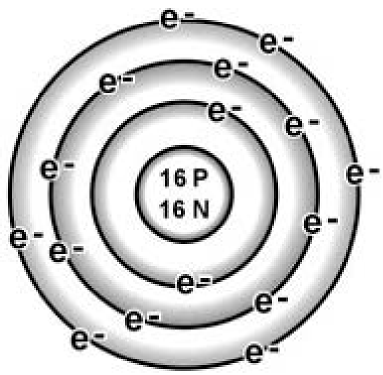
7. Explain what is wrong with this electron dot diagram for the element Nitrogen (N).



8. The figure below illustrates Hund's rule. What does Hund's rule state?



9. Is this atom more likely to gain electrons or to lose electrons? Explain how you can tell.



10. A metal, magnesium, forms an ion by losing two electrons. What will be the formula of one formula unit of the ionic compound between magnesium and oxygen?

11. Elements in groups 1 and 2 in the periodic table form positively charged ions by loss of electrons. What will be the charge on an atom, if it belongs to group 1A?

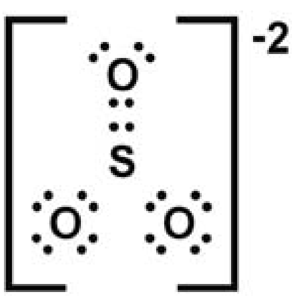
12. Elements in groups 5, 6, and 7 in the periodic table form negatively charged ions by gain of electrons. What will be the charge on an atom, if it belongs to group 6A?

Electron-Dot Structures

Group	1	2	13	14	15	16	17	18
Diagram	Li·	·Be·	·B·	·C·	·N·	·O:	:F:	:Ne:

13. Look at the electron-dot diagram for neon in the table above. Based on the table, explain why does neon have a very high ionization energy?

14. What phenomenon related to molecular structure is displayed by the molecule shown? Explain how this occurs.



Problem

1. Why is PCl_5 an exception to the octet rule, while PCl_3 is not?

Essay

1. The molecule PCl_3 has trigonal pyramidal shape, while the molecule BCl_3 has trigonal planar shape. Explain why these molecules have such different shapes despite their similar formulas. Use Lewis structures to support your answer.

APPENDIX G

CLASS-CHEMSITRY
(Colorado Learning Attitudes about Science Survey)

CLASS-Chemistry
(Colorado Learning Attitudes about Science Survey)

Name: ______________________________ Student ID #: _____________

Introduction

Here are a number of statements that may or may not describe your beliefs about learning chemistry. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

Survey

1. A significant problem in learning chemistry is being able to memorize all the information I need to know.

Strongly Disagree 1 2 3 4 5 Strongly Agree

2. To understand a chemical reaction, I think about the interactions between atoms and molecules.

Strongly Disagree 1 2 3 4 5 Strongly Agree

3. When I am solving a chemistry problem, I try to decide what would be a reasonable value for the answer.

Strongly Disagree 1 2 3 4 5 Strongly Agree

4. I think about the chemistry I experience in everyday life.

Strongly Disagree 1 2 3 4 5 Strongly Agree

5. It is useful for me to do lots and lots of problems when learning chemistry.

Strongly Disagree 1 2 3 4 5 Strongly Agree

6. After I study a topic in chemistry and feel that I understand it, I have difficulty solving problems on the same topic.

Strongly Disagree 1 2 3 4 5 Strongly Agree

7. Knowledge in chemistry consists of many disconnected topics.

Strongly Disagree 1 2 3 4 5 Strongly Agree

8. As chemists learn more, most chemistry ideas we use today are likely to be proven wrong.

Strongly Disagree 1 2 3 4 5 Strongly Agree

9. When I solve a chemistry problem, I locate an equation that uses the variables given in the problem and plug in the values.

Strongly Disagree 1 2 3 4 5 Strongly Agree

10. I find that reading the text in detail is a good way for me to learn chemistry.

Strongly Disagree 1 2 3 4 5 Strongly Agree

11. I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions.

Strongly Disagree 1 2 3 4 5 Strongly Agree

12. If I have not memorized the chemical behavior needed to answer a question on an exam, there's nothing much I can do (legally!) to figure out the behavior.
Strongly Disagree 1 2 3 4 5 Strongly Agree

13. I am not satisfied until I understand why something works the way it does.
Strongly Disagree 1 2 3 4 5 Strongly Agree

14. I cannot learn chemistry if the teacher does not explain things well in class.
Strongly Disagree 1 2 3 4 5 Strongly Agree

15. I do not expect equations to help my understanding of the ideas in chemistry; they are just for doing calculations.
Strongly Disagree 1 2 3 4 5 Strongly Agree

16. I study chemistry to learn knowledge that will be useful in my life outside of school.
Strongly Disagree 1 2 3 4 5 Strongly Agree

17. I can usually make sense of how two chemicals react with one another.
Strongly Disagree 1 2 3 4 5 Strongly Agree

18. If I get stuck on a chemistry problem on my first try, I usually try to figure out a different way that works.
Strongly Disagree 1 2 3 4 5 Strongly Agree

19. Nearly everyone is capable of understanding chemistry if they work at it.
Strongly Disagree 1 2 3 4 5 Strongly Agree

20. Understanding chemistry basically means being able to recall something you've read or been shown.
Strongly Disagree 1 2 3 4 5 Strongly Agree

21. Why chemicals react the way they do does not usually make sense to me; I just memorize what happens.
Strongly Disagree 1 2 3 4 5 Strongly Agree

22. To understand chemistry I discuss it with friends and other students.
Strongly Disagree 1 2 3 4 5 Strongly Agree

23. I do not spend more than five minutes stuck on a chemistry problem before giving up or seeking help from someone else.
Strongly Disagree 1 2 3 4 5 Strongly Agree

24. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
Strongly Disagree 1 2 3 4 5 Strongly Agree

25. If I want to apply a method used for solving one chemistry problem to another problem, the problems must involve very similar situations.
Strongly Disagree 1 2 3 4 5 Strongly Agree

26. In doing a chemistry problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.

Strongly Disagree 1 2 3 4 5 Strongly Agree

27. In chemistry, it is important for me to make sense out of formulas before I can use them correctly.
Strongly Disagree 1 2 3 4 5 Strongly Agree

28. I enjoy solving chemistry problems.
Strongly Disagree 1 2 3 4 5 Strongly Agree

29. When I see a chemical formula, I try to picture how the atoms are arranged and connected.
Strongly Disagree 1 2 3 4 5 Strongly Agree

30. In chemistry, mathematical formulas express meaningful relationships among measurable quantities.
Strongly Disagree 1 2 3 4 5 Strongly Agree

31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question.
Strongly Disagree 1 2 3 4 5 Strongly Agree

32. It is important for the government to approve new scientific ideas before they can be widely accepted.
Strongly Disagree 1 2 3 4 5 Strongly Agree

33. The arrangement of the atoms in a molecule determines its behavior in chemical reactions.
Strongly Disagree 1 2 3 4 5 Strongly Agree

34. Learning chemistry changes my ideas about how the world works.
Strongly Disagree 1 2 3 4 5 Strongly Agree

35. To learn chemistry, I only need to memorize how to solve sample problems.
Strongly Disagree 1 2 3 4 5 Strongly Agree

36. Reasoning skills used to understand chemistry can be helpful to me in my everyday life.
Strongly Disagree 1 2 3 4 5 Strongly Agree

37. In learning chemistry, I usually memorize reactions rather than make sense of the underlying physical concepts.
Strongly Disagree 1 2 3 4 5 Strongly Agree

38. Spending a lot of time understanding where mathematical formulas come from is a waste of time.
Strongly Disagree 1 2 3 4 5 Strongly Agree

39. I find carefully analyzing only a few problems in detail is a good way for me to learn chemistry.
Strongly Disagree 1 2 3 4 5 Strongly Agree

40. I can usually figure out a way to solve chemistry problems.
Strongly Disagree 1 2 3 4 5 Strongly Agree

41. The subject of chemistry has little relation to what I experience in the real world.
Strongly Disagree 1 2 3 4 5 Strongly Agree

42. There are times I solve a chemistry problem more than one way to help my understanding.
Strongly Disagree 1 2 3 4 5 Strongly Agree

43. To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed.

Strongly Disagree 1 2 3 4 5 Strongly Agree

44. Thinking about a molecule's three-dimensional structure is important for learning chemistry.

Strongly Disagree 1 2 3 4 5 Strongly Agree

45. It is possible to explain chemistry ideas without mathematical formulas.

Strongly Disagree 1 2 3 4 5 Strongly Agree

46. When I solve a chemistry problem, I explicitly think about which chemistry ideas apply to the problem.

Strongly Disagree 1 2 3 4 5 Strongly Agree

47. If I get stuck on a chemistry problem, there is no chance I'll figure it out on my own.

Strongly Disagree 1 2 3 4 5 Strongly Agree

48. Spending a lot of time understanding why chemicals behave and react the way they do is a waste of time.

Strongly Disagree 1 2 3 4 5 Strongly Agree

49. When studying chemistry, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Strongly Disagree 1 2 3 4 5 Strongly Agree

50. When I'm solving chemistry problems, I often don't really understand what I am doing.

Strongly Disagree 1 2 3 4 5 Strongly Agree

Retrieved: http://www.colorado.edu/sei/class/

APPENDIX H

Attitudinal Survey on Laboratory

Attitudinal survey on students' learning:
Please use the 7-point scale to indicate your agreement or disagreement with each statement.
ORGANIZATION
1 -strongly disagree
2- disagree
3- neutral
4- agree
5- strongly agree
LAB
1 Often in lab I didn't understand the concept behind the lab experiment.
1 2 3 4 5
2 I like labs where I get to help design an experiment to answer a question.
1 2 3 4 5
3This course provided opportunities for me to help design experiments to answer a question.
1 2 3 4 5
4 It was clear how the lab experiments fit into this course.
1 2 3 4 5
5 Doing labs in this class was like following a recipe in a cookbook.
1 2 3 4 5
6 The lab manual for this course was well-written (easy to understand).
1 2 3 4 5

Assuming that all the following activities are equally well-implemented, **I learn well by ...**
1-strongly disagree
2- disagree
3- neutral
4- agree
5- strongly agree

7 doing homework assignments. **1 2 3 4 5**

8 using diagrams and other visual media. **1 2 3 4 5**

9 using computer-based materials. **1 2 3 4 5**

10 reading a (good) textbook. **1 2 3 4 5**

11 working with my lab partner. **1 2 3 4 5**

12 getting good help / tutorial aid. **1 2 3 4 5**

13 doing hands-on activities. **1 2 3 4 5**

14 listening to lecture. **1 2 3 4 5**

15 completing lab notebooks or lab reports. **1 2 3 4 5**

16 reading and re-reading materials. **1 2 3 4 5**

I know I understand when ...
1-strongly disagree
2- disagree
3- neutral
4- agree
5- strongly agree

18 I can work problems in the book. **1 2 3 4 5**

19 I can apply ideas to new situations. **1 2 3 4 5**

20 I get a good grade on an exam. **1 2 3 4 5**

21 I can explain the ideas to someone else. **1 2 3 4 5**

22 I can see how concepts relate to one another. **1 2 3 4 5**

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