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MAKING THE UNSEEN REAL: ACTIVITIES TO IMPROVE

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MAKING THE UNSEEN REAL: ACTIVITIES TO IMPROVE SECONDARY STUDENT COMPREHENSION OF ATOMIC STRUCTURE

By

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ABSTRACT

MAKING THE UNSEEN REAL: ACTIVITIES TO IMPROVE SECONDARY STUDENT COMPREHENSION OF ATOMIC STRUCTURE

By

Mark Vincent Falzon

The world of atoms, ions, molecules, and subatomic particles is abstract and ethereal for many students in an introductory chemistry class. Anecdotal evidence from past teaching experience suggests that students do not comprehend this topic post instruction. Students who are primarily visual, linguistic or other non-analytical thinkers often have difficulty in this area of chemistry. Research demonstrates activities and methodologies that improve student comprehension of this material. The purpose of this study is to develop and implement activities, labs, demonstrations, and technologies that will increase student comprehension of this 'challenging' topic. This material will be taught in an atomic structure unit for an introductory chemistry class at the secondary level. The success of this study will be evaluated using pre/post-tests, pre/post-surveys, and journaling of student responses.

DEDICATION

This thesis is dedicated most of all to my Heavenly Father who gave me the skills to complete it and the stamina to keep going. It is also dedicated to my friend Doug Hutson who forced me to stay on track, and my wife Jeanne whose great restraint and patience kept me alive during this long process.

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Introduction

Students have a difficult time understanding the invisible nano-world of atoms, ions, molecules, and their interactions and constructs. This problem is exacerbated by prior knowledge based on an inaccurate and misleading fundamental understanding of the particle nature of matter. The atom is 'not' the fundamental particle of matter although it is often taught as such.

> If it is possible to identify a level of 'fundamental' particles most appropriate for discussing chemistry, then I suggest that this would be at the level of protons, neutrons, and electrons. Although physicists may work with 'particle zoos' at a finer grain, these three particles are fundamental enough to discuss most aspects of chemistry up to University entrance level. Chemical structures may be understood as arrangements of these basic particles. (Taber, 2003)

In addition to this foundational problem, students' ability to think abstractly has often not progressed adequately to comprehend and develop a working knowledge of these particles and their interactions. In one study only 54 % of general chemistry students in their first year of college were at Piaget's formal operational level (i.e., "students are able to do proportional reasoning, make inferences from data, control variables, and understand conservation of matter.") (Cooper, Cox, Nammouz, and Case, 2008). The group in the study reported here are almost entirely 11th grade high school students. Certainly, much less than 54 % of these students would have attained the formal operational level that is required to comprehend atomic structure and theory. It would have been helpful to use the Group Assessment of Logical Thinking (GALT) instrument with the students (Bunce, and Hutchinson, 1993). This would have allowed the researcher to determine each participant's cognitive operational stage, but the researcher did not become aware of this tool until after the study was completed.

How can the topic of atomic structure and theory be taught in a way that facilitates both short and long-term comprehension? Previous anecdotal classroom experience (the researcher has taught this topic for 19 years) has shown that most students develop only a cursory understanding of facts and little in depth knowledge. They may pass the unit test, but when confronted with new information that builds on previous learning about atomic structure and theory, they are unable to move forward in a cogent fashion. For example, students often had difficulty understanding that the nucleus remains unchanged in chemical bonding. If a higher percentage of the students had attained Piaget's formal operational level would they be able to apply their learning to chemical bonding? Are there more effective methods to teach this topic? Are there activities, material, and exercises that will allow the students to progress from a basic ordering of facts to analysis, synthesis, and even evaluation of relevant information? This study is an attempt to develop and implement these modalities (as related to atomic structure and theory) using a set of activities, material, and exercises developed during research on the campus of Michigan State University during the summer of 2007 and afterward.

There are a number of other reasons why the researcher decided to focus this study on the topic of atomic structure and theory. As mentioned previously anecdotal evidence suggested that students were not really learning this topic. Since much of chemistry at the secondary level requires a sequential ordering of information and understanding built upon a base of knowledge about atomic structure and theory, it often became obvious later in the course that students had not really grasped this topic. The general lack of comprehension demonstrated by the students was quite frustrating. Were there deficits in my understanding? Was my methodology inappropriate, ineffective or misleading? Did they need more lab experiences? Were there classroom models or activities that might improve comprehension? My research also focused on answering these questions.

Developing explanations of atomic theory and structure that are hardwired to their intellectual schema requires students to construct their own personal understandings within the classroom and laboratory settings (Tein, et. al., 2007). It is the teacher's responsibility to both teach the chemistry and encourage and enable students to learn how to learn (Johnstone, 1997). Johnstone has developed ten educational commandments which are very insightful. These will form the basis of meaningful change in the researchers teaching of atomic theory and structure.

1. What you learn is controlled by what you already know and understand.
2. How you learn is controlled by how you have successfully learned in the past.
3. If learning is to be meaningful it has to link on to existing knowledge and skills enriching and extending both.
4. The amount of material to be processed in unit time is limited.
5. Feedback and reassurance are necessary for comfortable learning, and assessment should be humane.
6. Cognizance should be taken of learning styles and motivation.
7. Students should consolidate their learning by asking themselves what is going on in their own heads.

8. There should be room for problem solving in its fullest sense to exercise and strengthen linkages.
9. There should be room to create, defend, try out, and hypothesize.
10. There should be opportunity to teach (you don't learn until you teach). (Johnstone, 1997)

Ausubel's learning theory is tied to this idea of meaningful change (Johnstone, 1997). Imagine two ends of a spectrum. At one end new learning correctly links to old knowledge and understanding allowing branched, retrievable, and usable learning, while at the other end rote, boxed, and unconnected learning occurs. A new view of learning stimulated by cognitive science and based on cognitive neuroscience, cognitive psychology, and artificial intelligence is emerging. This view can be expressed thusly: learners construct their own understanding, understanding is based on knowing relationships, and knowing relationships are rooted in having prior knowledge (Lowery, 1998). This author discusses the learning that occurs as students balance a cardboard figure then change its center of gravity using clothespins and rebalance the figure. This type of learning requires rehearsal, which is different from practice. Rehearsal increases the likelihood that the learning that takes place will not be task-specific and therefore will be transferable to other situations. Practice, on the other hand, is task specific and difficult to apply to novel situations. This type of rehearsal strengthens connections between storage areas in the brain (Lowery, 1998).

It became clear from this information that for meaningful learning to occur my students needed educational experiences that involved as much sensory input as possible. My research led to a package of activities, exercises, and labs intended to accomplish that goal.

The focus of research was the third unit of the introductory chemistry curriculum. There are two chemistry courses taught at Ithaca Jr./Sr. High School. One is a two trimester introductory course and the other is a two trimester honors chemistry course. The researcher is currently the sole instructor for these courses. The curriculum for introductory chemistry is divided into six or seven units (depending on how many are completed in a two trimester sequence). Unit one is an introduction to chemical calculations (including a brief overview of moles and stoichiometry), the metric system, dimensional analysis, significant figures and basic laboratory procedures. Unit two focuses on matter and its various forms and combinations. Two paradigms are used to give students a diagrammatic overview of the material. The first relates the basis of science e.g., its foundational goals and assumptions, to the study of chemistry. The second relates matter and energy and their changes to chemistry. These paradigms are diagrams that form an organizational foundation for the second unit of the chemistry course. This unit also emphasizes physical and chemical changes in matter in the laboratory, and procedures to recognize each. Unit three is the focus of this research project. It covers an overview of atomic structure and theory. Unit four covers reactions and bonding. It includes the five basic types of reactions, ionic and covalent bonds, and nomenclature. Unit six involves the mole concept, percent composition, empirical and molecular formulae, and stoichiometry. Unit seven adds solution chemistry and an introduction to acids and bases. In every unit there is a focus on problem solving in collaborative groups using ChemQuests© (Neil, 2002), open ended questioning, and other materials. The need for this focus is highlighted by Cooper, et. al., (2008), which address the subject of problem solving.

> It has been said that problem solving is the ultimate goal of education, and certainly this is true in any chemistry course... A number of attempts have been made to define problem solving, including “any goal-directed sequence of cognitive operations”, and many now agree with the general definition: “what to do when you don't know what to do”. Problem solving can be closely allied to critical thinking, that other goal of most science courses, in that it involves the application of knowledge to unfamiliar situations. Problem solving also requires the solver to analyze the situation and make decisions about how to proceed, which critical thinking helps.

So, where does all this lead? My students should experience meaningful learning in Ausubel's sense of that term. They should also become problem solvers able to know what to do when confronted with a new arrangement of information made up of concepts previously learned. This can only occur if, instead of being passive spectators in the learning process, they instead become active learners (Metz, and Pribyl, 1995).

The literature is rich with research directed at the goal of developing students that are active learners who demonstrate meaningful learning through resourceful problem solving. One group of researchers used the Group Assessment of Logical Thinking (GALT) instrument to group students in one of three levels based on Piaget's theories of intellectual development (Formal, Pre-Formal, and Concrete). The students were then paired in cooperative groups using all possible combinations of these levels. The results of this research show that most students develop and retain improved problem solving strategies and are better problem solvers when working alone after being part of a collaborative group (Cooper, et. al., 2008). Cognitive learning theory and classroom research also suggest that improved learning occurs when students are actively engaged in the classroom and are encouraged to construct their own understanding. With this in mind, Farrell, et. al., (1999) set up a course with the following basic structure: No lectures were given. Students were given assigned roles in groups (usually four individuals). Guided inquiry activities following a learning cycle paradigm were used to develop and learn concepts. A five minute quiz on the previous day's material was given each day. Students read the textbook to reinforce learning only after the concept was introduced in class. Students were graded individually using one-hour exams and a final exam. Another researcher used the periodic table as a mnemonic device to facilitate interactive construction of electron configurations (Mabrouk, 2003). An interesting approach to the problem of teaching atomic theory and structure relates chemical concepts as having perceptible and imperceptible examples and attributes. Those concepts with perceptible examples and attributes are viewed as concrete concepts within Piaget's theory, and those with imperceptible examples and attributes are viewed as formal concepts within Piaget's theory. Atoms and molecules have some imperceptible examples and attributes and therefore it is likely that they cannot be totally understood apart from formal operational reasoning. This insight was part of a critical analysis of the teaching of atomic and molecular structure, and as such is extremely valuable. Unfortunately, the analysis did not include usable remedies (Tsaparlis, 1997). Research about the use of analogies in chemistry teaching demonstrates that these can be powerful teaching tools by allowing students to compare new material with that which is familiar (Orgill, and Bodner, 2004). Several groups of researchers have worked with the Model-Observe-Reflect-Explain (MORE) Thinking Frame in secondary science classrooms. Of particular interest to my research is the model portion of the framework where students discuss what they expect to observe both macroscopically and at the molecular, atomic and ionic levels. Next, they compare their models to the models of other student groups. They then carry out an experiment and refine their models at both levels, again comparing their models to those of other student groups (Carillo, et. al, 2005), and (Mattox, et. al, 2006), and (Tien, et. al, 2007). The work of Patricia Metz and Jeffery Pribyl (1995), mentioned earlier developed a measurement activity that turned a boring, confusing and rule-based lecture activity into an exercise that used concrete examples to allow students to construct their knowledge of the importance of measurement in science.

An overview of the literature related to teaching chemistry at the secondary level has convinced the researcher of several things. Choosing to focus on the topic of atomic theory and structure was a wise choice. There is much research that demonstrates that secondary level chemistry students do not develop an adequate understanding in this area. The problem is multi-faceted, but several important points have bubbled to the surface. A robust understanding of this material requires a student to possess formal operational reasoning skills. Secondly, previous learning of this topic often serves to instill misconceptions rather than a build a solid base of knowledge. Thirdly, students must actively participate in hands on, minds on classroom and laboratory exercises using as many of their five senses as possible. The package of activities developed during the summer of 2007 and afterward was designed to compensate for the first two points and utilize the third point as much as possible.

The atomic structure and theory unit at Ithaca Jr./Sr. High School is divided into five main topics; the structure of the atom, it's historical development, electromagnetic radiation and the atom, isotopes and radioactivity, and electron notation.

Study Site

The following data came from (Landauer-Menchik, B., http://ed-web3.educ.msu.edu/outreach/k12out/, 2006) Ithaca, Michigan is a small rural town about 35 miles north of Lansing and has a population of about 3,098 people. The Ithaca Public Schools District has a population of about 7,800 people since it extends beyond the city limits. The district is comprised of two elementary and one Jr./Sr. High School. South Elementary houses the kindergarten through second grade, the population at North Elementary consists of third through six grades, and the Ithaca Jr./Sr. High School supports the seventh through twelfth grades. The population of the district has remained relatively constant since 1990. A breakdown by race and ethnicity shows 94% white, 4% Hispanic, 1% African American, 1% Asian, and about 1% American Indian (due to rounding errors percents do not add to 100). Age distribution is 27% below 18, 8% from 18-42, 28% from 28-44, 23% from 46-64, and 14% 65 and over. District households that have children comprise 36% of the total, of that 27% have married couples, 3% have single fathers, and 6% have single mothers. Approximately 71% of the children in the district live with married couples, 13% live with single mothers, 6% with single fathers, 5% with grandparents or other relatives, and 3% live with non-relatives or in a group home. The median income for single mother families is $21,900, single father families is $34,308, and married couples is $65,238. Families with children are less affluent than the state of Michigan average with almost one third of district students receiving free or reduced price lunches. About 55% of parents with children in the district have only a high school diploma. Only 26% of the parents have employment that requires education beyond the post secondary level. Out of 1533 students in the 2004/2005 school year, 200 qualified for Special Education, which amounts to 13.0% of Ithaca students. Special Education enrollment has increased an average of 1.9% per year over the 10 year period ending in 2005.

Implementation

The package of activities, exercises, and labs contained in table 1, were developed during research on the campus of Michigan State University (MSU) during the summer of 2007 and following. The purpose of this research was to develop a revised teaching unit on atomic structure and theory for my introductory High School Chemistry class. This unit would incorporate what I had learned in the Master of Science Degree Program in Physical Science for Secondary Physical Science Teachers offered by the Division of Science and Mathematics Education (DSME) at MSU. The table below contains, new, repurposed, and conventional activities, exercises, and labs used in the unit. New activities were developed specifically for the unit, repurposed activities were modified or used in new ways, and conventional activities were used as is from old lesson plans.

Table 1: Unit Overview

Atomic Theory and Structure Unit				
Name and Order of Activity	**Teacher Activity**	**Student Activity**	**Expected Student Outcome**	**Is Activity New, Repurposed or Conventional**
1. Particle Adventure Lab	Overview explanation with connections to previous learning	Active participation	Appreciate the breadth of this topic	Conventional
	Handout and expectations	Handout	Understand assignment requirements	
	Computer lab tutorial	Complete tutorial and handout	Understand the scale and complexity of the atom	
2. Nuclear Structure Diagram Chart	Overview of nuclear structure with Particle Adventure connections and Cyclotron teaser	Active listening and note taking	Basic understanding of nuclear structure, Apply Particle Adventure learning	New
	Partner breakout, material handout, diagramming instructions	Move to new location with lab partner, practice diagram work	Practice diagramming structure of first three elements	
	Guided instruction	Make diagram	Synthesize the structure of elements 4-36 using periodic table only	

Table 1: (con't)

Atomic Theory and Structure Unit				
Name and Order of Activity	**Teacher Activity**	**Student Activity**	**Expected Student Outcome**	**Is Activity New, Repurposed or Conventional**
3. Nuclear Decay Half Life Demonstration	Use Cyclotron isotope charts to explain isotope formation and structure	Actively participate in discussion, demonstration, and wrap-up	To apply the information learned in the Particle Adventure and the nuclear structure diagram	New
	Demonstrate isotope decay on overhead			
	Explain equipment used and Ba-137 generator		To recognize that there are real world applications of what they had learned	
	Run demonstration with graph on large monitor			
	Wrap-up and check for understanding			
4. Electronic Structure Diagram Chart	Overview of electronic structure	Active listening and note taking	Basic understanding of electronic structure	New
	Partner breakout, material handout, diagramming instructions	Move to new location with lab partner, practice diagram work	Practice diagramming structure of first three elements	
	Guided instruction	Make diagram	Synthesize the structure of elements 4-36 using periodic table only	

Table 1: (con't)

Atomic Theory and Structure Unit				
Name and Order of Activity	**Teacher Activity**	**Student Activity**	**Expected Student Outcome**	**Is Activity New, Repurposed or Conventional**
5. ChemQuest© #8-10	Review electronic structure diagram activity as related to each section of this activity	Complete each section of handout	Reinforce Electronic chart work	*Repurposed * Researcher has used this material in the classroom previously, but not with the nuclear and electronic structure charts as a foundation
	Guided practice, repeat both as needed until activity completed		Build on knowledge base to synthesize new knowledge	Repurposed
6. Simple Spectroscopy with Drawing Lab	Overview lecture relating ChemQuest© # 10, Bohr's work, and the electronic structure diagram	Active listening and note taking	To recognize that there are real world applications of what they had learned	New
	Partner breakout with equipment explanation	Complete lab and drawing	To extend the understanding of Bohr's work	
	Lab work with drawings			

Table 1: (con't)

Atomic Theory and Structure Unit				
Name and Order of Activity	**Teacher Activity**	**Student Activity**	**Expected Student Outcome**	**Is Activity New, Repurposed or Conventional**
7. ChemQuest© #11, and 13-15	Review electronic structure diagram activity as related to each section of this activity	Complete each section of handout	Reinforce electronic chart work	Repurposed
	Guided practice, repeat both as needed until activity completed		Build on knowledge base to synthesize new knowledge	Repurposed

Table 1, lists ChemQuests© as a repurposed activity used in the unit. ChemQuest© Inquiry lessons are part of the Constructing Chemistry lessons series developed by Jason Neil (2004). The researcher has used these lessons in the classroom for several years before this research project. I am calling them repurposed for several reasons. To start with, the nuclear and electronic diagramming activities, and the nuclear decay lab are new to the unit. When the students have the background knowledge developed from these activities, they are using the ChemQuest© Inquiry lessons from a much different perspective.

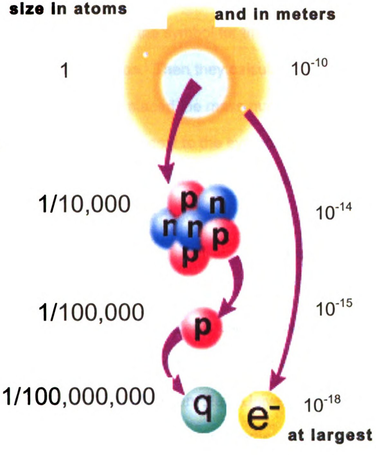
Many of the lecture and discussion questions that had been raised in previous years never came up. Students moved through the lessons with less instruction and more confidence. Researching the educational literature has also changed the way I use these lessons. Cooper, et. al., (2008), discussed the value of working in short-term collaborative groups. These groups improved student problem solving even when no other intervention occurred. Bunce, and Hutchinson, (1993), noted that students having educational difficulties in class often remain anonymous until it was too late to get help. Since students worked in small collaborative groups and were frequently called upon for responses the ChemQuest© Inquiry lessons allowed educational problems to surface quickly and prevent anonymity. Many of Johnstone's, (1997) ten educational commandments discussed in the introduction section of this paper apply to the use of the inquiry lessons. He discusses how feedback and reassurance are necessary for learning, and the necessity of giving students an opportunity to teach so that they can really learn. The inquiry lessons break up the material into manageable chunks with application and inquiry questions following. Students get immediate feedback by responding at their tables or on the blackboard after completing each section, thus they are able to teach others what they have learned. In summary, these ChemQuest© Inquiry lessons were repurposed for effective use in this newly developed atomic structure and theory unit.

Before the unit was taught parent and student participation forms were distributed to all introductory chemistry students. Three (3) classes participated in this project. Two (2) classes were taught during the first trimester of the 2008-

2009 school year, and the third class was taught during the second trimester of that same school year. Copies of the permission forms were distributed and collected by a colleague to protect student anonymity per agreement with the Human Research Protection Program at MSU. There were thirty-one (31) students who ultimately participated in the survey. Reproductions of these forms are included in Appendix A (pg 46-50). A pre-survey and pretest were then completed by each student. Copies of both instruments are also included in Appendix A (pg. 51-52, 55-57). The purpose of both instruments was to assess student knowledge and develop a statistical baseline against which student progress after the unit could be evaluated.

Activity One: A web exploration using inquiry questions based on the "Particle Adventure Tutorial" website (http://www.particleadventure.org/). This tutorial is very useful to present an overview of atomic structure and theory. When used at the beginning of the unit it expands the students' understanding of the complexity they will face while studying this topic. The Particle Data Group of the Lawrence Berkeley National Laboratory (LBNL) developed the site, with funding from the U.S. Department of Energy, the National Science Foundation, and Lawrence Berkeley National Laboratory. Most students are somewhat familiar with protons, neutrons, electrons and the basic structure of atoms due to their middle school instruction at Ithaca. They are usually not aware of the particles that make up protons and neutrons nor the forces involved in creating or maintaining the structure. Students go to the computer lab with a set of inquiry questions to challenge their thinking as they go through the tutorial. One of the most important concepts is for them to grasp was the scale of the atom by comparison with everyday objects. Here is the comparison from the *Particle Adventure*: "If we drew the atom to scale and made protons and neutrons a centimeter in diameter, then the electrons and quarks would be less than the diameter of a hair and the entire atom's diameter would be greater than the length of thirty football fields!" (http://www.particleadventure.org/). Another important concept taught in this tutorial is that the volume of the atom is 99.9999999 % empty space. This shocks students. They often ask what's in the empty space? I then ask them what is small enough to fit in that space other than subatomic particles? Also, are there forces involved that would prevent subatomic particles from occupying that space? The tutorial also emphasizes the search for fundamental particles that have no internal structure. The quark and electron are the fundamental particles that make an atom. "While an atom is tiny, the nucleus is ten thousand times smaller than the atom and the quarks and electrons are at least ten thousand times smaller than that. We don't know exactly how small quarks and electrons are; they are definitely smaller than 10^{-18} meters, and they might literally be points, but we do not know." (http://www.particleadventure.org/)

Figure 1: Atomic scale



(http://www.particleadventure.org/)

Figure 1, above comes from the tutorial and illustrates the extreme scale of sizes involved in the internal structure of atoms.

Activity Two: This is a new activity developed for this unit. Students worked in collaborative groups to diagram the nuclear structure of the first 36 elements. My classroom is set up with tables in longitudinal groups of two. Two students sit at each table facing the two students at the table across from them. To start this activity, students moved to a table with their lab partners. The students then picked out a piece of butcher-block paper approximately forty-eight

(48) inches by twenty-four (24) inches. They drew thirty-six (36) equal sized rectangles on the sheets according to directions on the blackboard. In each rectangle they drew the symbol for the element starting with hydrogen and continuing to krypton. Then they calculated the structure of the atom from a periodic table, and placed the mass number, atomic number, and charge if any in the appropriate place next to the symbol. Then they calculated the neutron to proton ratio and recorded the number in each rectangle. Many of the groups asked to decorate their charts with colored markers and pencils, which the teacher readily agreed to. This work continued until all the groups had finished their charts.

Activity Three: Students used isotope charts from the National Superconducting Cyclotron's PAN program attended by the instructor in the summer of 2004 at Michigan State University. They were given a packet of material and instructed from the overhead projector how to use it. Students were surprised to find that there were many isotopes of each element. A discussion about the half-life of many of the isotopes demonstrated that almost any isotopic structure could form, but that only fairly stable forms will exist in nature. Drawing the nuclear structure charts previous to this activity allowed lessons about radioactivity and nuclear decay to flow naturally in this discussion. This worked so well that the researcher will continue to use this in his classroom every year. This led perfectly into a nuclear decay demonstration involving a metastable form of Ba-137. The instructor had previously obtained a nuclear decay kit that produces the Ba-137 from Cs-137. This kit was purchased with grant money that came from JINA (Joint Institute of Nuclear Astrophysics) as a result of my participation in the PAN program. Using a PASCO® Geiger-Mueller tube and Data-Studio® software students were able to watch the Ba-137 (half-life is about 2.5 minutes) decay on the large TV screen in class. This really impressed the students with the reality of short-lived isotopes.

Activity Four: This is a new activity developed for this unit. Students worked in collaborative groups to diagram the electronic structure of the first 36 elements. Students used a new piece of butcher-block paper to diagram the atoms. The chart was made by drawing thirty-six (36) rectangles slightly bigger than the ones for the nuclear structure charts. Students again worked at their tables with their lab partners. This time they again started with drawing the symbol for each element. Then, in each rectangle they drew the different forms of electron configuration notation. The instructor modeled each form on the overhead and the blackboard and then the students practiced using each by completing their chart for that particular notation. They learned electron configuration notation first, then orbital notation, then dot notation and finally Bohr diagrams. Practicing each type of notation immediately after learning it seemed to agree well with the students. Many commented that the work was very easy.

Activity Five: In this activity, students completed ChemQuest© Inquiry lessons eight (8) through ten (10). ChemQuest© eight (8), the "Structure of the Atom" Neil, (2000) is the first inquiry based lesson in this unit. Students were given information about a portion of the topic and then answered a series of inquiry questions based on the information. The questions usually started with answers requiring simple recall, then progressed to answers based on analysis or synthesis of the given information. The first information section included two diagrams detailing the structure of hydrogen and carbon atoms with their isotopes. The notation for each species was given using X for the chemical symbol, A for the mass number and Z for the atomic number (which reinforces the information learned from the nuclear chart activity). The meaning of isotope and nucleus were also given in the information. This information section was followed by a section of critical thinking questions. Students worked in a cooperative group of four to address critical thinking questions. The first three questions required only simple information gathering. Questions four and five are only slightly more advanced. Many students asked for help at that point. I referred them back to the ChemQuest© information for answers. Those students that were quick to comprehend new information flew through the first five questions but often stumbled at questions six and seven. Here they were required to analyze information to arrive at an answer. Question eight caused even more problems because students were required to assemble a definition based only on the diagrams and information given. Students unsure of their abilities really struggled to arrive at the 'right' definition. Question nine required use of the definition formed in question eight. If they had synthesized a correct definition that was usually not a problem, but I found that few students had enough confidence in their ability to trust their answer. The next information section presented the atomic mass unit, related it to the gram, and diagrammatically represented the atoms and ions of fluorine and magnesium. Student groups then worked through another set of nine questions. The second question in this set asked the students to determine the mass of an electron in atomic mass units (amu). This was a great question because in the information diagrams only the mass of the atom and ion are given. Students needed to discern the answer based on the difference between an atom and an ion from the diagram. Many had difficulty answering until I pointed out the mass difference from the diagram. Approximately half the students still could not complete the question without further help. I learned to give just enough information to prevent their giving up in frustration, but not enough to keep them from working

ChemQuest© nine (9) followed next. Students calculated average grades from a sample table of five test scores for each of two students. Then they calculated a weighted average for each student from the same table. An information section explained that the average atomic mass of an element was calculated using the same procedure. Students then used the mass and percent abundance data for neon and chlorine to calculate their average atomic mass. Then they compared the calculated average to that given on the periodic table. The last section of this ChemQuest© reviewed using the complete symbol of an atom (with atomic number, mass number and charge) to find the number of neutrons, protons, electrons, atomic number and mass number.

ChemQuest© ten (10) started with information comparing gravitational effects in the solar system with the nucleus electron system in an atom.

Scientists in the early 1900's were unable to explain how an electron moved around the nucleus of an atom without collapsing into it. Neils Bohr proposed his solar system model of the atom to address the problem (actually Rutherford first proposed it in 1911, Bohr refined it in 1913 adding quantization of the electrons angular momentum). Students were asked to explain these systems: a rock moving in large circles held by a string, the Earth orbiting the sun, and the moon orbiting the Earth. Then they were asked to compare these systems to the nucleus electron system explaining why the electron does not collapse into the nucleus. The next information section gave a brief introduction to light. Students then used the formula $c = f * \lambda$ where c is the speed of light in m/s, f is the frequency in Hertz, and λ is the wavelength in m to calculate the wavelength, and frequency of light. Bohr's energy levels are covered in the next information section. Students learned that electrons can transition from lower to higher energy levels by absorbing energy and fall to lower levels by giving off energy. The energy gained or lost is given by the formula $E = h * f$ where E is energy in Joules, h is Planck's constant in J * s, and f is frequency in Hertz. Electrons that move to higher energy levels are said to be "excited". Electrons that fall to lower energy levels emit electromagnetic radiation. I emphasized to students that this process of electrons in atoms falling to lower energy levels and emitting electromagnetic radiation is the source of **all** of this type of radiation. I also introduced a large chart to the students that diagrams the location of energy levels, sublevels and orbitals for the first seven energy levels. Students used this information to calculate energy, wavelength, and frequency of absorbed and emitted electromagnetic radiation. The last question of this lesson challenged students to determine whether the visible light emissions of two different elements would be the same color and explain why or why not. This is a great inquiry question that requires a synthesis of everything students have learned in the lesson.

Activity Six: The next part of the package of material is the "Simple Spectroscopy with Drawing Lab". This really fit well with the electronic structure material from the ChemQuests©, and the charting activity. The lab is very short. Students used prism glasses from Educational Innovations® (double axis diffraction grating) to view a mercury spectrum tube and a mercury vapor fluorescent tube from a goggle cabinet sanitizer (clear glass with no fluorescent coating) and then drew what they saw with colored pencils. Students were not told that both lights were examples of mercury vapor emissions. This led to a class discussion of emission spectra and their meaning. The website http://jersey.uoregon.edu/vlab/elements/Elements.html was used in class to view the spectra of various elements. Some students realized that both emission sources in lab were the same. Others caught on soon afterwards. This led to further discussion of why they were the same.

Activity Seven: This activity includes ChemQuest© Inquiry lessons eleven (11), thirteen (13), fourteen (14), and fifteen (15). ChemQuest© eleven (11) introduced the location of electrons in energy levels, sublevels and orbitals. Inquiry questions required students to demonstrate their understanding of the location of the electrons. Clockwise and counterclockwise electron spin and how to represent it diagrammatically was also introduced then demonstrated by students using inquiry questions.

The final activity in the package of material was ChemQuest© thirteen (13) through fifteen (15). ChemQuest© twelve (12) was not used because of time constraints. The first information section explained the energy of sublevels, the Aufbau Principle, and the Pauli Exclusion Principle. According to the Aufbau principle, electron orbitals fill starting at the lowest available energy states before filling higher states (e.g. 1s before 2s). The order in which these orbitals are filled is given by the n+1 rule, where n is the energy level. The Pauli Exclusion Principle requires that no two electrons have the exact same set of quantum numbers. They must vary by at least the electron spin. Students used this information, a basic periodic table, and the large chart I hung in the room along with ChemQuest© ten (10), to answer questions about the sublevels occupied by the electrons of various elements. The next information section introduced Hund's Rule and its application to orbital notation diagrams. Students practiced using Hund's rule to write orbital notation diagrams for various elements. The rule states that electrons will add to an atom at ground state so that unoccupied orbitals at the same energy level will fill with single electrons before electrons with opposite spins can pair to fill an orbital. The third information section of this ChemQuest© compared electron configuration notation and orbital notation. Inquiry questions following the information had students write both types of diagrams and compare them. One important comparison is between the diagrams for a sulfur atom. Electron configuration notation shows the last group of electrons as $3p^4$. Orbital notation shows that sulfur has two unpaired electrons in the 3p sublevel. These unpaired electrons are very important when bonding is discussed later in the course. ChemQuest© fourteen (14), and fifteen (15) were then used to reinforce the electron notation material the students had previously learned.

A post-survey and post-test (see Appendix A, pg 53-54, 58-60) were used to assess student learning for the unit. The instructor also used oral recitation both at the blackboard and at their seats to assess student progress. A random generator which displays on the large TV monitor at the front of the class was used to focus attention for these assessments because they do not know when they will be called. Class participation points were awarded for correct answers.

Results/Evaluation

The students who participated in the research took a pre-survey and a pretest to evaluate their baseline understanding and then an identical post-survey and post-test at the end of the unit to evaluate what they had learned. The atomic structure and theory unit under investigation in this research was the third and final unit of the trimester for each class. A minimum of twenty-nine (29) students from the three classes were evaluated (some students did not return their forms). The pre/post-test instrument contained nine (9) matching vocabulary questions, sixteen (16) multiple-choice questions and six (6) short answer/application type questions (Appendix A, pg 55-57, 58-60). A paired student's t-test was used to determine if there were statistically significant differences between pre and post-test responses.

The first nine (9) test questions were matching vocabulary where students had to match nine (9) vocabulary words with twelve possible definitions. Figure 2 shows the number of correct responses before and after instruction. The paired student's t-test was used to compare pre-test and post-test answers to each of the nine questions. The first question asked students to match the definition of atomic mass. The results of the paired student's t-test was $t = 1.00$ and a p value of 0.326. There is not a statistically significant difference of means between pre and post-tests for this question. Next was the definition of atomic number. The results were $t = 4.22$ and a p-value of 0.000. In this case there is a statistically significant difference of means between pre and post-tests. Sixteen (16) out of thirty one (31) students answered this question correctly on the pretest and twenty three (23) out of thirty (30) answered correctly on the posttest. The remaining vocabulary terms were light, isotope, orbital, mass number, photon, representative element, and atomic weight. Out of nine (9) vocabulary questions, three (3) returned statistically significant differences between pre and posttest means and one was very close. The three terms were atomic number, mass number, and photon. The term that was very close was isotope. For questions one (1), three (3), four (4), five (5), and nine (9) the pre-test responses were correct either more often or equal to the post-test responses. This will be discussed in the discussion section.

Figure 2: Pre/Post-Test Vocabulary Question Analysis

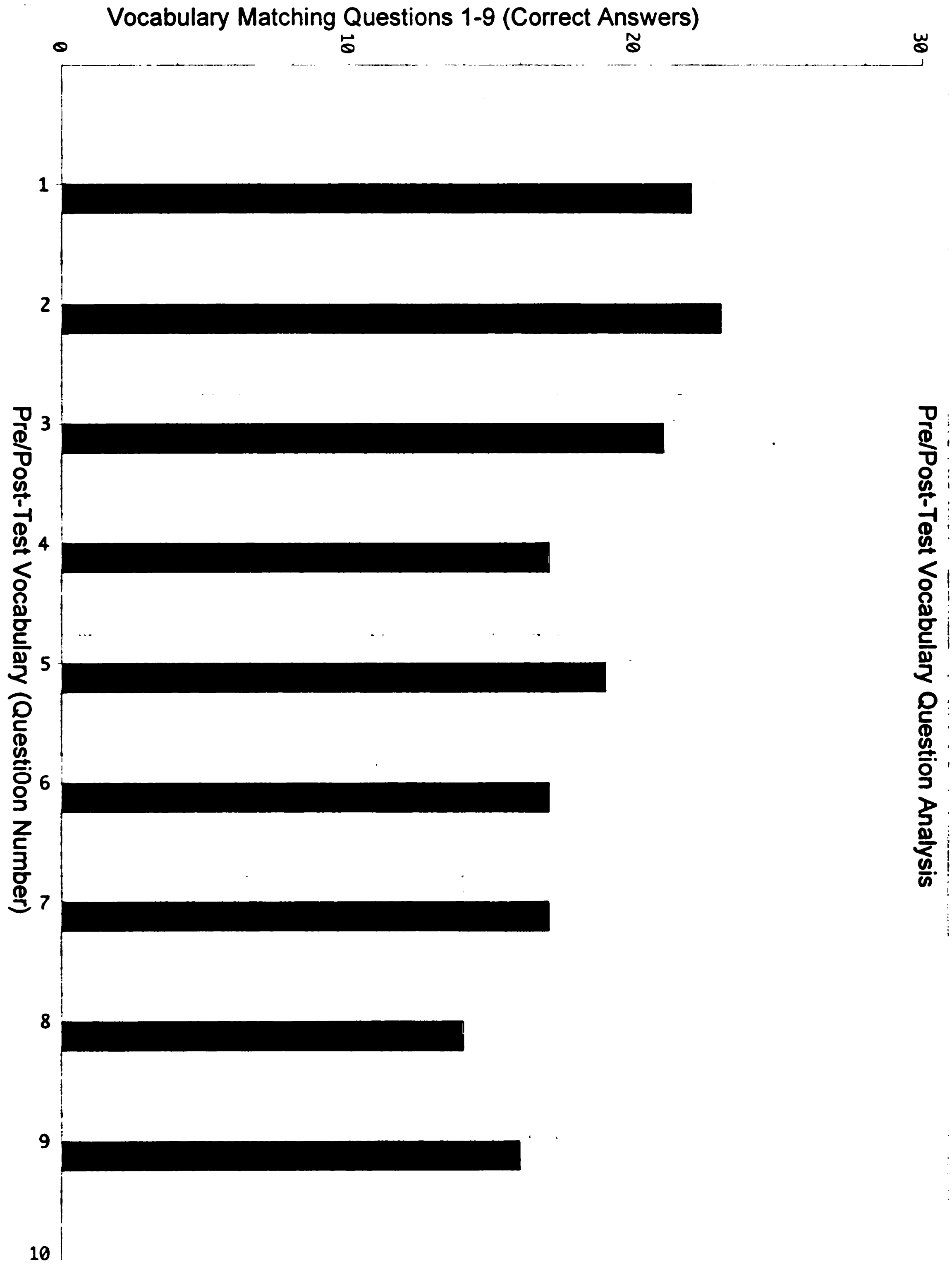
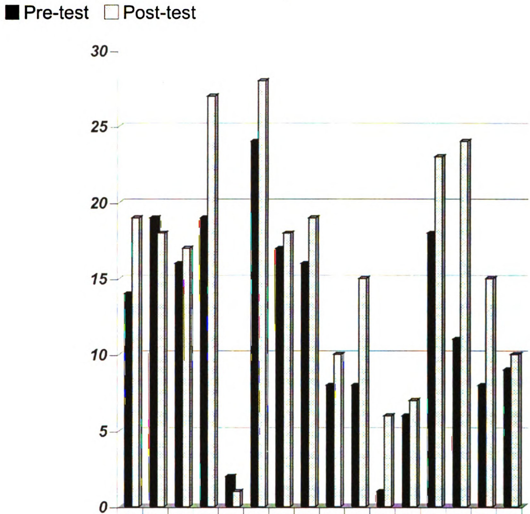


Figure 2, shows the number of correct responses on the pre-test and post-tests for these first nine questions. Figure 3, shows the number of correct responses pre and post instruction for multiple choice questions ten (10) through twenty-five (25). A paired student's t-test ran for these sixteen (16) multiple-choice questions showed the following. Five (5) had a statistically significant difference of means with a p-value < 0.006, while three (3) questions were very close to being statistically significant with p-values < 0.071. Question thirteen (13) asked students to determine the number of protons in a fluorine atom. Nineteen (19) students answered correctly on the pretest while twenty-seven (27) students answered correctly on the posttest. The p-value for all students was 0.005 for this question. Question 22 asked students to identify a type of electron notation, eighteen (18) students answered correctly on the pretest while twenty three (23) students answered correctly on the posttest. The p-value for this question was 0.001. Question 23 also asked students to identify a type of electron notation. In this case 11 students answered correctly on the pretest while twenty four (24) answered correctly on the posttest. The p-value for this question was 0.000. Question 24 asked students to relate electron configuration to periodic table placement. Eight (8) students answered correctly on the pretest while fifteen (15) students did so on the posttest. The p-value for this question was again 0.000. Figure Three (3) is below.

Figure 3: Pre/Post-Test MC Questions



	Q-10	Q-11	Q-12	Q-13	Q-14	Q-15	Q-16	Q-17	Q-18	Q-19	Q-20	Q-21	Q-22	Q-23	Q-24	Q-25
Pre-test	14	19	16	19	2	24	17	16	8	8	1	6	18	11	8	9
Post-test	19	18	17	27	1	28	18	19	10	15	6	7	23	24	15	10

MC Question Number

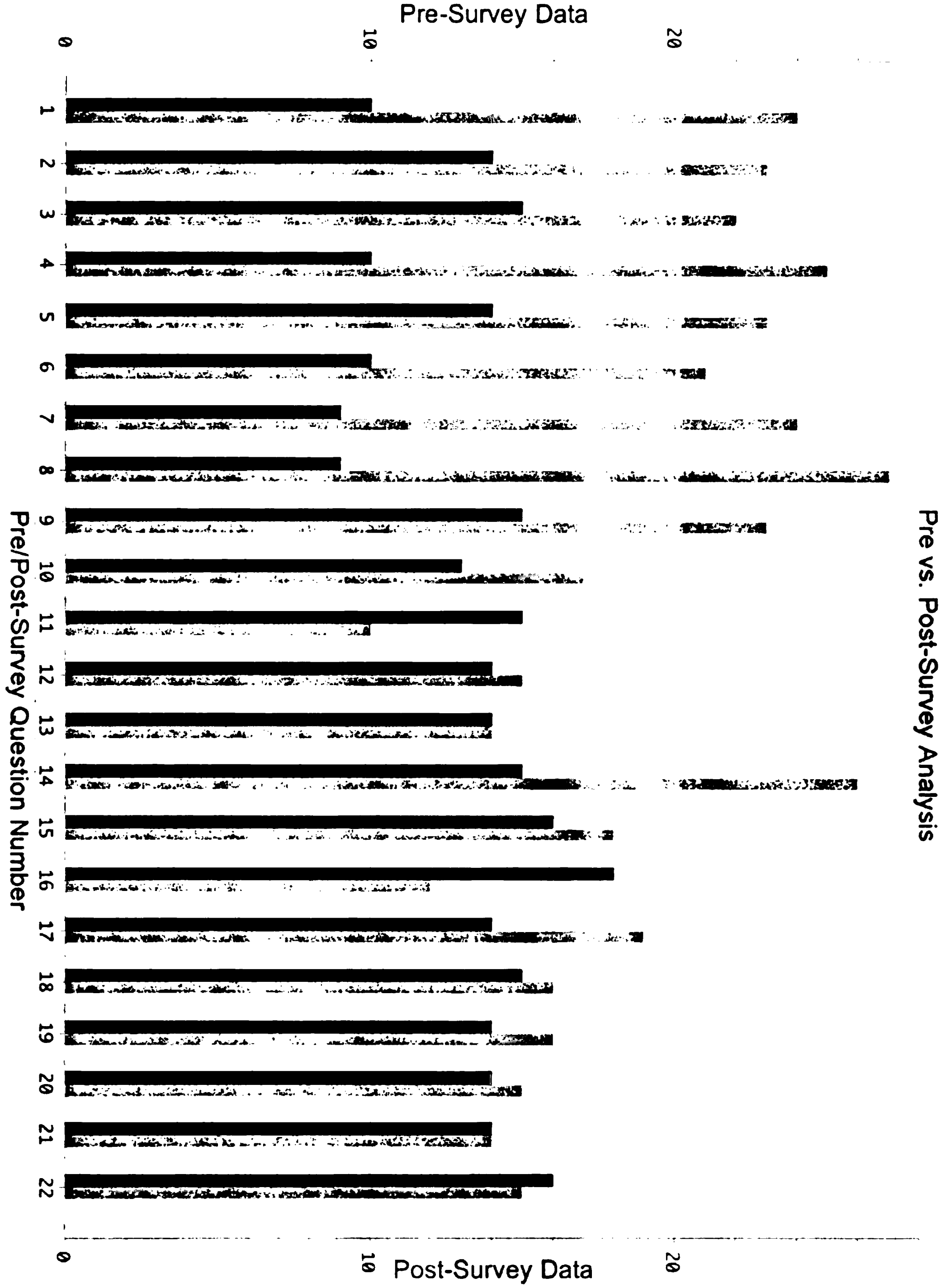
The short answer/application questions all showed a statistically significant difference in means between pre and post-tests (Table 2, below). Question one (1) required students to fill-in a chart on the structure of various ions and atoms. On the pretest no students achieved full credit and eleven (11) students achieved partial credit. On the post-test seven (7) students achieved full credit and twenty-two students achieved partial credit. The p-value for this question was 0.000. Question two (2) asked students to diagram the electron configuration notation for Arsenic using the long and short form of the notation. No students received full credit and only one (1) student received partial credit on the pretest. Sixteen students received full credit and seven (7) students received partial credit on the posttest. The p-value for this question was 0.000. Question three (3) challenged the students to diagram the orbital notation for iron. On the pretest no one earned either full or partial credit. On the posttest, fifteen students earned full credit while eight (8) students earned partial credit. The p-value for this question was 0.000. Question four (4) required students to diagram the dot notation for the first four halogens. Again no one earned either full or partial credit on the pretest. On the posttest sixteen students earned full credit while six (6) students earned partial credit. The p-value for this question was 0.000. Question five (5) asked students to draw Bohr diagrams for Calcium and Bromine. Once again no one earned full or partial credit on the pretest. On the posttest thirteen earned full credit while ten (10) earned partial credit. The p-value for this question was 0.000. Question six (6) challenged students to locate the s, p, d, and f blocks, alkali metal, alkaline Earth metal, oxygen, halogen, and noble gas groups on the periodic table. No students earned full credit and seven (7) students earned partial credit on the pretest. On the posttest nineteen (19) students earned full credit and ten (10) students earned partial credit. The p-value for this question was 0.000. Table 2 below summarizes the results from this section of the instrument.

Table 2: Pre/Post-Test Short Answer Analysis

Short Answer Questions		**PreTest Full Credit**	**PreTest Partial Credit**	**PreTest No Credit**	**Post Test Full Credit**	**Post Test Partial Credit**	**Post Test No Credit**	**p-value**
Question #	Topic							
1	Atomic Infromation Chart	0	11	20	7	22	0	0.000
2	Electron Configuration Notation	0	1	30	16	7	6	0.000
3	Orbital Notation	0	0	31	15	8	6	0.000
4	Dot Notation	0	0	31	16	6	7	0.000
5	Bohr Diagrams	0	0	31	13	10	6	0.000
6	Periodic Table Locations	0	7	24	19	10	0	0.000
	Average	0	3	28	14	11	4	0.000

Pre and post-surveys were also used to analyze student progress in this unit. Copies of each instrument are located in (Appendix A, pg. 51-52, 53-54). The pre and post survey questions were the same for all classes. Students were asked to rank their knowledge for each question as: Five (5) (my knowledge and or ability of this topic are very high), four (4) (my knowledge and or ability of this topic are fairly good), three (3) (my knowledge and or ability of this topic are OK), two (2) (my knowledge and or ability of this topic are fairly poor), or one (1) (my knowledge and or ability of this topic are very poor). The results are shown in Figure 5, below. For questions one through nine (1-9) and fourteen (14) > ten (10) students who did not answer four (4) or five (5) on the pre-survey, changed their answer to four (4) or five (5) on the post-survey. This indicates that they had changed their estimation of what they knew and were able to demonstrate. Figure 4 below, is a summary of the data.

Figure 4: Pre/Post-Survey Analysis



Discussion/Conclusion

The pretest and posttest were compared to determine if statistically significant differences between the two occurred. In the vocabulary section of the test three terms showed a statistically significant difference and one was very close. Three of the terms (atomic number, mass number, and isotope) were studied extensively in the nuclear and electronic charting activities. It would be safe to conclude that student learning probably occurred in these cases as a result of what was taught. The content of the questions is important in light of the new activities developed for this unit. Diagramming nuclear and electronic structure of atoms in lab groups seemed to increase student learning of the topics covered. It can be stated conclusively that the increased student scores were not the result of chance.

Figure three (Pre vs. Post-test MC Paired t-test) in the results and evaluation section compares the student scores on the pre and post-test instrument for multiple choice questions ten through twenty-five (10-25). Half of the multiple-choice questions (eight of sixteen) showed either statistically significant or very close to significant differences between pre and post-test answers ($p \leq 0.05$). What does this mean? Questions thirteen (13), twenty two (22), twenty three (23), and twenty four (24) tested the students understanding of the nuclear and electronic structure of atoms. Each showed statistically significant differences when a paired t-test was applied ($p \leq 0.05$). I believe this demonstrates the effectiveness of the nuclear and electronic diagramming activities developed for this unit. The work of Tein, et. al., (2007) focused on the need for students to develop their own personal understanding of science concepts hardwired to their own intellectual schema. These four questions relate very closely to the hands on diagramming activities and quite strongly suggest that meaningful learning occurred because of what was taught. Questions fifteen (15), seventeen (17), nineteen (19), and twenty (20) tested the students understanding of the relationship between electromagnetic radiation and atomic structure. Only question fifteen (15) showed statistically significant differences between pre and post-tests, while the other questions were very close to showing statistical significance using a paired t-test ($p \leq 0.05$). The relationship between electromagnetic radiation and atomic structure is a consequence rather than a component of the electronic structure of atoms. Therefore it requires a level of abstraction once removed from the mechanics of the basic structure. The hands on diagramming activity suggests this consequence of electronic structure but does not directly teach it. Possibly, student learning suffered slightly due to their inability to actively participate in their learning (Metz, and Pribyl, 1995). There were eight questions out of the sixteen where a statistically significant difference between pre and post-test answers did not occur. Question eleven (11) queried the students regarding simple information about atomic mass numbers. They should have learned this information since it was taught through lecture, inquiry, guided practice, and hands on activities. The researcher is really baffled by the student performance on this question. Questions ten (10) and fourteen (14) related to Rutherford's experiment and Dalton's Atomic Theory respectively. These topics were covered in lecture only. There was no guided practice or other reinforcement to tie these topics to other learning. The researcher plans to incorporate rehearsal activities for these topics in future lessons. Question twelve (12) asked students to name a chloride ion. Looking back at my lesson plans, I found that there was very little time spent naming ions. This will be corrected in future lessons. Questions sixteen (16) and eighteen (18) challenged the students to recall the mathematical relationships between components of electromagnetic radiation. Lecture, inquiry work, and guided practice were used to help students learn this topic. The researcher is not clear why the students did not test well on it. Perhaps more reinforcement later in the unit would help. It is interesting to note that three (3) other questions in this set (questions 10-25) covered this topic and returned statistically significant or close to significant differences between pre and post-tests. Question twenty-one (21) queried the students about quantum numbers. Through the oversight of the researcher this topic was not taught, so the poor testing results should be expected. Question twenty-five, the last question in this set, investigates how well students understand atomic structure. They were asked to choose a correct answer among three plausible foils. Possibly this question was difficult for the students because their knowledge of atomic structure did not have enough depth for them to separate the correct answer from the plausible foils.

Figure 4 in the results and evaluation section compares the student scores on the pre and post-test for the short answer section of the test. There were six questions on this section of the test. When the pre and post-test answers were compared with a paired t-test each question showed a statistically significant difference with a p-value of 0.000. Question one (1) asked students to fill in a table for three (3) atoms or ions. For each isotope the students were required to write the complete symbol, mass number, number of protons, number of neutrons, number of electrons, and the atomic number. Enough information was given so that students who had a reasonable understanding of atomic structure would be able to complete the table using only a periodic table. Questions two (2) through six (6) were similar in that each asked students to demonstrate graphically what they had learned about atomic structure. As mentioned in the results/evaluation section student performance increased markedly on all the short answer questions. Statistical analysis demonstrates that the increased performance was not due to chance. I believe the package of activities, exercises and labs developed or modified for this unit effectively improved student learning of this topic. This set of questions in particular show much promise for future work and appear to be reproducible in other settings due to the very low probability of the increase in means resulting from random causes. Why are the gains in demonstrated student learning much more evident for these short answer questions than for the matching and multiple-choice questions? Johnstone, (1997) expressed the importance of relating new learning to previous learning if it is to be meaningful. Students completing the *Particle Adventure*, the two drawing activities, and the Nuclear Decay Half-Life Demonstration Lab developed a solid background of learning which the ChemQuest© activities built upon. Students were actively engaged in constructing their own knowledge (Farrell, et. al., 1999). The net result of this progression of learning activities was demonstrated by the obvious student learning which occurred on the short answer section of the post-test. A framework that tied to previous learning was built, populated with ideas, and then extended to incorporate new knowledge structures (Tsaparlis, 1997).

The pre and post-survey questions were not subject to the paired t-test due to the nature of the instrument. However, each pre-survey and post-survey question was compared to determine the changes. The questions that produced the most change in the students perception of their ability all had something in common. Questions one through nine (1-9) and fourteen (14) generally related to knowledge, comprehension or application of a skill. The questions where the students rated their ability more poorly generally related to analysis, synthesis, or evaluation of what they had learned. They appear to be more difficult to answer, hence the poorer results. Apparently the new and repurposed material used in this unit did not sufficiently address the deeper levels of atomic structure and theory. However, it is interesting to note that these responses indicate that the students were being honest in their self-assessment.

The researcher would like to use the GALT instrument Bunce, and Hutchinson, (1993) mentioned earlier in this study to determine if measuring the Piagetian operational level of students and then grouping them collaboratively would affect their learning. The diagrams of nuclear and electronic structure seem to be quite effective based on the statistical significance shown in the pre versus post-test analysis. The concept of rehearsal stated by Lowery, (1998), as opposed to practice is used effectively in the drawing activities. Students are building knowledge as they determine the proper characteristics of each nuclear and electronic structure and then go through the physical activity of drawing the structure on their charts. They are able to apply and extend what they have learned and then scaffold from that base to new knowledge, which they themselves construct. Use of the *Particle Adventure* tutorial seems to give students a good overview of the complications inherent in this topic, but it would be difficult to give any statistical credence to its use. The ChemQuest© inquiry material may contribute to the statistical significance shown in the pre versus post-test analysis, but this researcher is not sure how to document that.

The ten educational commandments from Johnstone, (1997) were quoted in the introduction of this paper. These statements have had a great deal of impact on this researcher. Students have been able to hypothesize and then implement solutions to challenges in the drawing and ChemQuest© Inquiry activities. They have authenticated their learning by teaching others students and the researcher through random questioning and blackboard validation activities. New learning must link to existing knowledge and skills in order to be meaningful. Overall, it can be shown that for the most part, in the areas where students have demonstrated statistically significant improvements in learning, e.g., 'meaningful learning', it has occurred because the activities, exercises, and labs implemented in this research have contributed to the development of this linkage.

Certainly research in the educational literature surrounding the teaching of atomic structure and theory has been a valuable exercise that has expanded my horizons and given me much to chew on in the future. I look forward to expanding and deepening this unit as time allows!

APPENDICIES

APPENDIX A

SURVEY AND TEST INSTRUMENTS

To: Parents of Mr. Falzons chemistry classes

Re: "Making the Unseen Real: Activities to Improve Secondary Student Comprehension of Atomic Structure", Masters Thesis Project 2007-2009

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education. (DSME). My thesis research is on the effect of having students do multiple activities and experiments related to the study of atomic structure to see if it has an impact on the student's content knowledge and their ability to use the terms in context properly. School administrators are aware of this study and have given permission for me to conduct it.

Data for the study will be collected from standard student work generated in the course of teaching the unit such as pre and post tests, lab activities, quizzes, and surveys. I am asking your permission to include your child's data in my thesis. Your child's privacy is a foremost concern. During the study, I will collect and copy student work. These assignments will have the students' name removed prior to use in the study. All work being collected will be stored in a locked cabinet until my thesis is finished and will be shredded after that time. In addition your child's identity will not be attached to any data in my thesis paper or in any images used in the thesis presentation. Your child's privacy will be protected to the maximum extent allowable by law.

Participation in the study is completely voluntary. Students who do not participate will not be penalized in any way. Students who do not participate in the study will still be expected to participate in class and complete assignments. Students who participate in the study will not be given extra work to complete. You may request that your child's information not be included in this study at any time and your request will be honored. There are no risks associated with participating in this study. Participation in this study will contribute to determining the best way to present atomic structure tc high school students.

If you are allowing your child to participate in the study, please complete the attached form and return it to me by 10-05-07. Please seal it in the provided envelope with your child's name on the outside of the envelope. The envelopes will be stored in a locked cabinet and opened after the unit is completed. Any work from a student who is not to be included in the study will be returned.

If you have any questions about the study, please contact me by e-mail at mfalzon@ithacaschools.net or by phone at (989) 875-3373 ext. 1205. Questions about the study may also be directed to Dr. Merle Heidemann at the DSME by e-mail at heidma2@msu.edu, by phone at (517) 432-2152, or by mail at 118 North Kedzie, East Lansing, Michigan 48824. If you have questions or concerns about your role and rights as a research participant, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

Thank you,

Mark Falzon
Science Teacher
Ithaca High School

Parent Permission Form

I voluntarily agree to allow ______________________ to participate in this study.
(Print student's name)

Please check all that apply.

______ I give Mr. Falzon permission to use data generated from my child's work in chemistry class to be used in the thesis project. All data from my child will remain confidential.

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

______ I give Mr. Falzon permission to use my child's pictures during the presentation of his thesis project. My child will not be identified in these pictures. Realize that even though your child will not be identified by name in these pictures, their identity could be recognized by someone who knows them.

______ I do not wish to have my child's picture used at any time during this thesis project.

______________________________ ______________
(Parent/Guardian signature) (date)

To: Students of Mr. Falzons chemistry classes

Re: "Making the Unseen Real: Activities to Improve Secondary Student Comprehension of Atomic Structure" , Masters Thesis Project 2008-2009

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education. (DSME). My thesis research is on the effect of having my students do multiple activities and experiments related to the study of atomic structure to see if it has an impact on their content knowledge and their ability to use the terms in context properly. School administrators are aware of this study and have given permission for me to conduct it.

Data for the study will be collected from your work generated in the course of the unit such as pre tests, post tests, lab activities, quizzes, and surveys. I am asking your permission to include data from your work in my thesis. Your privacy is a foremost concern. During the study, I will collect and copy some of your work. These assignments will have your names removed prior to use in the study. All work being collected will be stored in a locked cabinet until my thesis is finished and will be shredded as soon as the university, and the Institutional Review Boards (IRBs) allows. In addition your identity will not be attached to any data in my thesis paper or in any images used in the thesis presentation. Your privacy will be protected to the maximum extent allowable by law.

Participation in the study is completely voluntary. Students who do not participate will not be penalized in any way. Students who do not participate in the study will still be expected to participate in class and complete assignments. Students who participate in the study will not be given extra work to complete. You may request that your information not be included in this study at any time and your request will be honored. There are no risks associated with participating in this study. Your participation will contribute to determining the best way to present atomic structure to high school students.

If you decide to participate in the study, please complete the attached form and return it to me wit'-in one week. Please seal it in the provided envelope with your name on the outside of the envelope. The envelopes will be stored in a locked cabinet and opened after the trimester is completed. Any work from a student who is not to be included in the study will be returned.

If you have any questions about the study, please contact me by e-mail at mfalzon@ithacaschools.net or by phone at (989) 875-3373 ext. 1205. Questions about the study may also be directed to Dr. Merle Heidemann at the DSME by e-mail at heidma2@msu.edu, by phone at (517) 432-2152, or by mail at 118 North Kedzie, East Lansing, Michigan 48824. If you have questions or concerns about your role and rights as a research participant, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

Thank you,
Mark Falzon
Science Teacher
Ithaca High School

Student Permission Form

I voluntarily agree ________________________ to participate in this study.
(Print your name)

Please check all that apply.

______ I give Mr. Falzon permission to use data generated from my work in chemistry class to be used in the thesis project. All data will remain confidential.

______ I do not wish to have my work used in this thesis project. I acknowledge that my work will be graded in the same manner regardless of participation in the study.

______ I give Mr. Falzon permission to use my pictures during the presentation of his thesis project. I will not be identified in these pictures. Realize that even though you will not be identified by name in these pictures, your identity could be recognized by someone who knows you.

______ I do not wish to have my picture used at any time during this thesis project.

I voluntarily agree to participate in this thesis project.

________________________________ ____________
(Student signature) (date)

Atomic Structure Pre-Survey

Please rate your knowledge and/or ability honestly by circling the number that best applies. Use the following scale:

(5) My knowledge and/or ability of this topic are very high. I would score ≥ 85% if tested on it.

(4) My knowledge and/or ability of this topic are fairly good. I would score ≥ 70% if tested on it.

(3) My knowledge and/or ability of this topic are OK. I would score ≥ 50% if tested on it.

(2) My knowledge and/or ability of this topic are fairly poor. I would score ≥ 25% if tested on it.

(1) My knowledge and/or ability of this topic are very poor. I would score < 25% if tested on it.

1. I could identify the location, relative mass, and charge of an electron in an atom.
   5 4 3 2 1

2. I could identify the location, relative mass, and charge of a proton in an atom.
   5 4 3 2 1

3. I could identify the location, relative mass, and charge of a neutron in an atom.
   5 4 3 2 1

4. I would describe an atom as mostly empty space with an extremely small, dense nucleus consisting of protons and neutrons and an electron cloud surrounding the nucleus.
   5 4 3 2 1

5. Protons inside a nucleus repel each other and a strong force must be present to keep the nucleus intact.
   5 4 3 2 1

6. Give the number of electrons and protons present in a representative ion of the first three periods on the periodic table.
   5 4 3 2 1

7. List the number of protons, neutrons, and electrons for any given atom, ion, or isotope.
   5 4 3 2 1

8. Recognize that atoms with the same number of protons must be the same element.
   5 4 3 2 1

9. Demonstrate the ability to write the symbol for an isotope, X Z A, where Z is the atomic number, A is the mass number, and X is the symbol for the element.
   5 4 3 2 1

10. Flame tests of elements produce characteristic colors. Explain this by describing the energy transitions which produce these characteristic colors.
5 4 3 2 1

11. Contrast the mechanism of energy changes and the appearance of absorption and emission spectra.
5 4 3 2 1

12. Explain why an atom can only absorb certain wavelengths of light.
5 4 3 2 1

13. Compare different wavelengths of light using frequency and relative energy.
5 4 3 2 1

14 Demonstrate the ability to write the complete electron configuration of any element in the first four periods of the periodic table.
5 4 3 2 1

15. Demonstrate the ability to write the kernel structure for a representative element.
5 4 3 2 1

16. Use the electron structure of representative elements to predict oxidation states and bonding capacity.
5 4 3 2 1

17. Draw *s* and *p* orbitals on the x, y, and z axis of three dimensional space.
5 4 3 2 1

18. Electron location cannot be exactly determined at any given time. Please explain what this means.
5 4 3 2 1

19. Demonstrate an overview of the basic types and why they occur.
5 4 3 2 1

20. Understand the concept of half-life and how it applies to the ratio of stable to unstable isotopes
5 4 3 2 1

21. Understand the concept of half-life and how it applies to determining the age of a material.
5 4 3 2 1

22. Matter is not conserved in nuclear reactions. Please explain.
5 4 3 2 1

Atomic Structure Post Survey

Please rate your knowledge and/or ability honestly by circling the number that best applies. Use the following scale:

(5) My knowledge and/or ability of this topic are very high. I would score ≥ 85% if tested on it.

(4) My knowledge and/or ability of this topic are fairly good. I would score ≥ 70% if tested on it.

(3) My knowledge and/or ability of this topic are OK. I would score ≥ 50% if tested on it.

(2) My knowledge and/or ability of this topic are fairly poor. I would score ≥ 25% if tested on it.

(1) My knowledge and/or ability of this topic are very poor. I would score < 25% if tested on it.

1. I could identify the location, relative mass, and charge of an electron in an atom.
   5 4 3 2 1

2. I could identify the location, relative mass, and charge of a proton in an atom.
   5 4 3 2 1

3. I could identify the location, relative mass, and charge of a neutron in an atom.
   5 4 3 2 1

4. I would describe an atom as mostly empty space with an extremely small, dense nucleus consisting of protons and neutrons and an electron cloud surrounding the nucleus.
   5 4 3 2 1

5. Protons inside a nucleus repel each other and a strong force must be present to keep the nucleus intact.
   5 4 3 2 1

6. Give the number of electrons and protons present in a representative ion of the first three periods on the periodic table.
   5 4 3 2 1

7. List the number of protons, neutrons, and electrons for any given atom, ion, or isotope.
   5 4 3 2 1

8. Recognize that atoms with the same number of protons must be the same element.
   5 4 3 2 1

9. Demonstrate the ability to write the symbol for an isotope, X Z A, where Z is the atomic number, A is the mass number, and X is the symbol for the element.
   5 4 3 2 1

10. Flame tests of elements produce characteristic colors. Explain this by describing the energy transitions which produce these characteristic colors.
5 4 3 2 1

11. Contrast the mechanism of energy changes and the appearance of absorption and emission spectra.
5 4 3 2 1

12. Explain why an atom can only absorb certain wavelengths of light.
5 4 3 2 1

13. Compare different wavelengths of light using frequency and relative energy.
5 4 3 2 1

14. Demonstrate the ability to write the complete electron configuration of any element in the first four periods of the periodic table.
5 4 3 2 1

15. Demonstrate the ability to write the kernel structure for a representative element.
5 4 3 2 1

16. Use the electron structure of representative elements to predict oxidation states and bonding capacity.
5 4 3 2 1

17. Draw *s* and *p* orbitals on the x, y, and z axis of three dimensional space.
5 4 3 2 1

18. Electron location cannot be exactly determined at any given time. Please explain what this means.
5 4 3 2 1

19. Demonstrate an overview of the basic types and why they occur.
5 4 3 2 1

20. Understand the concept of half-life and how it applies to the ratio of stable to unstable isotopes.
5 4 3 2 1

21. Understand the concept of half-life and how it applies to determining the age of a material.
5 4 3 2 1

22. Matter is not conserved in nuclear reactions. Please explain.
5 4 3 2 1

Atomic Structure Unit Pre-Test

Name ________________________ **Hour** ________ **Date** ______

Vocabulary: Match the following

1. atomic mass_____
2. atomic number_____
3. light_____
4. isotope_____
5. orbital_____
6. mass number_____
7. photon_____
8. representative elements_____
9. atomic weight_____

a. elements in which s or p sublevels are being filled

b. particle or quantized packet of electromagnetic radiation with an energy, wavelength, and frequency

c. electromagnetic radiation that can be seen by human beings

d. mass of an atom, expressed in atomic mass units

e. number of protons in the nucleus of an atom

ab. number of neutrons in the nucleus of an atom

ac. Number of protons and neutrons in the nucleus of an atom

ad. elements in which the d sublevel is being filled

ae. Atoms with nuclei containing the same number of protons but different numbers of neutrons

bc. Region of space where there is a high probability of finding an electron.

bd. A principle, which states that electrons in atoms emit unique bright line spectrums

be. A weighted average of the mass of the naturally occurring isotopes of an element

Multiple Choice: Be careful, there may be more than one correct answer.

10. In Rutherford's experiment, almost all alpha particles passed through a sheet of gold foil. This showed that:
    a. alpha particles had mass
    b. gold atoms are mostly empty space
    c. gold atoms had large nuclei
    d. none of the above

11. The mass number of an atom is the
    a. number of neutrons plus protons
    b. number of neutrons
    c. number of protons
    d. none of the above

12. Cl^- is a(n)
    a. cation
    b. anion
    c. protion
    d. none of the above

13. The element fluorine has:
   a. 9 protons b. 10 protons
   c. 11 protons d. none of the above

14. According to Dalton, atoms:
   a. are indivisible b. may combine in different ratios in molecules
   c. have isotopes d. all of the above

15 Electromagnetic radiation has:
   a. frequency b. wavelength
   c. energy d. all of the above

16. For all electromagnetic radiation frequency and wavelength are:
   a. inversely related b. directly related
   c. unrelated d. exponentially related

17. For all electromagnetic radiation frequency and energy are:
   a. inversely related b. directly related
   c. unrelated d. exponentially related

18. For all electromagnetic radiation wavelength and energy are:
   a. inversely related b. directly related
   c. unrelated d. exponentially related

19. Electromagnetic radiation with a wavelength between 400 and 700 nm is:
   a. infrared b. visible
   c. ultraviolet d. none of the above

20. Electrons in atoms can:
   a. absorb energy and rise to new energy levels b. join with the nucleus
   c. emit energy and fall to lower energy levels d. answers a and b

21. No two electrons can possess the same set of quantum numbers. This is called
   a. Hund's rule b. the Pauli exclusion principle
   c. the Aufbau principle d. none of the above

22. The notation $1s^2 2s^2$ is called
   a. Campbell notation b. Shower notation
   c. Aufbau notation d. configuration notation

23. The type of notation that indicates only outer shell electrons is called
   a. quantum notation b. magnetic number notation
   c. dot notation d. spin notation

24. Elements having similar outer shell configurations of electrons have
   a. the same mass b. similar properties
   c. the same group or family number d. the same period number

25. All atoms of same element have the same
   a. mass b. # of protons
   c. # of protons and neutrons d. # of neutrons

Short answer:

1-15

Complete symbol	Mass number	Protons	Neutrons	Electrons	Atomic Number

16a-b. Give the electron configuration notation for Arsenic (As). **Please use the long form and the noble gas shortcut form.**

17. Give the orbital (arrow) notation for Iron (Fe). Please use **the noble gas shortcut.**

18. Give the dot notation or Lewis structure for the first four halogens.

19a-b. Draw a Bohr diagram for the elements Ca and Br.

20a-i. **Neatly and clearly** mark the location of the s, p, d, and f blocks **on the periodic table at** the end of the test. Also mark the location of the alkali metals, **alkaline earth metals,** oxygen family elements, halogens, and noble gases. **If the locations are not clearly** marked you will not receive credit.

Atomic Structure Unit Post Test

Name ______________________________ **Hour** __________ **Date** _______

Vocabulary: Match the following

1. atomic mass_____
2. atomic number_____
3. light_____
4. isotope_____
5. orbital_____
6 mass number_____
7. photon_____
8. representative elements_____
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d. mass of an atom, expressed in atomic mass units

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19a-b. Draw a Bohr diagram for the elements Ca and Br.

20a-i. **Neatly** and **clearly** mark the location of the s, p, d, and f blocks on the periodic table at the end of the test. Also mark the location of the alkali metals, alkaline earth metals, oxygen family elements, halogens, and noble gases. If the locations are not clearly marked you will not receive credit.

APPENDIX B

LESSON INFORMATION

The ChemQuest© Inquiry material discussed in this research is available from Mr. Jason Neil at:

http://www.chemistryinquiry.com/

APPENDIX C

STATISTICS

Table 3: Pre/Post Survey Data

Q # Post-Survey	My knowledge, and or ability of this topic are very high. (5)	My knowledge, and or ability of this topic are fairly good. (4)	My knowledge, and or ability of this topic are OK. (3)	My knowledge, and or ability of this topic are fairly poor. (2)	My knowledge, and or ability of this topic are very poor. (1)	N	# of Students in class A, B, and C who answered 4 or 5	# of Students in class A, B, and C who answered 1, 2, or 3	# of Students who changed to answers 4 or 5 Pre. Vs. Post
1	12	12	6	1	1	32	24	8	14
2	9	14	7	1	1	32	23	9	13
3	9	13	8	1	1	32	22	10	12
4	21	4	6	1	0	32	25	7	15
5	14	9	7	2	0	32	23	9	13
6	14	7	9	2	0	32	21	11	11
7	14	10	6	2	0	32	24	8	14
8	17	10	3	2	0	32	27	5	17
9	12	11	6	2	1	32	23	9	13
10	4	13	10	3	2	32	17	15	7
11	3	7	13	7	1	31	10	21	0
12	5	13	6	7	1	32	18	14	8
13	8	6	10	6	2	32	14	18	4
14	20	6	5	1	0	32	26	6	16
15	9	9	7	3	2	30	18	12	8
16	2	10	10	6	4	32	12	20	2
17	8	11	11	2	0	32	19	13	9
18	9	7	10	5	0	31	16	15	6
19	6	10	9	5	1	31	16	15	6
20	9	6	8	7	2	32	15	17	5
21	8	6	9	7	2	32	14	18	4
22	5	10	6	5	3	29	15	14	5

Table 4: Pre/Post MC Test Analysis

Question #	Pretest Correct A, B, C	Pretest Wrong A, B, C	Post-Test Correct A, B, C	Post-Test Wrong A, B, C	p-value
1	26	5	22	8	0.326
2	9	22	23	7	0.000
3	21	10	21	6	0.184
4	12	19	17	13	0.070
5	18	10	19	11	0.424
6	4	27	17	13	0.000
7	8	23	17	13	0.010
8	10	21	14	16	0.602
9	12	19	16	14	0.477
10	16	15	19	11	0.326
11	13	18	18	12	0.136
12	16	15	17	13	0.769
13	19	12	27	3	0.005
14	2	29	1	29	0.573
15	23	8	28	2	0.001
16	14	17	18	12	0.169
17	12	19	19	11	0.050
18	11	20	10	20	1.000
19	8	23	15	15	0.070
20	1	30	6	24	0.057
21	8	23	7	23	1.000
22	10	21	23	7	0.001
23	2	29	24	6	0.000
24	0	31	15	15	0.000
25	7	24	10	20	0.537
	11.28	19.6	16.92	12.96	0.271

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