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The particulate nature of polyatomic ions: an exploratory study using molecular drawing software

Leodore Mathew, Jr. Amiot
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THE PARTICULATE NATURE OF POLYATOMIC IONS: AN EXPLORATORY STUDY USING MOLECULAR DRAWING SOFTWARE

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

In

The Department of Educational Theory, Policy, and Practice

by

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August, 2007
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Abstract

The purpose of this study was to determine if the use of molecular drawing software would improve student understanding of polyatomic ions. Using software designed for producing drawings of molecules, students developed drawings of polyatomic ions during a regular activity of the state mandated core curriculum on ions. The sample consisted of students enrolled in chemistry at a rural south Louisiana high school—both Honors and Regular. Pretest and posttest scores were analyzed with a number of covariants.

The statistical analysis of test scores indicated that there was no significant difference in the improved test scores between the treatment and control groups. The lack of a significant improvement in test scores fails to mirror the results of other documented studies such as that performed by Wu, Krajcik, and Soloway (2001), which made use of similar representations and produced positive gains in the understanding of formulas. However, interviews that were conducted seemed to indicate that the treatment students did obtain a greater understanding of polyatomic ions than did the control group students. More sensitive test items may be needed to detect changes in understanding caused by the intervention.

Despite learning this new computer visualization skill in addition to mastering the traditional content, statistical analysis showed the intervention did not have a detrimental effect on test performance.

Through personal observation of student performance in later lessons, some transfer appears to have been achieved amongst the students in the treatment group. The possibility of transfer follows some of the findings of Haskell (2001). It was also observed that students that had the opportunity to utilize the computer software had improved inquiry skills. The
average test scores for all groups increased with the greatest increases in the treatment group scores. Despite these gains, there was no significant increase in test scores for the treatment group. Analysis of the Birnie-Abraham-Renner Quick Attitude Differential (Williamson, 1992) scores indicated no correlation between student attitudes and the intervention. From the analysis of the interviews, there is an indication that an improved understanding of polyatomic ion structure resulted from the intervention.
Introduction

In the study of chemistry, and to some extent biology and geology, it is absolutely necessary that the learner has not only a familiarization with the concept of the particulate nature of matter, including the polyatomic ion, but also an appropriate understanding of this concept. The concept of particulate nature is one of the underlying foundations of chemistry. One researcher (Nussbaum, 1985) suggests that “the fundamental notion that all matter is particulate and not continuous is of prime importance for all causal explanations of any kind of change in matter” (p. 124). Without an appropriate understanding a learner faces great difficulty in mastering more complex concepts and skills to be found in chemistry. It is also one of the most difficult concepts to teach in the classroom as many students have a demonstrable inability to visualize the submicroscopic world of chemistry. This difficulty may be reduced when students obtain an understanding of the “models of chemistry,” which were developed to explain the submicroscopic world (Coll & Treagust, 2003). This study involved the ability of students to interpret, translate, and transfer an understanding of the representations known as chemical formulas when used to represent polyatomic ions. More specifically, the students were encouraged to visualize the particulate nature of, as well as, the structure of the polyatomic ions that are so common in the products used in their daily lives.

Interest in the Topic

Interest in investigating the understanding of the concept of the particle nature of polyatomic ions was a result of several years teaching experience as well as conversations with colleagues. These interactions have demonstrated that students have a tendency to overlook the fact that polyatomic ions are particles that exist as a specific species. Often
when encountering these particles in equations involving dissociation of ionic substances, students will divide the polyatomic ion into constituent atoms instead of allowing the ion to continue to exist. The use of computer graphics to provide a visual cue for students is made possible through the use of molecular drawing software. These visual cues prompt students to expand and enhance their conceptions of the particulate nature of matter once they have worked with polyatomic ion drawings. One useful aspect of the software is the ability to change from one model of particle to another (i.e., from ball-and-stick to space-filling). This capability is useful since the ball-and-stick model is more useful in portraying the three-dimensional properties of the ions while the space-filling model provides a better view of the volume occupied and the general shape of the particles (Balaban, 1999).

In order to improve students’ understanding of this important concept, it becomes necessary to assist the students in improving their ability to reason about the submicroscopic world of chemistry. This improvement may be accomplished through the application of inquiry-based instruction in a medium with which the students are familiar. There are a number of possible ways in which students may develop their own ideas and conceptual understandings of atomic and molecular structures.

When students enter a classroom, they have already developed their own concepts and beliefs about how the world is and how it works (NRC, 2000a). These beliefs and concepts must be identified and then used as a base upon which to build new conceptions and understanding. Identification of these pre-existing ideas may be determined in a number of ways: concept inventory, testing, or even simple questioning. Regardless of the manner in which the pre-existing concepts are determined, the building of new conceptual understandings will involve making use of that portion of inquiry involved with the transfer
of learning from one situation to a new situation. As students are being encouraged to
develop their own thoughts and theories, they will need to transfer what they already know
into the building of new concepts. This transfer may be enhanced through the use of
analogies and metaphors (Haskell, 2001). The utilization of an analogy will allow students to
understand unseen phenomena in terms of some common experience in the macroscopic
world. To successfully use the analogy, the analogy’s characteristics must be mapped, or
transferred, from the known to the unknown in one-to-one correspondence (Hackney &
Wandersee, 2002) so that students are able to make the connection between the two ideas.
The analogies and metaphors the teacher makes use of may be conveyed by graphics,
discussion, models, or even macroscopic events or experiences with which the students are
familiar. The use of computer software to allow students to draw the polyatomic ionic
particles they are studying should provide a connection between the subatomic world of
chemistry and familiar ideas from the macroscopic world of everyday life.

In addition, students should be encouraged to exchange the ideas they develop with
one another, as the goal of education is the formation of shared meanings (Mintzes &
Wandersee, 1998), a tenet of human constructivism. Constructivism is dedicated to the belief
that an individual’s knowledge is built by the individual as a result of their own experiences
and understandings. Another idea that may be of consequence is that of sideways learning
(Langer, 1997), which calls for the changing of concepts as the circumstances and conditions
change.

Learning Conceptually

Hewson (1996) proposes that learning is a process in which a person changes his or
her conceptions by capturing new conceptions, restructuring existing conceptions, or
exchanging existing conceptions for new conceptions. In order for conceptions to change, certain conditions must be met. The conditions must make sure that the conception is intelligible, plausible, and fruitful.

In experts, the gap between the observable and the non-observable is bridged by the large amount of content knowledge they possess and use when dealing with sub-microscopic concepts. Students may attain some of this vast knowledge through the continual expansion of their experiences and a concerted effort by the teacher to provide a large number of examples and facts. It will also be necessary for the teacher to provide instruction in ways of organizing this quantity of knowledge into a conceptual framework that will make it readily available for use when needed (NRC, 2000a). This framework will make retrieval of knowledge much easier. This characteristic is also present in experts and is referred to as fluent retrieval (Haskell, 2001).

In conjunction with the provision of facts, students will receive instruction through the use of conceptual models. The use of these models has been shown to shift thinking more towards the behaviors exhibited by experts (Shih & Alessi, 1993). The use of modeling activities in the teaching of chemistry is strongly encouraged as the focus of future research (Justi & Gilbert, 2002). “The possibility of improving students’ understanding of chemistry and models, as well as of their ability to produce their own chemical models, suggests the outcomes of this research may well be the basis for a revolution in chemical education” (Justi & Gilbert, 2002, p. 51) Conceptual thinking will be further advanced by instruction in metacognitive skills, which allow students to monitor their own thinking and decide when it is inadequate (Haskell, 2001).

Specific activities used to aid students in the development of their own conceptual
models will of necessity be devised and decided upon by the individual teacher. For the purposes of this question however, activities may include the use of computer-aided instruction, the building of models, and Internet-based inquiry projects.

The traditional activity of model building with molecular-model building kits, jellybeans, marshmallows, or other similar materials is of greatest value for those who have previously developed a mental model of the concepts involved. The benefit to students struggling with the conceptual understanding of atomic and molecular structure is most likely minimal. These models provide only one aspect of the concepts involved in understanding how atoms combine to form molecules. In addition, these models are static, whereas atoms and molecules are constantly moving and vibrating. Model building does have the ability of representing, however minimal, the theoretical structure of molecules and may in some way assist students in the development of their own conceptual understanding.

The Computer in the Classroom

The introduction of the computer into the classroom has expanded the instructional method possibilities for teachers desiring to take advantage of the tasks it can perform. With the proper software, teachers can provide students with experiences that were not possible before. An activity that makes use of the computer and a molecular drawing program is another example of a means by which student understanding of atomic and molecular structures may be enhanced. Features of most of the drawing software programs include various representations of the structures that the students create. The normally included representations are: ball-and-stick, structural, and space-filling spheres. The software also has the ability to put these structures into motion, which in some ways mimics the expected motions of the structures.
This means of viewing the sub-microscopic particles of the chemical world is more realistic and more interesting than the static models discussed above. This particular activity is of greater interest since the use of the computer is involved as a component of my future research project.

The computer is also an integral part of the third activity suggested above and involves the use of Internet-based projects, such as directed browsing or Web Quests. In these types of activities, students would be led to ask an appropriate question concerning the structures of interest and then allowed to search for information that will provide an answer. The unstated goal of this type of activity will be the discovery by the students of the huge amounts of information available for the determination of a response to their query. If coordinated and prepared properly, the activity could lead students to the realization that their own understandings need to be improved and their conceptual understanding must undergo revision.

Inquiry learning, when properly applied and utilized, is the one of the best methods for the teaching of science for understanding (Layman, 1996). The National Science Education Standards also make reference to the use of inquiry for the learning and understanding of science (NRC, 2000b). With proper research and careful development, effective activities for the teaching of the concepts of atomic and molecular structure are possible.

The Particulate Nature of Matter

Various studies concerned with learning and teaching about the particulate nature of matter (Ben-Zvi, Eylon, & Silberstein, 1986; Burke, Greenbowe & Windschitl, 1998; Gabel, Samuel & Hunn 1987; Haidar & Abraham, 1991; Nurrenbern & Pickering, 1987; Sanger,
2000; Sanger & Badger, 2001; Sanger, Phelps, & Fienhold, 2000; Williamson & Abraham, 1995; Yarroch, 1985) present evidence of learner inability to succeed in advanced chemical topics without a sufficient understanding of this topic. Not only does a failure to understand this concept result in little or no success in chemistry, it may lead the learner into the establishment of an alternate conception about the nature of matter (Basili & Sanford, 1991; Griffiths & Preston, 1992; Harrison & Treagust, 1996; Lin, Cheng, & Lawrenz, 2000; Nakhleh, 1992; Peterson & Treagust, 1989; Smith, Blakeslee, & Anderson, 1993; Wandersee, Mintzes, & Novak, 1994; Zoller, 1990). Harrison and Treagust (2002) suggest that it would be to students’ advantage if additional evidence is provided to fill cognitive gaps in developing their ideas that matter is particulate. With the inclusion of the Science as Inquiry strand in the National Science Education Standards, the inclusion of the historical development of the particle theory may be of great use. Within the same report, it is argued that when chemistry teachers teach the particle nature of matter they should avoid the ‘quick tell’ of the topic and “encourage students to examine the broad range of data pertaining to particles and negotiate communal understandings that are compatible with science and the students’ intellectual level” (Harrison & Treagust, 2002, p. 203). These alternative conceptions, also referred to as misconceptions, result when a learner’s understanding of a specific topic fails to succumb to the generally accepted scientific explanation of some phenomena and the learner creates a mental compromise between the two different ways of understanding a concept.

The Work of Nussbaum

When stating that “the fundamental notion that all matter is particulate and ‘not continuous’ is of prime importance for all causal explanations of any kind of change in
matter” (p. 124), Nussbaum (1985) describes the research that had been and was being conducted into students’ understanding of the particulate nature of matter. Early in his research, Nussbaum determined that the conceptions of children change with age and experience—from naive/egocentric views to more scientifically accepted views (Nussbaum, 1979). These more scientifically accepted views of the particulate nature of matter are the goals of chemistry educators. In one study, it was suggested that students’ “transition from a primitive continuous to a particulate conception of matter is a major change in pupils’ outlook on the physical world” (Novick & Nussbaum, 1978, p. 273). The authors also warn that proper care must be taken to account for the psychological structure of the learners. This psychological aspect involves accepting one model in place of another, already internalized model. The teacher must have an understanding of where the students are in their understanding on matter and work to increase their understanding so that the more scientifically accepted model of particulate matter replaces incorrect models that the students may hold. A difficulty the teacher may encounter is the idea that a particulate picture sometimes contradicts one’s sensory perception of matter (Novick & Nussbaum, 1978). Teachers must work to show that even though visual inspection tends to support that matter is continuous, it is particulate.

An additional study performed by Novick and Nussbaum (1981) determined that in order for students to internalize the particulate model of matter, students must overcome basic cognitive difficulties of both a conceptual and a perceptual nature. The authors found that the “aspects of the particle model which are most in conflict with immediate perception present the greatest cognitive difficulty and are therefore least internalized” (Novick & Nussbaum, 1981, p. 187). The conflict between the particulate model of matter and the visual
evidence that students gather from their own observations of matter create the greatest obstacles in presenting and accepting the particulate model of matter. The teachers must put forth as much effort as possible to overcome these discrepancies in theory and observation. With age, the students, in increasing numbers, tend to accept the particulate model (Novick & Nussbaum, 1981). The authors found that students commonly have a static particle picture. Due to this condition, students do not apply particle motion to explain uniform distribution of particles when a gas sample’s conditions are manipulated. Even though there is a steady increase over grade level to senior high in the percentage of students attributing uniform particle distribution to inherent particle motion, the figure does not reach 50% (Novick & Nussbaum, 1981). It was also determined that many attribute decreased gas volume with cooling, not to reduced particle motion but rather to increased attractive forces. Many of the students involved with the study had a tendency to “think that the particle model held only for gases and that liquids (and presumably solids) are continuous matter” (Novick & Nussbaum, 1981, p. 193). These are some difficulties that teachers must overcome when presenting the particulate model of matter in the course of instruction in chemistry.

In the course of studying children’s ideas of matter, Nussbaum (1985) determined that “the majority of pupils claimed that air is made up of particles, but only a minority demonstrated the internalizations of the idea of empty space between particles (at best 50 per cent of an age group) and of intrinsic particle motion (at best 40 per cent of an age group)” (p. 132). So even though students claim to understand and accept the ideas of the particulate model, few demonstrate a cognitive change to the model. Nussbaum asserts that the concepts of the particle theory are intellectual constructs based on various assumptions that are beyond direct observation. This indicates that students have a great difficulty in accepting ideas that
they themselves cannot see. The author indicates that in order to initiate conceptual changes a conceptual conflict must exist between a previously held conception and contradictory evidence – ‘a discrepant event.’ These findings show that although it may be difficult to create a conceptual change in students, with persistence and hard work it is possible.

The studies and researches conducted by Nussbaum allowed for the development of arguments supporting and ideas enhancing constructivist teaching (Nussbaum, 1998). Nussbaum asserted that there are three academic areas nurturing the evolution of the constructivist approach in science education: 1) research on students’ misconceptions, 2) new developments in cognitive psychology, and 3) new developments in the history and philosophy of science. It is during a discussion of the history of science and the use of analogies that Nussbaum describes the contribution of Newton to the atomic model of matter. He states: “Newton … significantly promoted the physical view of atomism. As an analogy to his universal gravitational forces which acts from a distance, he proposed similar forces between microscopic particles” (Nussbaum, 1998, p. 179). Continued discussion into the constructivist method of teaching leads to the description of strategies to be used.

**Strategies**

1. Learn by debating essential ideas.

2. Initiating instruction with a discussion of the concept of vacuum.
   The main innovative idea of particle theory is the fact that vacuum is a significant immanent component of physical existence.

3. Initiating the study of the particle model by investigating the behavior of air and other gases.
4. Utilizing analogies and key experiments which have been found to be effective in the history of science. An important element of scientific thinking has always been the use of analogies.

5. A study of the particle model is a lengthy process of conceptual change.

6. Misconceptions may have a positive role. Misconceptions may be viewed as essential steps in the evolution of innovative ideas (pp. 180 – 182).

Chemical Formulas

The topic of this research study is the concept of chemicals and chemical formulas and how learners perceive them. Friedel and Maloney (1992) performed a preliminary exploration of this topic and determined that college students struggling with this concept failed to think in terms of atoms and molecules and instead made use of algorithms to determine the desired outcome of a conceptual question presented by their instructor. Yarroch (1985) found similar problems among learners working on the balancing of chemical reaction equations. These learners had little understanding of the particle concept yet solved the problems through the use of algorithms as opposed to finding a solution via the concepts involved. Improving students’ understanding of the particle nature of matter enhances their abilities to solve problems cognitively without having to fall back on the algorithmic methods of problem solving.

Exploration Evolution

The evolution of this exploration, graphically represented below, began with initial registration and enrollment into the doctoral program of the LSU Department of Curriculum and Instruction in January 2000. The idea resulted from personal observations of students in high school chemistry and from discussions with colleagues concerning the problems being
January 2000
Began course of study to develop theoretical background

Fall 2001
Develop research idea and questions.

August 2001
Begin Literature Review

Summer – Fall 2004
Write first draft of prospectus

Spring 2006
Delivery of lesson on ionic compounds

Spring 2006
Data from pre- and posttests is analyzed and controlled for several covariates

Fall 2004 – Spring 2005
Refine and edit questions

Fall 2004 – Spring 2005
Edit and refine prospectus

Fall 2005
Prospectus approval by committee

Fall 2005
Experimental group works with HyperChem Lite to draw particles

Drawings are collected from students as files on disk

Data from pre- and posttests is analyzed and controlled for several covariates

Figure 1: Flow Chart of Exploration
exhibited by these high school students in understanding the nature of polyatomic ions as
discrete particles with their own identity. A more concrete form of the topic was developed in
Fall 2001 while on graduate sabbatical. Coursework and discussions with instructors
provided the knowledge and guidance to focus on the concepts and ideas to
be investigated. The development of a concept map, found in Appendix A, and a Vee
diagram, found in Appendix B, assisted in focusing the scope and aims of the exploration.
With the establishment of the basic ideas of the exploration, the search of relevant literature
was undertaken. This literature review refined the scope of the exploration and initiated the
particular methods to be used.

During the literature review, the initial research questions were developed. Additional
searching, review, and discussion brought about revisions and refinement to the questions.
The present form of the research questions was created in the spring of 2004. A consequence
of the literature review was the introduction of ideas and concepts related to the basic topic
being investigated so that the end result was the present form of the questions being posed
and the exploration as it exists.

Purpose of the Study

The purpose of this exploratory study was to determine the extent to which the use of
chemical structure drawing software enhances high school chemistry students’ understanding
of the particulate nature of chemicals, specifically polyatomic ions, when used in conjunction
with the traditional lecture/discussion instruction on the topic of chemical formulas of ionic
compounds. In addition, the study addresses the following questions:

1. Does a polyatomic ion’s nature as a particle improve with molecular drawings as a
visual cue?
2. Do the high school students using selected computer drawing software perceive that this learning experience adds value to the lecture/discussion method normally used as the instructional strategy?

3. Does the use of the computer modeling software in the lesson improve student attitudes toward chemistry, as determined with the Birnie-Abraham-Renner Quick Attitude Differential (Williamson, 1992), for those students using the strategy?

4. Does the use of the new strategy increase student competency to represent a chemical formula in multiple representational forms and increase near transfer?

5. Does the new strategy improve chemistry test performance in the topic area of chemical formulas?

6. Does the level of conceptual understanding as indicated by testing correlate with attitude-toward-chemistry scores?

The chapter on methods addresses the manner in which these questions were answered.

Significance of the Study

The interest in improving learners’ understanding of the particulate nature of matter has been the subject of a growing body of research over the last 20 years. The use of computer technology as a general, all-purpose instructional assistance tool has improved in popularity in the classroom as well as become a research topic in an increasingly larger number of studies, both in and out of the field of education. Barnea and Dori (1996) developed an integrated strategy that instilled excitement and interest in both teachers and learners. Brooks (1993) asserted that the use of computer technology was transform teaching, most likely in terms of new instructional strategies being used and in the manner in which
course materials are delivered to the students. Computer technology has been tested as the mode of delivery for instruction in many different and interesting ways (Donovan & Nakhleh, 2001).

Through the use of new computer technology, it may not only be possible to improve the understanding of the particulate nature of matter in students, but, with time, enhance the scientific literacy of the general population, as defined by Cajas (2001). Cajas believed that research can serve as a means of providing guides for the interactions between science and technology. This indicated that Cajas believed that research was necessary to determine the optimal manner in which this constantly evolving technology may serve the public, science, and science education.

Justi and Gilbert (2002) asserted that the representational and computational capabilities of computers should be used to design multiple, coordinated representations. It was also contended that using computerized models has been advocated as a means of improving students’ understanding of chemical phenomena. This service may be utilized by enhancing the relationships that exist between these groups through improved communication and understanding.

Most of the studies conducted with the assistance of computer technology have used college students as the subjects of the new strategies being tested. There is a need to study the high school learner interacting with this potentially powerful teaching tool to determine its feasibility as an effective strategy to improve chemical concept understanding. With the increased introduction of computer technology into the schools over the past ten years, it now may be possible to tap into this available computer technology in order to make it work for the improvement of science teaching and learning.
Rationale of the Study

A deep conceptual understanding of the particulate nature of matter is essential for real success in chemistry as opposed to simply ‘making the grade’ as is practiced in most of our schools today. Once again it is necessary to remember that Nussbaum (1985) stated that “the fundamental notion that all matter is particulate and not continuous is of prime importance for all causal explanations of any kind of change in matter” (p. 124). In a study of student conceptions, Driver (1989) advances the argument that learning involves more than just the learner’s making sense of their own personal experiences but also involves being initiated into the “ways of seeing” as established by the scientific community. As an argument, it indicates the very real need to assist students in developing not only a conceptual understanding of the scientific principles and concepts, but also an understanding of how science is done. A study conducted by Rop (1999) reports that some students are discouraged by traditional methods of chemistry teaching but have a desire for a deeper understanding of the nature of the field. This study provided further evidence of the need for conceptual understanding in order to assure that students develop a true scientific perspective that allows them to become members of the scientific community.

Keeping Students Interested

In another aspect, Ebenezer and Zoller (1993) report that students find science class so ‘boring’ that many see no reason for continuing their studies in any of the fields of science. The use of computer technology may help break the chain of traditional instruction and breathe a little life into science classes. A new instructional strategy that includes the computer might improve student interest and provide them with an interactive partner, something that is very difficult for a teacher with a classroom full of students. This new
strategy may also produce advantages in student understanding through increased student
‘mindfulness’ (Langer, 1997) as a result of the introduction of variety to the teaching
strategies used by the teacher. In addition, the use of computer technology may increase
student enjoyment in the study of chemistry, which in turn results in a greater understanding
and improved learning. As Oliver Sacks (2001) states:

at school, I was forced to sit in classes, to take notes and exams, to use
textbooks that were flat, impersonal, deadly. What had been fun, delight,
when I did it in my own way became an aversion, an ordeal, when I had
to do it to order. What had been a holy subject for me, full of poetry, was
being rendered prosaic, profane. (p. 314)

Maintaining student interest is the only way teachers can ensure that students are receiving
the greatest benefit from instruction; computer technology can assist in maintaining interest.
The use of computer molecular modeling software has shown that there is a potential for
increasing the understanding of the concepts encountered by learners in the chemistry
classroom (Burke, Greenbowe, & Windschitl, 1998; Casanova, 1993; Kozma & Russell,
1997; Russell, Kozma, Jones, et al., 1997; Sanger & Badger, 2001; Sanger, Phelps, &
Feinhold, 2000; Williamson & Abraham, 1995). By improving the conceptual understanding
of this underlying principle, learner success in the study of chemistry and all related fields
may progress to levels far in advance of the present levels of measured achievement and
ability. It is therefore imperative that research attempts to identify those instructional
strategies or instructional assistance tools that ensure that learner success is raised to the
highest possible level.

Inquiry

Inquiry is described as the activities and thought processes that allow scientists to
expand human knowledge (NRC, 2000b). The inclusion of inquiry into the National Science
Education Standards was for the purpose of exposing students to these activities and processes. In addition, the inquiry factor is included as an additional means of trying to make learning meaningful to the students. Inquiry is the process by which one goes about discovering new knowledge about the world and how it works. Inquiry is the process and skills used by scientists to find this new knowledge (NRC, 2000b). Inquiry has been described by the National Science Education Standards as both a learning goal and a learning method (NRC, 2000b). As a teaching method, inquiry involves the use of classroom activities, which allow students the opportunity to gain new knowledge through hands-on labs that encourage and highlight the skills and processes of science. Upon the decision to include inquiry into their classroom, the teacher determines the definition of inquiry that will be used (Llewellyn, 2002).

Within the National Science Education Standards, inquiry is also a goal for science teaching. The purpose here is to improve student understanding and learning of science in such a way that students are capable of becoming lifelong learners. Through the proper design of instructional opportunities, students learn that science is more than a list of isolated facts and concepts; it is a dynamic ongoing process (Layman, 1996). Inquiry will afford students the opportunity for building their knowledge of science and developing the skills necessary to improve their understanding. Learning in this case is the changing of conceptions through the capturing of new conceptions (Hewson, 1996) as may be discovered with inquiry.

With inquiry integrated into their knowledge and understanding, students will be capable of advancing their learning in a manner that is best described by constructivism. The building of students’ science knowledge on previous knowledge is a basic idea of the human
constructivist theory of learning. In this model, there are three main principles: humans are meaning makers, the goal of education is shared meanings, and shared meanings may be facilitated by the active participation of well-prepared teachers (Mintzes & Wandersee, 1998).

This improving of abilities to learn through inquiry can be enhanced by utilization of metacognitive techniques. These techniques will provide the students with ways to check their understanding and determine when it is inadequate and needs improving. It is also a means of monitoring one’s own thinking and learning in order to assure the proper integration of new knowledge into a cognitive framework.

The National Science Education Standards also describe inquiry as a teaching method that may be used for the improvement of science learning and understanding. The National Science Education Standards make quite clear that inquiry is not the only method that should be used for the teaching of science (NRC, 2000b). Teachers must remember that there is no one universal method or strategy for teaching science, the most effective means is through the utilization of many different methods and strategies.

Inquiry as a method of teaching was reintroduced to American education during the reforms of the 1960s by two very prominent educators–Schwab and Bruner (Matthews, 1994). Although inquiry has been around since the early days of the Greek scholar Socrates, John Dewey is credited with introducing it into American education (Llewellyn, 2002). DeBoer (1991), however, intimates that the idea of inquiry was first brought out by Herbert Spencer during the 1860s. Whatever its origin, inquiry is a teaching method that is very beneficial to the student trying to learn and understand science.
Human Constructivism

The human constructivist model of teaching provides the best support for the introduction and implementation of inquiry teaching into the curriculum (Mintzes & Wandersee, 1998). This model advances the idea that learning builds on what the student already knows. This indicates that as a student’s knowledge is building upon what they previously believed about how the world works, the teacher considers this previous knowledge in planning appropriate activities. Ausubel believes in the principle asserting that: one should first determine what the learner already knows and then teach accordingly (Ausubel, 1968).

Many believe that the use of inquiry, or the constructivist model, means that the teacher never tells the student anything. This myth is very far from the actual proper use of inquiry. Within the methods of inquiry, there are many different ways to develop lessons that will achieve the goals of the National Science Education Standards. Inquiry activities exist at many different levels for teachers to use within the classroom. Inquiry itself may be perceived as having many different levels.

Another means of differentiating inquiry activities involved the idea of phasing (Duvall & Martinez-Bagwill, 1999). In this particular version of inquiry, the students are taken through a series of phases that involve differing amounts of initiative. In Phase 1, the students are presented with “cookbook” labs. Phase 2 requires the removal of a data table or graph, the students must determine how and what information must be collected. Phase 3 provides the students with a real-world scenario and an outline of the scientific method. In Phase 4, the student receives a real-world scenario only.
It is through the implementation and use of these methods of inquiry, as well as other methods, that the goals and objectives of the National Science Education Standards will be met and achieved by teachers in the classroom. The National Science Education Standards have set the bar at a level that will require the use of inquiry for the advancement of science learning and understanding.

Inquiry may be seen as having the potential to assist in the attainment of the national goal of science literacy for all Americans. One reason for making this connection is that science process skills are the tools of inquiry (NRC, 2000b). Education, through the methods of inquiry, will eventually lead to the improvement of the public’s understanding of science, both as a pool of knowledge and as an ongoing search for knowledge. With the launching of Project 2061, it has been acknowledged that the American public has little or no understanding of the nature of science (Rutherford & Ahlgren, 1990). Inquiry can help students understand that science is a human construct and not an absolute description of what is and what is not. By interacting with others, these students can come to have a true understanding and appreciation for science as a human endeavor used to explain our world.

It is possible that the use of inquiry methods will provide students the opportunity to share their ideas and understandings with others so that a consensus may be reached in how the world is seen. The application of inquiry methods in everyday life is the basis of scientific literacy which is seen as a very important goal for this country. Inquiry, once the brainchild of progressivism reform educators, may be the very tool needed to attain our goal of national science literacy. The development and implementation of the National Science Education Standards and their inclusion of inquiry are certainly steps in the right direction.
Literature Review

In this review, literature will be discussed in terms of the manner in which it pertains to this particular study. The main divisions of literature, in respect to major topics of concern that will be reviewed, include cognition and cognitive studies, the heuristics used to determine a change in conceptual thinking, conceptual change teaching strategies, dealing with learner misconceptions, using technology, and graphics. As these areas are very broad, it is to be expected that there will be a certain amount of overlap between topics.

Cognition and Cognitive Studies

Cognition as a field of study deals with human ways of thinking and how our knowledge is arranged and interconnected within our long-term memory so that it can be easily and readily retrieved when needed. It is proposed that humans produce webs of interrelated concepts within their long-term memory in such a way that upon the introduction of the proper stimulus the appropriate signal is sent and received, which results in a specific, targeted piece of information being accessed and called up into the working memory for use. Cognition deals with how people think and learn, topics of extreme interest to educators.

How People Learn

A two-year study of the research being conducted in the teaching and learning of science was culminated with the National Research Council’s initial publication of the findings of various committees in 1999. These findings and their implications are reviewed and analyzed within the expanded version of the original published report, How People Learn: Brain, Mind, Experience, and School (NRC, 2000a). A brief overview of the importance of prior knowledge and the ideas of “constructivist” theories are included in this publication as these topics are often mainstays of the various research reports. There is also
included some discussion of the increasing importance given to metacognition as a means of improving student learning and their abilities to transfer this learning to new situations is also included.

The first part of the book deals with the above topics as they are involved in the formulation of the report’s key findings. The first of the key findings deals with preconceptions with which learners enter the learning environment. It is necessary for these preconceptions to be identified and dealt with in such a way as to change these preconceptions to avoid interference which may result in a failure to learn new concepts and information being presented to the learners. In order to accomplish the feat of changing conceptions, it will be necessary for educators to identify the preconceptions held by the learners and then structure lessons that will engage the learners as they acquire the new concepts and information. These lessons must be capable of assisting learners in overcoming conceptions they have been building their whole lives as they observed the world around them.

The second of the key findings deals with the characteristics students should possess in order to be competent in a content area. It is suggested that the students have a solid foundation of factual knowledge, understand concepts based on a conceptual framework, and organize their knowledge so that it is easily retrieved and applied.

These particular characteristics are those which many tout as necessary to obtain within an area. The ability to quickly and easily retrieve information is of greatest benefit to learners as well as to experts. This ability is facilitated by the proper organization of the pertinent information either in the form of the often described schema or even in the form of cognitive concept maps. The idea of schema is one that regularly makes its way into the
discussion of conceptual change. In a similar way, conceptual mapping on the cognitive level can serve much the same purpose. It has also been suggested that these characteristics would increase a learner’s skill at transferring learning to a new situation (Haskell, 2001). Through the implementation of these characteristics, learners would greatly enhance their ability to apply previous learning to new events and situations.

The characteristics, as described in this second key finding, mesh well with the first in bringing about the changing of preconceptions developed by the learner during their lifetime. The preconceptions are developed through personal observation and does not always result in proper scientific concepts since the observations depend on the learner’s own senses without proper instrumentation, observation, or measurement for information outside the range of the learner’s senses.

This finding also meshes well with the third key finding which concerns the use of metacognitive approaches to instruction. This approach, in which the learners control their own learning, would most certainly become an enhancement of the learner’s skills when the learners develop the capability to develop and use the skills of the expert. The skills would allow the learner to easily and quickly determine what he/she already knows and what is still necessary to learn with a minimum of guidance from an outside instructor. The metacognitive approach when properly utilized would allow the learner to accumulate their own unique knowledge and at the same time give them ownership of their learning. This ownership could encourage learners to more quickly develop their knowledge and move toward a higher level of expertise at a rate greater than if they were constantly being required to learn information which they perceive as having no value. These approaches will require that instruction be changed so that learners gain greater control over their own learning.
These findings are the basics for three educational implications. As the findings previously described are supported by research, the derived implications are also the result of a large body of research findings. The implementation of these suggested ideas could produce a significant improvement in the areas of teaching and teacher preparation.

The first of the suggestions implied from the findings deals with teachers determining the existing conceptions of their students. Teachers are then to work with these beliefs in order to bend them in the proper direction to develop more scientifically appropriate beliefs as necessary. No longer can students’ minds be considered sponges into which teachers can just pour knowledge. One method that may assist in this procedure is the use of alternative assessment techniques. Relying on traditional pencil-and-paper tests may not identify student beliefs in a form that is useful to the teacher. The implementation of this idea will most likely require that changes be made in teacher in-service and pre-service educational opportunities.

Secondly, some subject matter must be taught in-depth in order to provide a strong foundation of factual knowledge. This foundation is a primary step in the formation of expertise in an area of study. It is upon this knowledge base that students can expand their horizons. A firm foundation will support a structure of knowledge much larger than the flimsy surface knowledge presently provided to students. With a wide range of knowledge provided, it is possible that interests will be awakened.

Finally, it is imperative that metacognitive skills be taught to students in a variety of subject areas. Through the use of metacognitive skills, student achievement can be improved and student abilities to learn independently could be greatly enhanced. Once students are aware of their own standing and needs, additional learning can be targeted by the student to improve their own knowledge as they see fit.
The report goes on to specific areas that are of particular interest to this project. These areas include: building of expertise, transfer of knowledge, and learning supportive technology.

The first area to be brought under consideration deals with the committee’s findings on how experts differ from novices. As high school science students are to be considered novices, they are beginning to build their knowledge base on their journey to eventual expertise. The study conducted by the committee found seven characteristics of expert knowledge. Given knowledge of these characteristics, teachers have a greater opportunity to guide their students along the proper path to expertise.

The first characteristic involves the ability of experts to perceive meaningful patterns in information that are beyond the ability of novices to discern. As students work their way through the instruction being delivered in the classroom, the information that they notice is usually a good deal different from the information noticed by the expert. With the continuation of instruction, the teacher must assist students in developing skill at recognizing patterns of information and ways of seeing this information more in line with the ability of experts. The emphasis that is placed on pattern perception by experts tends to suggest that this is an important strategy to develop students’ confidence and competence in their chosen field. The ability to recognize the most important information and various patterns present in the information will enhance the student’s overall organizational skills.

Knowledge organization is another characteristic common to the expert. Study has shown that experts organize their knowledge around a set of key concepts which guide their thinking about their field of expertise. The report states that “experts appear to possess an efficient organization of knowledge with meaningful relations among related elements
clustered into related units that are governed by underlying concepts and principles” (NRC, 2000a, p 38). This allows experts to develop an understanding of the problem being faced in terms of the relevant concepts. The fact that expert’s knowledge is organized around key concepts implies that the curriculum should also be organized so that conceptual understanding is achieved. In order to enhance conceptual understanding, changes in teaching strategies and methods will become absolutely necessary.

Once the knowledge has become meaningful and has been organized, it has no value unless it is readily available to the person who has possession of this knowledge. Research has shown that experts have not only accumulated the knowledge but are also capable of accessing and retrieving the pertinent knowledge when necessary. Expert’s knowledge has become “conditionalized.” Experts posses a vast store of knowledge, however only certain small portions are relevant to particular problems at any one time. The expert becomes fluent in the retrieval of knowledge and does so effortlessly, which reduces the demands on conscious attention to minor details.

The report moves to a discussion of transfer of learning, a topic to be discussed in greater detail later. The characteristics and conditions of transfer as reported in research findings are summarized. The report then describes and summarizes the various research findings on how children learn. The final part of the report which is relevant is the discussion pertaining to the mind and brain in terms of neurology, evolution, and cognition.

Overall, this report was quite useful as it combines and summarizes the findings of a large number of research studies dealing with learning and learners. The connections made between the various findings have allowed for the development of a greater understanding and appreciation of the various topics that have been mentioned. As with any field, this
understanding enhances the ability to make use of the information that has been learned. Being that this report made great use of the findings of research studies, individual findings and studies dealing with cognitive abilities will be highlighted.

Meaningful Learning

Anderson (1997) contends that meaningful learning involves the higher cortical centers of the human brain that contain interconnected networks of neurons that may be viewed as neurocognitive equivalents to the schemata used in psychology. A similar analogy may be the concept map as described and advocated by Novak and Gowin (1984). Anderson further contends that neurocognitive theory supports current innovative reforms in science education and will provide additional sources of evidence which will be the basis for building a comprehensive rationale for modern theories of learner-centered science teaching. Many educational researchers are using cognitive science as a basis for their studies involved with improving the educational system.

The tenets of cognitive science are being used in the study of the manner in which learners produce and refine their “mental models” of various aspects of chemical principles. According to Nakhleh (1992), in terms of the cognitive model, learners create meaning based on their background, attitudes, abilities, and experiences. Haidar and Abraham (1991) determined that learner responses to questions were influenced by the language used to present the problem. In response to queries delivered in everyday language, learners used macroscopic concepts; however, when presented using scientific terms, learners responded in terms of microscopic concepts. Harrison and Treagust (1996) found that students described scientific phenomena based on their own individuality and unique construction. These novice learners produced a variety of mental constructs based on unintended interpretations of the
teacher’s metaphors and analogies. Lee, et al. (1993) describe a situation in which the understanding of the word ‘matter’ caused conceptual problems in learners at the middle school level. Many of the learners had difficulty in conceptualizing matter as being made of particles and therefore tended to describe molecules as having the same properties as substances they could observe. Staver and Lumpe (1995) noted that learners exhibited the “inability to transfer understanding between the macro and atomic/molecular levels in problem solving” (p. 190).

Chemical Conceptual Understanding

The findings from studies of chemical education indicate that learners having conceptual understanding difficulties tend to make use of memorized formulas and/or algorithms to solve conceptual problems (Friedel & Maloney, 1992; Gabel & Bunce, 1994; Nakhleh, 1993; Nakhleh & Mitchell, 1993; Noh & Scharmann, 1997; Nurrenbern & Pickering, 1987; Pickering, 1990; Sawrey, 1990; Staver & Lumpe, 1995; Yarroch, 1985). Dreyfus, et al. (1990) assert that students may also fall back to their own established, or ‘naive’, knowledge if these methods fail them, resulting in their own ideas being reinforced to the detriment of acceptable scientific knowledge and principles. Instead of creating the appropriate connections between concepts, learners tend to make use of algorithms to solve chemical problems. Part of the blame for this falls upon chemical educators. For years chemical educators have equated being able to solve chemistry problems with an understanding of the underlying concepts (Nakhleh & Mitchell, 1993; Nurrenbern & Pickering, 1987; Sawrey, 1990). In all levels of chemistry instruction, the ability to solve chemistry problems conceptually has lagged behind the ability to solve chemistry problems utilizing algorithms. Nakhleh and Mitchell (1993) have found that more than 50% of the
chemistry majors in a study sample were rated as low conceptual problem solvers. In a study by Nurrenbern and Pickering (1987), it was found that the majority of learners use “plug-and-chug” methods instead of having an appreciable understanding of the particle on the microscopic level. Pickering (1990) discovered that learners enrolled in non-science chemistry courses had better conceptual understandings of the particulate nature of matter than did learners enrolled in science major courses. Sawrey (1990) contends that chemistry educators and textbooks devote a great deal of effort in improving methods to increase learners’ problem solving abilities. As a consequence, alleges Sawrey, “the qualitative and conceptual side of the discipline has suffered. Students view the traditional type of test questions as mere exercises, but the pictorial concept questions as true problems.” Yarroch (1985) believes that learners balance chemical reaction equations, not through the application of conceptual understanding, but through the use of mathematically manipulated symbols - an algorithm.

Visual Cognition

The use of visual representations of the polyatomic ions seems to indicate the necessity for a discussion of visual cognition. This relatively new branch of cognitive psychology has not been as heavily researched as have other aspects of cognition. The topic is quite interesting and deserves additional investigation.

In Ways of Seeing (Jacob & Jeannerod, 2003) the authors for the most part investigate the philosophical aspects of visual cognition. An initial idea presented is that “Sight, visual experience or visual perception, is both a particular kind of human experience and a fundamental source of human knowledge of the world” (p. ix) The authors also contend that sight interacts in multiple ways with human thought, human memory and the rest of
human cognition. These points underscore that vision is the primary source of information about the world for humans. Or as described by the authors, “sight is a particular kind of human phenomenal experience and a fundamental source of knowledge of the world” (Jacob & Jeannerod, 2003, p. xii).

The idea presented by the authors concerning the basic job of sight is to “provide what philosophers often call the ‘belief box’ with relevant visual information” (Jacob & Jeannerod, 2003, p. xiii). It is within this belief box where mental representations of facts are stored. Vision is also responsible for providing information for the performance of certain actions.

The authors contend that not all mental representations need have purely conceptual descriptive content. Mental representations are neurophysiological states with content according to the authors. They define mental representations as thoughts, judgments, beliefs, desires, intentions, perceptual experiences, memories and mental images. It is the job of cognitive neuroscientists to attempt to “map the activation of neurons in selected areas of the visual system with particular visual attributes instantiated by objects in the environment” (Jacob & Jeannerod, 2003, p. 5). Additional discussion of the philosophical aspects of visual cognition are developed and expounded upon by the authors.

The Thinking Eye, The Seeing Brain (Enns, 2004) provides information, ideas, and concepts that may be of more immediate use to the classroom teacher or educational researcher. The author begins quickly in an attempt to improve understanding of visual cognition by challenging accepted beliefs and ideas with the statement that common understanding of vision and thought are based on inaccurate and outmoded concepts. One of the first beliefs denigrated is the idea that eyes see. As the author states: “no amount of
seeing is actually accomplished by the eyes at all” (Enns, 2004, p. 3). He continues in this
vein when contending that much of what is referred to as thinking relies heavily on are those
portions of the brain that are accessed when seeing the world around us. These ideas have a
tendency to cause an inspection and re-evaluation of our beliefs about vision and its purpose.

As has been stated in previous works, the author here also refers to vision as the
“sense that we as modern beings rely on most of all. Yet we probably spend the least amount
of time thinking about it” (Enns, 2004, p. 4). Vision is the most important source of
information we use, as stated earlier, however we take it for granted without really
understanding how it works or how it interacts with our own cognitive processes.

The author moves on to debunk commonly held beliefs which he refers to as ‘myths.’
In order to think about vision in a new way, it is useful to know what vision is not. The first
of these is the myth that the eye is a faithful recorder of visual experiences. The author makes
use of the presence of optical illusions to prove that the eye can be, and is often, mistaken.
The second myth challenged by the author is that seeing occurs automatically without any
conscious input on our part. Thirdly, the idea that the eyes are responsible for sight is
discussed and shown to be incorrect. The final myth to be brought to task by the author is the
idea that we are capable of thinking without using our senses. When considering the author’s
ideas and arguments, one must re-evaluate established concepts and beliefs concerning sight.
This re-evaluation encourages and enhances growth.

As opposed to the two works described above, Cognition and the Visual Arts (Solso,
1994) does not deal exclusively with visual cognition. The authors discussion and
exploration of visual cognition is only a small part of the work. This work is included due to
the fact that it was this researcher’s initial introduction to the concept of visual cognition.
It is Solso’s contention that in order to understand human visual cognition, one must consider three stages within the problem:

1. Visual cognition (“seeing and understanding”) involves the basic analysis of shapes, forms, colors, contours, contrasts, and movements. These primitives are sensed by the peripheral nervous system located in the eye. Electromagnetic signals in the form of physical energy are transduced to electrochemical signals and passed along the visual cortex for further processing. It is during this latter stage that visual recognition and higher-order processing takes place.

2. Primitive information is organized into fundamental forms. These fundamental forms are the basis for higher-order processing (such as the interpretation of what a form means) and are perceived mostly without prior learning or experience. An example of a fundamental form is the figure-ground pattern, in which an object (figure) stands out from the background (ground). The letters on this page (figure) stand out from the paper (ground). Psychologists who subscribe to the Gestalt (configuration) theory of cognition have studied fundamental forms in detail.

3. Fundamental forms are given meaning through association with previous knowledge of the world stored in long-term memory (LTM). This final stage of the information processing model is sometimes called higher-order cognition, not because it is more elegant but because it occurs as the consequence of previous, “lower” stages. Furthermore, the thinking brain directs our attention to specific parts of a visual scene, giving greater notice to salient features or things that are of personal interest. Finally, the brain adds information to the raw visual impressions, which gives a richness of meaning far beyond the simple stimuli it receives (Solso, 1994, pp. 75, 78).

These works should provide a very brief introduction to the concepts of visual cognition.

Transfer of Learning

During the course of a school year, teachers must impart many lessons to their students. One of the most difficult of these lessons is that the knowledge gained in the classroom can be used in situations other than just answering questions in the classroom. This inability to make use of knowledge in new or different situations is attested to by the
presence of the age old question: “What am I ever going to use this for?” Students must be
given specific instruction in ways to make use of learned knowledge in various situations and
circumstances. Students need to learn how to think and consider every aspect of problems
they face. The capacity to make use of learning in new situations is referred to as transfer of
learning.

In *Transfer of Learning: Cognition, Instruction, and Reasoning* (Haskell, 2001),
Robert Haskell provides a comprehensive overview of the topic of transfer of learning. The
author provides an in-depth look at the concept of transfer of learning based on the literature
that exists. Connections to various educational theories and the implications of these
connections are explored as well. The first part of the book deals with describing transfer of
learning and related topics, including implications arising from the proper utilization of
transfer of learning. The second part of the book involves an exploration of the relationships
between transfer of learning and various educational theories and strategies.

Transfer of learning is defined as the “use of past learning when learning something
new and the application of that learning to both similar and new situations” (Haskell, 2001,
p. xiii) Despite this seemingly simple definition of transfer of learning, there is abundant
documentation attesting to a general failure, both individually and as instructional
institutions, to achieve any significant levels of transfer of learning.

Of the characteristics of transfer of learning discussed, perhaps the most frustrating is
what the author terms the double paradox of transfer. The first of the paradoxes is that
despite the fact that transfer occurs all the time for learning, it seldom occurs within the
instructional environment. It is suggested that transfer of learning fails to occur because most
of our learning tends to be situational (a certain place or a certain subject matter). Secondly,
transfer of learning from the instructional environment to everyday life seldom occurs on any significant level. These paradoxes support the general theme carried throughout, there is a general failure in the transfer of learning.

Based on research findings, Haskell has developed a simple taxonomy containing six levels of transfer of learning: nonspecific transfer, application transfer, context transfer, near transfer, far transfer, and displacement or creative transfer. Of these levels, the first two are considered to be simple learning with the last two being essentially far transfer. When considering that ‘true’ transfer requires the learning of something new to make the transfer, only the last three levels involve significant transfer of learning. Without the learning of something new, the transfer is not viewed to be transfer but only the application of the same learning.

The author develops and supports the existence of a relationship between transfer and thinking. Independent thinking ability is a skill all teachers strive to enhance within their students. Haskell contends that learning is usually welded to the environment in which the learning took place and the manner in which the learner stores the learning. This is considered to be an important finding since the author strongly suggests that a failure to transfer indicates a failure to think. Optimism is expressed for cases in which certain conditions are achieved. Eleven principles that have been derived from research are considered to be required to achieve transfer. These principles are discussed in order to provide guidance for encouraging and building transfer abilities.

The author considers there to be seven models of transfer. It is stated, however, that of these seven models, only four have been recognized as primary models. The models named and discussed are: Formal Discipline Model, Identical Elements Model, General
Principle Model, Stimulus Generalization Model, the Cognitive Information-Processing Model, the Metacognition Model, and the Instructional Model. It is the first four that are the ones considered to be primary models. Discussion of these models is carried out in a fairly unbiased manner. It is concluded that

the transfer models suggest that transfer has been approached in seven basic ways: (a) that transfer exists as an ‘inherent formal property’ of certain disciplines; (b) that transfer occurs by the recognition of ‘concrete identical elements’ between two stimuli existing in reality; (c) that transfer results from the application of ‘general principles’ from particular events; (d) that transfer occurs by ‘stimulus generalization’; (e) and the induction of ‘cognitive schemas’; (f) that transfer is promoted by the delineation and use of ‘metacognitive strategies’; and (g) that transfer is a property of individual learning characteristics (Haskell, 2001, p. 89).

The second part of the work concerns itself with what are considered to be the characteristics, conditions, and concepts necessary for making transfer of learning work. Amongst these necessities are knowledge base, spirit of transfer, the learner’s theoretical knowledge, practice, and cognitive functions. These requirements are discussed and analyzed by the author while drawing on research findings developed personally and by additional researchers.

The first, and possibly the most essential, of these pre-requisites for transfer is knowledge base. The statement that transfer depends on the knowledge level of the learner supports the suggestion of its importance. It is also suggested that recent research and teaching programs have abandoned the acquisition of a knowledge base for quickie solutions for learning. Opposed to these new trends, the author believes that research supports the contention that knowledge base is the primary ingredient and absolute requirement for transfer. An extensive knowledge base should certainly facilitate transfer as the learner will
be given a wider range of experiences and situations upon which to draw when faced with unfamiliar ground.

The spirit of transfer is described as a psychological, emotional, and motivational disposition toward deep learning. Caution is given not to consider spirit of transfer as another term for motivation which, it is contended, has come to refer to short-term, task-specific activities. It is stated that the spirit of transfer gives information meaning because meaning changes information into transferable knowledge. This spirit and its attendant characteristics and attributes are discussed in a manner that indicates it is related to various ideas about purposeful and beneficial learning.

Transfer in Science Learning

In learning science, learners often have their own ideas, developed from personal experiences, which inhibit the learning of correct science. The author states much the same when claiming that “erroneous theories about scientific phenomena that students come into the classroom with block their learning of science” (Haskell, 2001, p 158). Further, he states that “our personal experience is often a poor basis for developing valid theoretical knowledge that we can use outside of some very concrete and restricted situation” (Haskell, 2001, p. 164). These views are supported by a large number of research findings as pointed out by the author and through other readings. All of us develop our own personal beliefs and theories and often these must be overcome or changed in order to attain more commonly accepted beliefs.

Teachers are aware that in order to improve student understanding and retention of learning, it is necessary to incorporate a fair amount of practice into their lessons. Haskell (2001) points out that transfer research indicates that practice is also necessary in order to
promote transfer of learning. Research suggests that a factor contributing to the failure to find transfer can be traced to a lack of sufficient practice, and thus mastery, of the original material. The author also encourages the idea of over-learning tasks, especially those which may not be engaged in often. “Extensive practice to automatic levels tends to create what is called routine expertise, which is based on procedural or how-to knowledge—not adaptive expertise, which tends to be based on conscious or controlled processing of information” (Haskell, 2001, p. 179). Regarding his call for practice, the author cautions that the practice students are engaged in must be of the proper kind. Mindless rote drill is not a beneficial practice, rather students must be engaged in ‘reflective’ practice to facilitate transfer of learning. The author also believes, from his own experience as well as from research, that

unless schools create cultures of transfer, teach about transfer, and instill a spirit of transfer, requiring a well-learned knowledge base, and practice and drill of some systematic sort, teachers can adopt any instructional method they like in the classroom but, with few exceptions, neither significant learning nor significant transfer will take place” (Haskell, 2001, p. 186).

The author provides a well researched and thought out overview of the topic of transfer of learning. The various ideas, concepts, and requirements are expressed in fairly clear language with a number of tips for the implementation of methods intended to enhance the transfer of learning. This work is an excellent source for the educational researcher. 

Heuristics

Novak and Gowin (1984) define a heuristic as “something employed as an aid to solving a problem or understanding a procedure” (p. 55). The term heuristic is used to identify those methods and/or constructs that researchers use for indicating the structure of conceptual interrelations. Perhaps the best known of the many presently utilized heuristics is ‘concept mapping’, which was developed into its present form by Novak (Novak & Gowin,
Concept mapping is seen as a way to help learners and educators see the meanings of learning materials and concepts. The Vee diagram (Novak & Gowin, 1984) is a method devised to aid learners and educators to “penetrate the ‘structure’ and ‘meaning’ of the knowledge they seek to understand” (p. 1). Wandersee (1990) sees concept maps as charts to human cognitive structure much like the maps of the world produced by cartographers.

More recently developed heuristic devices include semantic networking and the ordered-tree technique. Fisher (1990) describes semantic networking as a multi-dimensional concept map. Through the use of computer software, a network of interrelated concepts can be developed that escapes the confines of the two dimensional concept map. Fisher contends that a semantic network can be envisioned as a space-filling sphere of knowledge. A semantic network captures each concept’s position in psychological space identifying both the concepts to which it is connected and the nature of the links that bind them together (Fisher, 1990).

Nash, Liotta, and Bravaco (2000) make use of the ordered-tree technique which is described as yielding a “hierarchal representation of an individual’s knowledge structure in a particular domain of information” (p. 333). This technique involves comparing the ordered-tree produced prior to instruction with the ordered-tree produced after instruction to ascertain the change in conceptual knowledge. The results of their study indicate that the ordered-tree provides a useful procedure for revealing various aspects of a learner’s cognitive structure in a chemistry course.

Conceptual Change Teaching Strategies

The way to change conceptual understanding is through the application of the appropriate instructional strategy. Basili and Sanford (1991) made use of small groups as an
instructional intervention to foster conceptual change in learners’ understanding of the particulate nature of matter. They found that group tasks encouraged the learners to interact in such a way as to be supportive of conceptual change. Brooks (1993) believed that the next major strategy will involve the infusion of computer technology into the classroom. Bunce, Gabel, and Samuel (1991) engaged learners in the ‘explicit method of problem solving’ and problem categorization as a means of improving problem solving ability. The results were mixed, higher achievement on combinational problems but lacking in linkages between conceptual understanding and improved problem solving ability. Haderlie (1994) proposed that several strategies be used together: peer tutoring, university partnership, micro scale chemistry, special projects, special problems, the Internet, supercomputing opportunities, and electronic mail and bulletin boards. Milne (1999) advocated the use of learner-prepared flip-books as a means of observing the dynamic nature of matter interactions. Noh and Scharmann (1997) contended that learners presented with instruction including pictorial materials at the molecular level more effectively integrate conceptual understandings. Roth and Roychoudhury (1993) performed a study with results that encourage usage of open-ended inquiry laboratories based in authentic contexts. Smith, Blakeslee, and Anderson (1993) advocated complex activities such as making explanations require conceptual understanding as a means of improving learning. They believed that conceptual change strategies should promote not only mastery of specific scientific conceptions but also a more general understanding of the nature of science. Tingle and Good (1990) found that cooperative grouping based on proportional reasoning alone does not improve learner problem solving skills. The criteria for establishment of the groups should also include conceptual understanding as evidenced by learner achievement. Von Secker and Lissitz
(1999) made the statement that the National Science Education Standards call for a move away from teacher-centered instruction to learner-centered instruction.

Misconceptions

Abraham, Williamson, and Westbrook (1994) found certain misconceptions that existed across-age. Unfortunately, these misconceptions were the inevitable and unavoidable outcomes of instruction. In a study by Ben-Zvi, Eylon, and Silberstein (1986) the most persistent misconception held by learners was the continuous model of matter. The study performed by Griffiths and Preston (1992) identified a total of 52 misconceptions relating to atoms and molecules amongst their students. Lin, Cheng, and Lawrenz (2000) determined that learners and educators shared several misconceptions about the nature of gases. Nakhleh (1992) suggests that the basis for misconceptions may be due to conflicting definitions for common words. Peterson and Treagust (1989) propose that educators become more aware of the possible misconceptions their students may be battling.

Using Technology

A special online conference concerning computer use in education was reported by Long, Pence, and Zielinski (1995) in which the participants agreed that new tools, i.e. computers, were necessary for future successful instruction in chemistry. One concern that was expounded on in the report was the failure of current science education methods to prove themselves effective in producing a scientifically literate citizenry. It was also suggested that students who have been exposed to a great deal of visual entertainment would be best served by a more visual approach to teaching chemistry. It was further argued that visuals such as videos, films, and especially computer simulations or computer based modeling activities can be more effective when coupled with discussion, written assignments, and various
assessment and/or evaluation techniques. The report concludes with the contention that changes to new technologies and new methods are inevitable.

In a report by Burke, Greenbowe, and Windschitl (1998), tips and guidelines for preparing computer animations are provided. They report that student achievement is enhanced through the use of these computer-based animations by means of correcting particular misconceptions that may be held by the students. Animations supplied by computer technology have the capability of improving student conceptual understanding of many basic chemical concepts. A study found that students instructed with computer animations of chemical processes at the molecular level were better able to answer conceptual questions concerning particulate phenomena (Sanger, Phelps, & Fienhold, 2000). Additional findings of this study indicated that students receiving computer animation instruction in conjunction with regular instruction were less inclined to quote memorized mathematical relationships and more inclined to mention concepts.

Improving Conceptual Understanding

Williamson and Abraham (1995) contend that use of animations may increase conceptual understanding through the formation of dynamic mental models of the phenomenon being animated by the computer. The dynamic mental models that the students were believed to have developed are more like the models found in expert chemists than the normal static models that result from traditional instruction in chemistry. Through the use of computer simulations, credible representations of reality can be presented to students (Zietsman & Hewson, 1986). These representations can be used to assist students in exchanging incorrect prior knowledge for a more scientifically acceptable knowledge. According to Berger (1984), a simulation is a model of some real-life event or process
described in mathematical terms. Simulations are proposed as a bridge between concrete and abstract reasoning.

Improving the cognitive models of students is a common theme in a number of studies that have been published in the last 20 years. Casanova (1993) relates how a graphics intensive computer can mimic a chemist’s mental and mechanical modeling and manipulating of images. He also calls for classroom teachers to rethink the traditional lecture/discussion method in favor of the new technologies being introduced into the world of education. By means of computer representations, modeling of how experts think microscopically as well as simultaneous representations of microscopic and macroscopic views of the same phenomena can be presented to the student (Russell et al., 1997). Russell et al. also contend that technology can be used to expand the means for visualizing chemical phenomena and systems to the microscopic scale and by means of these multiple representations students can translate from one representation to another.

In another study, Wu, Krajcik, and Soloway (2001), used computer generated diagrams of various models of molecular structure to enhance learner understanding. In this study, they used ball-and-stick, space filling, and structural formulas to assist students in learning the concepts involved in understanding chemical formulas. A major drawback in the use of models in teaching chemistry is that students often confuse these models for reality. Many teachers fail to emphasize that models are simulations of theory and not an exact picture of a molecule (Barnea & Dori, 1996). Computer aided instruction allowed for the use of many different models to represent a molecule, thereby reducing the chance that students perceived any one model as a true picture of a molecule. A similar problem was found in
those instances when teachers made use of concrete models of molecules as opposed to computer generated representations (Dori & Barak, 2002).

Through the use of concept mapping it is possible to use pencil and paper as a means of learning how student learning works. The computer presents another means of determining how students learn. Krajcik, Simmons, and Lunetta (1988) provide a strategy for the researching of student concepts. It is their expressed opinion that computers are capable of aiding in the search for understanding of how students learn. Zietsman and Hewson (1986) have shown that conceptual change can be effected through the use of appropriate computer simulations.

It is now believed that complex forms of learning involve cognitive restructuring which is itself both process and product of learning (Martin & Szabo, 1990). Improvement in student understanding can result when the student interacts strongly with the instructional device and is encouraged to explore the subject matters independently as possible. Furthermore, Martin and Szabo contend that an expert’s access to knowledge is distinguished from the novice’s in that it is bound to conditions of application and of goal structures.

The Internet

Donovan and Nakhleh (2001) describe a case in which the Internet was used as an additional source of learning materials. A study of their students indicated that the use of a web-based tutorial was not as beneficial as it was originally thought it was going to be. The study did find, however, that those students less strong in chemistry had improved attitudes after using the website for additional instruction. Carpi (2001) however, found that properly designed web-based course supplements can increase student interest and success in science education. Mistler-Jackson and Songer (2000) describe telecommunications-enhanced
science projects that may be developed or found on the Internet. Results of the study indicated significant gains in content knowledge in students as measured by written assessments and interviews. The use of the Internet could be a powerful tool in improving educational opportunities and outcomes.

The studies that were reviewed indicate that conceptual change and understanding are possible although they are often difficult to achieve and measure. The use of modern technology in the form of the computer is a new means of delivering instruction which could improve student understanding and visualization abilities in ways superior to the traditional lecture/discussion and problem-solving techniques that are presently being utilized in the Chemistry classroom. The use of this technology may also improve the students’ ability to transfer learning of chemical concepts to new situations and concepts.

In order to improve student understanding of chemical concepts that may not be directly visible, students must be provided with a means for developing new methods of visualizing ideas. Once students have developed means of cognitively visualizing concepts, there is an improvement in conceptual understanding as opposed to simply applying an algorithm that has produced adequate results in the past. Student understanding and improved learning will result when cognitive change is achieved.
Methods

Sample

The sample for the study, a result of circumstances and convenience, consisted of 59 high school students enrolled in Honors and Regular Chemistry courses in either their 11th or 12th grade year. The number of participants was reduced from the original 91 students enrolled in all four sections of Chemistry to include only those students who were present for all data gathering activities. The students lacking a complete data set and therefore not used represented the whole student body with no one group being overrepresented. Ages of the students ranged from 15 to 18 years of age. The students represented a broad spectrum of socioeconomic status levels. There was a mix of racial backgrounds and genders. All students had completed at least one computer literacy course, as well as, biology and physical science courses.

The study was conducted in a rural south Louisiana parish (county). The students were enrolled in the chemistry course of the investigator. A total of two sections each of Honors and two sections of Regular Chemistry comprised the two groups, experimental and control. The two populations were stratified according to scores in science reasoning from the Iowa Test of Educational Development (ITED) into lower, middle, and upper level ability for random selection of interview subjects.

The Nature of the Problem

In chemistry, students need an appropriate conceptual understanding of chemical formulas in order to solve a variety of chemical problems that they will encounter in later courses and even within the high school chemistry course in which they are presently enrolled. The greatest obstacle to understanding the concepts of chemical formulas appears to
be the inability of the students to mentally visualize the particle that is being described by the formula. Through the use of the graphics produced by the molecular modeling software, students were presented with a variety of representations visually that could enhance their ability to understand the concept so that they can create their own knowledge about the particles represented by the formula.

The “traditional” instructional strategy of lecture and discussion does not always convey a scientifically accurate representation that allows the students to construct their own cognitive understanding of the particles represented by chemical formulas. With the addition of the computer software into the strategy, students were given another means of representing the formula in a manner that is intended to enhance their success at interpreting, writing, and using chemical formulas.

Protocols

The investigator collected computer software, Hypercube, Incorporated’s HyperChem Lite™, and hardware for the study. With the introduction of the Comprehensive Curriculum by the state, the opportunity to provide this exploration as part of the regular curriculum was improved. This exploration was introduced as an extension to an activity suggested by the state. The lesson plans, found in Appendix C, outlines the plan for implementing the original activities, as well as the extension, in the classroom. A copy of Unit 4, Activity 2 as it exists in the state’s Comprehensive Curriculum is located in Appendix D. The treatment group made use of the software while the control group used the unmodified activity. During the activity, students received instruction in ion formation, types and names of ions, ionic compounds, and ionic compound formulas. Instruction in the use of the computer software was provided by the teacher during the activity to the students in the treatment group.
Questions that arose during the exploration were dealt with in a prompt and efficient manner. The intent of this exploration is to determine the efficiency of this particular teaching strategy and the general improvement of the teaching and learning of chemistry.

Procedure

With the implementation of the state’s Comprehensive Curriculum, the exploration’s original schedule of activities was altered. Instead of providing an isolated activity in the drawing of polyatomic ions, the exploration was incorporated into Unit Four, Activity Two of the Comprehensive Curriculum. In the course of this activity, the computer-aided drawing of polyatomic ions was added to the use of ‘ionic cards’ (part of the Comprehensive Curriculum) which were used to produce formulas of ionic compounds. Examples of the ‘cards’ are provided below, the entire set is pictured in Appendix E.

![Ion Cards](image)

**Figure 2: Examples of Ion Cards**

During the activity, as the students used the ‘ion cards’, the treatment groups were given instruction in the use of the molecular drawing software and provided the opportunity to draw the particles that were identified by a list of polyatomic ions. This addition to the established activity gave the students alternate visualizations of the structure and composition of polyatomic ions in contrast to the visualization provided by the ‘ion cards.’ It was hoped that the use of this software assisted the students in overcoming the idea that ions are ‘saw-toothed’ particles that fit together like pieces of a jig-saw puzzle.
Students worked in groups of two in order to make use of the computer and the software to develop their own ideas of what the polyatomic ions look like. Instruction was provided that assisted in leading them to the accepted version of how these particles should appear. The desired effect was that students take the information provided to them and develop scientifically acceptable drawings of the polyatomic ions. Pictures of the student activities and the environment of the study may be found in Appendix F.

Measurement

This exploration made use of various instruments to gain information about the students. At the beginning of the study, a pretest was administered. At the conclusion of the treatment, an attitudinal survey in addition to a posttest was administered. Six students, three from each of the two total population groups representing the three levels of achievement, were selected randomly to participate in the interview portion of the study.

Chemistry Pretest and Posttest

The instruments each consists of 14 multiple choice items with one item asking for justification of a response (see Appendix G). The pretest was administered approximately one week prior to the beginning of the exploration and the posttest was administered at the conclusion of the treatment period in order to determine the extent of change in conceptual understanding of chemical formulas. Three of the items were adapted from testing instruments administered in several different studies. Items 2 and 7 are from private correspondence with Dr. Treagust of Curtin University of Technology. The remaining items were developed by the principal investigator and had been used in the classroom for a minimum of three years, except for the last three items, which were developed for this
exploration. The last item includes a graphic to determine the ability of students to recognize various visual representations of polyatomic ions.

Attitude Survey

Student attitudes towards the instructional strategy to which they are exposed was determined using the Birnie-Abraham-Renner (BAR) Quick Attitude Differential (Williamson, 1992). The BAR (Appendix H) is a 12 item semantic differential instrument. Two factors have been established within this instrument. The ‘contentment’ factor is identified as the student’s degree of satisfaction with the study of the particular concepts. The ‘comprehension’ factor is identified as the student’s perception of the progress towards understanding the concepts involved. The contentment factor score is the sum of questions 1, 2, 4, 8, 11, and 12 and the comprehension factor is the sum of questions 3, 5, 6, 7, 9, 10, and 12. Since item 12 is in both factors, it is half assigned to each factor.

Interview

The interviews were conducted on a one-to-one basis between the student and the investigator. Interviews were semi-structured, as described in Educational Research: An Introduction by Gall, Borg, and Gall (1996). The purpose of the interview is to determine the extent of conceptual understanding that exists in students from the three levels of the two groups. The interview protocols are to be found in Appendix I.

The interview data was analyzed using the verbal analysis method developed by Chi (1997). This method is different from the protocol analysis in that it focuses on capturing the representation of the knowledge that a solver has and less on the processes of problem
solving. The method of coding and analyzing verbal data in this method consists of eight
functional steps:

1. Reducing or sampling the protocols.
2. Segmenting the reduced or sampled protocols (sometimes optional).
3. Developing or choosing a coding scheme of formalism.
4. Operationalizing evidence in the coded protocols that constitutes a
   mapping to chosen formalism.
5. Depicting the mapped formalism (optional).
6. Seeking pattern(s) in the mapped formalism.
7. Interpreting the pattern(s).
8. Repeating the whole process, perhaps coding at a different grain size
   (optional).

Experimental Design

This study is a mixed method study, as described by Tashakkori & Teddlie (1998). It
combined elements of both quantitative and qualitative methodology. The arguments
supporting the use of mixed methods stem from the ideas and principles of pragmatism as
interpreted and expressed by the authors. Within this school of thought, the most important
aspect of the research project is the question. Once the question has been established, it is the
researcher’s responsibility to use any and all methods that lead to a successful, acceptable
culmination of the project. The authors contend that regardless of whether the project
involves asking a question, evaluating a program, or solving a problem, mixed methods are a
viable option for the researcher. There exists the belief that, in the case of different methods,
“cohabitation is not a luxury; it is a necessity if any fruitful outcomes are to be expected” (Salomon, 1991, p. 17).

Tashakkori and Teddlie (1998) base their arguments on what they refer to as “paradigm relativism,” which they describe as a “whatever works” approach to the decisions about which research methods are to be used in their program. Within this approach, the participants, referred to as pragmatists, decide on the subject/purpose of their study depending on their own particular values. The authors describe the worldview of the pragmatists as having two basic parts. The first is that a real world exists that is independent of our mind. The second expresses the belief that the “Truth” cannot be known once and for all. This belief about truth is the basis of the different researchers’ level of optimism. Tashakkori and Teddlie describe themselves as cautiously optimistic pragmatists (p. 29).

During their arguments, the authors advance the idea that there has been an evolution of methodology away from mono-methods towards the use of mixed-methods models. The evolution described in the book has three phases as interpreted by the authors to support their contention that mixed method models are a viable and proper way to carry out research in the quest for knowledge. The first phase consists of the acceptance of mixed methods as an acceptable research option. The second phase was the application of the mixed methods model. The third phase states that the ‘paradigm wars’ having been going on for 30 years and movement towards combining methods was occurring at an increasing rate. This contention is supported by other researchers, “I believe that one of the most promising developments in the field of education in the past two decades has been the widening of methods and assumptions in educational research and evaluation” (Eisner, 1983, p. 24).
Another argument that the authors use to support their position is that of triangulation. Triangulation, as described by the authors, is the convergence of results derived from two different sources or methods. This convergence is used as a means of supporting the findings resulting from the various methods employed to collect data. The analysis of data through the use of triangulation allows a researcher to develop conclusions that are closer to the ‘truth’ than those developed using a single set of results. Triangulation becomes a very important tool for those researchers utilizing a mixed methods model in their research.

Embedded in their arguments, the authors include examples and suggestions for the design of mixed method studies. The designs advocated by the authors involve methods being used at the same time or one after the other and a distinction between the greater or lesser use of a particular methodology. Designs that allow for the two major methodologies employed having equal status can be described as: Sequentially (one after another) QUAN/QUAL or QUAL/QUAN; or Simultaneously/Parallel QUAL + QUAN or QUAN + QUAL. The utilization of the methods in a dominant – less dominant manner may be described as: Sequentially (one after another) QUAN/qual or QUAL/quan; or Simultaneously/Parallel QUAL + quan or QUAN + qual. These variations of design are described by the authors who also note that there are additional possibilities in the formation of mixed methods designs (Tashakkori & Teddlie, 1998, p. 43).

The authors also argue for caution, on the part of the researcher, when deciding upon a particular research design. They advise that the design take into consideration the MAXMINCON Principle. This principle, as described by the authors, suggests that the design maximize the experimental variance, minimize the error variance, and control the
extraneous variance. The successful application of this principle will improve the results and conclusions of the project.

The authors make a good and valid argument for the combining of methodologies in educational research. However, as in any human endeavor, there is opposition, sometimes referred to as the ‘purists,’ to the belief that mixing methods is a viable format for the design of research. One of the objections to mixed methods involves the idea that quantitative methods constrain our beliefs while qualitative methods determine what counts as facts, positions which are incompatible in our present way of thinking (Smith, 1983). This position is based on the assumption that those involved in either one of these methodologies subscribe to a specific epistemology. Contrary to this stance was the expressed opinion that there was no good reason for avoiding combinations (Howe, 1985). Again, the compatibility of the methods was advanced as being an unsustainable position due to differences between objectivism and relativism (Smith & Heshusius, 1986).

A recent objection to mixed methods contends that when the methodology is used in a study, the study becomes more about the methods being used than about the topic that the study was originally intended to research (Bogdan & Biklen, 1998). This objection seems to concern the conclusions drawn by the researchers more than it does the use of mixed methods. Another objection criticizes the utilization of mixed methods based on the conviction that an observer will cause changes in the environment that will invalidate the collected data (Lincoln & Guba, 1995). Of course, it is possible that there are methods which may be employed to reduce the effect of the presence of an observer on the environment being observed. It would appear that most of the objections to, and the approval for, mixed methods are a matter of personal partiality and viewpoint. As outside observers are not an
integral part of this exploration, it is unlikely that this aspect will not affect the outcome of
the exploration.

This study’s research interest lies in determining whether or not student understanding of ionic bonding concepts can be enhanced through the addition of a computer and molecular drawing software in conjunction with the normal instruction delivered in class. Students often fail to consider the nature of a polyatomic ion when dealing with them in either reaction equations or dissociation equations; students exhibit a tendency to separate these polyatomics into their constituent atoms. This research was conducted in order to determine if this computer-aided instruction improved student understanding about the nature of the polyatomic ions, that they are covalently bonded atoms that normally do not separate into individual atoms during solution or simple ionic reactions.

The design that was used for this exploration is a dominant–less dominant, sequential (QUAN/qual) design. Collection of quantitative data in the form of pre- and posttest results as well as from an attitude survey was involved in this design. Post-treatment interviews served as the source of qualitative data. Quantitative data was analyzed using appropriate statistical tests, including a test of covariance with ITED science reasoning scores as one of the covariants. Qualitative data was analyzed through the use of verbal analysis, a methodology for quantifying the subjective or qualitative coding of the contents of verbal utterances (Chi, 1997). To review, the sample consisted of two sections each of Honors–Chemistry and Regular Chemistry. The sections were randomly designated either treatment or control group. A total of six students were randomly chosen for interviewing, one from each of three levels based on ITED science reasoning scores in conjunction with membership in treatment or control groups.
Data Analysis

When analyzing the data, a linear regression was used with the variable of interest being how the class was taught while controlling for age, gender, race, socio-economic status (SES), ITED science reasoning score, and extra-curricular activity. Appendix J contains a copy of the table used for the data collected. The form used for the collection of demographic data, which served as secondary variables, is also found in Appendix J. Of these secondary variables, age, race, and gender are self-explanatory. The SES variable was determined by the status of the student in terms of lunch program participation, i.e. free lunch, reduced lunch or full-price lunch. Participation in extra-curricular activities indicates that a student has a greater vested interest in education and the success of their school, this variable was determined by the participation of the student in athletics (including team sports, track & field, and cheerleading squads), band (including marching band, flag line, and specialty bands), and student government (class officer and student council). ITED science reasoning scores were obtained from student records.

All data was entered into and analyzed with SPSS software. With the assistance of the Department of Experimental Statistics, the results of the analysis were interpreted to determine whether or not the strategy that was explored is effective in improving student understanding of polyatomic ions and their particulate nature.

Consent and Assent

As there was no expected risk to the students involved in this exploration, a request for exemption from institutional oversight was filed and approved (Appendix K). In addition, a certificate of completion of the online course Human Participants Protection Education for Research Teams, sponsored by the National Institute of Health, is included in Appendix K.
In view of the fact that the students that participated in this exploration are minors, a letter of consent (Appendix L) was sent to the students’ guardians for approval. The students themselves were also provided the opportunity to agree to be included in the exploration by signing a letter of assent (Appendix L) or refusing to participate. Students who refused to participate were not penalized in any way. A letter granting permission for the modification of the Comprehensive Curriculum activity was signed by the school’s administrator (Appendix M).
Quantitative Results

During the course of the school year in which this study was conducted a number of unforeseen and unavoidable circumstances arose. One of these was the state mandated Comprehensive Curriculum which was previously discussed. In addition, there were the effects of two major hurricanes to contend with almost from the beginning of the school year. One consequence of these storms was a period of fluctuating enrollment as students were moving around from school to school after evacuating New Orleans due to Hurricane Katrina. Another consequence was the loss of a week’s instruction time as a result of Hurricane Rita. These situations, along with a change in personnel at one school and non-alignment of curriculum sequence with another, resulted in the primary investigator using students enrolled in Chemistry at only one school. The sample was derived from two sections of Regular Chemistry and two sections of Chemistry–Honors. Using only students for whom all data was collected, a total of fifty-nine data sets were used (Appendix N).

Ion Card Activity

During the ion card activity of Unit 4 in the Chemistry portion of the Comprehensive Curriculum, students in the sections designated as the treatment groups were provided instruction in the use of the molecular model drawing software. As part of the lesson on ions, the treatment group students were provided time to develop a computer-aided drawing of a polyatomic ion. Each group of students was instructed to save copies of all three computer renderings (stick, ball-and-cylinder, and sphere) of the chosen polyatomic ion. Examples of the resulting drawings may be seen in Figure 3. Three additional examples are located in Appendix O. The time for this activity was curtailed by administrative pressure to increase
the pace of instruction in order to ensure the coverage of all Grade Level Expectation (GLEs) as mandated by the state in the new Comprehensive Curriculum.

![Figure 3: Renderings of polyatomic ion developed by students during activity. (In order from left-to-right are stick, ball-and-cylinder, and sphere.)](image)

Student developed computer drawings were monitored so that no completely incorrect concepts were allowed. Scientifically accepted concepts were discussed with students exhibiting misconceptions of the structure of polyatomic ions. The students that indicated a lack of understanding were given a reinforcement of the lesson discussed as a class without direct instructions in the arrangement of atoms while preparing the polyatomic ion drawings.

**Basic Score Analysis**

The initial analysis of the information collected involved the normal analysis that teachers make use of in many instances; the calculation of averages (Table 1). The averages of the test scores were calculated per section and then again as a total group. Using these averages, the average change in scores was calculated per section and group. These changes were then divided by the pretest averages and multiplied by 100 to determine a percent change. The average science reasoning scores from the ITED were also determined per section and per group for comparison between the various groupings of students. As stated previously, this type of basic analysis is one used by teachers to obtain information on
student understanding and comprehension of regular instruction. This information can also be used to observe any increase in abilities between groups.

After carrying out this basic analysis on the different Chemistry sections, average scores were obtained and compared. The average pretest score averages ranged from a high of 6.37 to a low of 4.64 with the average posttest scores ranging from a high of 8.11 to a low of 5.93. The average change in scores ranged from a high of 1.74 to a low of 0.5. A percent change was calculated for each section using the previously described method with determined values ranging from a high of 29.3% to a low of 9.2%.

**Table 1: Section Averages – Scores and Change**

<table>
<thead>
<tr>
<th>Sections</th>
<th>Average ITED Scores</th>
<th>Average Scores</th>
<th>Average Change</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td></td>
</tr>
<tr>
<td>Honors – Control</td>
<td>281</td>
<td>6.37</td>
<td>8.11</td>
<td>1.74</td>
</tr>
<tr>
<td>Honors – Treatment</td>
<td>287</td>
<td>5.60</td>
<td>7.00</td>
<td>1.40</td>
</tr>
<tr>
<td>Regular – Control</td>
<td>258</td>
<td>5.43</td>
<td>5.93</td>
<td>0.50</td>
</tr>
<tr>
<td>Regular – Treatment</td>
<td>252</td>
<td>4.64</td>
<td>6.00</td>
<td>1.36</td>
</tr>
</tbody>
</table>

After the calculation of the averages for the different sections, similar analysis was conducted for averages of treatment and control groups (Table 2). The computed average pretest score values for the groups were 5.97 for the control group and 5.19 for the treatment group. The computed average posttest score values for the groups were 7.18 for the control group and 6.58 for the treatment group. These values were utilized to determine the average change in score which was calculated to be 1.21 for the control group and 1.39 for the treatment group.
Table 2: Group Averages – Scores and Change

<table>
<thead>
<tr>
<th>Groups</th>
<th>Average ITED Scores</th>
<th>Average Scores Pretest</th>
<th>Average Posttest</th>
<th>Average Change</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>270</td>
<td>5.97</td>
<td>7.18</td>
<td>1.21</td>
<td>20.3</td>
</tr>
<tr>
<td>Treatment</td>
<td>270</td>
<td>5.19</td>
<td>6.58</td>
<td>1.39</td>
<td>26.8</td>
</tr>
</tbody>
</table>

The average ITED science reasoning scores were also calculated and included in Tables 1 and 2 for purpose of comparing the various groups. The values of these scores for all students ranged from a high of 349 to a low of 212. The average scores for the Honors Chemistry sections were a little higher with averages of 281 for the control group and 287 for the treatment group. The average scores for the Regular Chemistry sections were calculated at 258 for the control group and 252 for the treatment group. However, the calculated averages for the entire control and treatment groups were the same at 270.

Statistical Analysis

The data that was collected was entered into the SPSS statistical analysis program for further analysis. The data used for this analysis is shown in Appendix M. The test run on the data was a linear regression corrected for several different variables. The dependent variable for the analysis was difference in pre- and posttest scores. The predictors input into the analysis were treatment, SES, race, gender, age, ITED science reasoning score, and involvement (the level of participation in the school community), reported by the software as type. A copy of the software statistical report is located in Appendix P.

The software default sets significance at a value of 0.05 (corresponding to 95% confidence) or below. The values were determined for the predictors by the software from the data entered into the program. Upon completion of the analysis, the software reported that
the only variables exhibiting a value that may be interpreted as indicating a significant
collection of the difference in pre- and posttest scores were age and ITED scores. The t-
score and the significance of the various variables are provided in Table 3. The treatment
value of 0.897 indicates a very minor contribution by the treatment in influencing the
difference between pre- and posttest scores.

Table 3: SPSS Calculated Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>t-score</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>-.130</td>
<td>0.897</td>
</tr>
<tr>
<td>ITED</td>
<td>3.758</td>
<td>0.000</td>
</tr>
<tr>
<td>Age</td>
<td>2.268</td>
<td>0.028</td>
</tr>
<tr>
<td>Race</td>
<td>-.620</td>
<td>0.538</td>
</tr>
<tr>
<td>SES</td>
<td>1.089</td>
<td>0.281</td>
</tr>
<tr>
<td>type</td>
<td>0.496</td>
<td>0.622</td>
</tr>
</tbody>
</table>

The basic analysis of the scores indicated a larger difference between pre- and
posttest scores within the regular chemistry sections while within the Honors sections the
control section out-performed the treatment section. Upon analysis of the regular sections
only, there is still no statistical evidence of significant difference (t = 0.805, Sig. = 0.428)
although there were improved values presented for this sample. The size of the sample (25
students) is not large enough to make any definite conclusions but does present some
interesting possibilities.

Despite the results garnered here, the opinion expressed earlier, that computer
technology is a very powerful and effective tool for education, continues to be strongly held
by this researcher. There are still many studies that support the use of computer technology
while this study, which utilized a specific type of software, has not presented results that are
supportive of the trend. It is possible that the use of different software and modification of the presentation and methods may produce results that fall more in line with these other studies.

The basic analysis of test scores indicates that the inclusion of the computer activity in which students developed graphical representations of polyatomic ions with molecular modeling software did not impair instruction and learning of the basic concepts concerning ions. The lack of impairment is supported by a general increase in test scores for all sections of Chemistry, Regular and Honors whether treatment or control, that were involved in the study. This increase, as small as it was, indicated that the use of the computer software to draw polyatomic ions was not detrimental to the overall instruction and learning that take place with normal classroom activities.

The lack of a significant improvement in test scores resulting from the use of the molecular modeling software fails to mirror the results of other documented studies in which computer assisted instruction produced significant improvements in achievement. A study performed by Wu, Krajcik, and Soloway (2001) made use of similar representations and produced positive gains in the understanding of formulas. Unlike Williamson and Abraham’s (1995) study, however, this investigation did not have animation to assist students in internalizing the models.

Also, from the analysis of the interviews, there appears to be an increased understanding of the structure of polyatomic ions as a result of the use of the molecular drawing software. One observation that was made concerning polyatomic ions was the reduction in instances of students misinterpreting subscript usage. A common mistake made by students is to apply the subscript in a polyatomic ion to all atoms present. For example,
students will see the polyatomic ion nitrate, $\text{NO}_3^-$, as consisting of three nitrogen atoms and oxygen atoms as opposed to the proper interpretation of one nitrogen atom with three bonded oxygen atoms. The instances of this kind of misinterpretation were decreased in the sections that had the opportunity to use the molecular drawing software to visually observe the accepted structure of polyatomic ions containing subscripts. This ability seems to reinforce the idea that transfer of learning is improved with the instances of visual activities as was stated in the research findings of previous studies. Unlike what Haskell (2001) termed the transfer paradox, transfer appears to have occurred within the instructional environment in this particular case. Students who participated in the computer-based activity had fewer instances of improper subscript usage when the instruction moved on to the balancing of chemical reaction equations. Those equations containing polyatomic ions were not improperly balanced due to the misapplication of subscripts as often as had occurred amongst those students who did not have the opportunity to use the computers to produce a visual representation of polyatomic ions.

The use of the computer software, which allowed for the development of visual representations of the polyatomic ions, not only appeared to assist in the transfer of the structure of polyatomic ions, but also seemed to improve student understandings of how the atoms were arranged spatially. This became evident during the interviews that were conducted after the activities and the administration of the posttest, and indicated that the students had a better understanding of how the atoms located in the polyatomic ions are arranged in three-dimensional space. The use of the software possibly allowed students to develop a graphical representation that improved their cognitive understanding of polyatomic
ions. The improvements that resulted from the use of the computer software package were small however; they do appear to be present.
Qualitative Results

The qualitative data to be analysis included the attitudinal surveys and the interviews conducted with the six randomly selected students from the four sections of Chemistry that served as subjects for the study. The attitudinal surveys were analyzed using the statistical software to determine if a correlation existed between the treatment and student attitudes. The interviews were analyzed to find any pattern that may have resulted from exposure to the software activity. The analysis of the interviews was carried out by the primary investigator.

Attitudinal Survey Analysis

The SPSS software was utilized to perform a statistical analysis to determine whether or not a correlation existed between the treatment and the two factors of the BAR: contentment and comprehension. The statistical values calculated by the software regarding the correlation between treatment and the two factors of the BAR are reported in Table 4. Again, the software default sets significance at a value of 0.05 or below. The values for the correlation were determined by the software from the data entered into the program. The lack of significant correlation seems to indicate there is no correlation existent between the treatment and student’s comprehension of and contentment with the lesson. Of the two, it is indicated that comprehension is much closer to being significant than is contentment.

<table>
<thead>
<tr>
<th>Table 4: SPSS Correlation Between Treatment and BAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment vs.</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>BAR – Contentment</td>
</tr>
<tr>
<td>BAR – Comprehension</td>
</tr>
</tbody>
</table>
The statistical results obtained from the analysis of the attitudinal survey data indicate that this particular study had no real significance on student outcomes. No correlation exists between the use of the computer software and student contentment or comprehension. The statistical evidence given presents one picture of the student response to this study’s methodology.

Interview Sample

The students chosen for the interview portion of this study were based on their ITED science reasoning scores, which ranged from a high of 349 to a low of 212. Three levels were established based on these scores, an upper being those scores above 295, middle ranging from 295 to 260, and a lower being those scores below 260. From each of these levels, one student was randomly selected from each group, treatment and control. From A total of six students were selected for interviews. These randomly selected students were representative of a diverse group. The characteristics of the group include: three females, three from each race group (white and non-white), five 16-year-olds with one 17-year old, and three from the lower SES group.

The demographic characteristics of the selected students are fairly consistent with the general demographic characteristics of the student body within the high school in which the study was conducted. All students selected for interview agreed to be participants and to allow their responses to be used. Identification of the students is by code number and their true identity was held in strictest confidence. The students selected, with ITED science reasoning score, for the interviews were Carol (315), Brianna (296), Andrew (280), Sarah (264), Jacob (246), and Kyle (227). All names used for the participating students are
pseudonyms for purposes of anonymity in order to protect the privacy of the students participating in this portion of the study.

Interviews

The interviews were conducted over a three day period following the administration of the posttest instrument. All interviews were conducted one-on-one between the researcher and the selected students. The tone of the interviews was established as a non-confrontational, comfortable discussion of the lesson in order to alleviate any apprehensions the students may have had in speaking to the researcher in this unfamiliar personalized setting. Even though all student participants were enrolled in the Chemistry classes, one-on-one discussions were not familiar and did not constitute a normal instructional procedure. Once students were in a less tense frame of mind, the questions, as reported in Appendix H, were posed to the students with additional follow-up questions as necessary to gain information or to clarify and/or establish meaning of a response. No particular order was utilized in interviewing the students; however the transcripts below are presented in order of high to low ITED scores with the students from the treatment group first.

Interview Transcripts

The first interview transcript of a student interview is that of the interview with Brianna (ITED – high). This student was not real responsive due to her shyness and reluctance to draw attention.

**What did you know about ions before the lesson?**

Not a whole bunch. We talked about them a little bit in physical science. I knew that they had different charges.
What do you know now?

I know that it isn’t just atoms that can have a charge. Bunches of atoms can have a charge so that they attract each other. Ions make compounds when they come together through ionic bonds.

Did the lesson help you to understand ions better?

Yes, it helped me see how ions bond together to make things.

What do you know about polyatomic ions?

They are charged atoms that are bonded to each other in a way that’s not ionic, it’s something stronger. They also seem to contain oxygen most of the time. The way they are arranged depends on the number of oxygen atoms there are.

What shape do you think polyatomic ions take?

Well, like I said, that depends on how many oxygen atoms there are. It looks like there is always one atom that is in the middle if there are more than two atoms.

Did the computer activity help you in understanding polyatomic ions?

Yeah, it showed different ways to see the polyatomic ions. I wish we would have had more time to play with it, it was fun to try and draw them.

The second interview transcript is from the interview with Sarah (ITED – middle). Sarah was a little less nervous about being interviewed; however her responses, like all of them, were short and rather pointed.
What did you know about ions before the lesson?

Nothing really, I think one of my other teachers mentioned them somewhere. I think maybe it was in Physical Science, I don’t remember.

What do you know now?

I know that atoms can have a charge when something happens to the electrons, lose or gain. This makes them want to get together, like attract. Ions don’t have to be just one atom. They can be more than one together. They are held together by a bond.

Did the lesson help you to understand ions better?

I guess, I mean I know more about them now than I used to. When we talked about them in class I heard things I didn’t know about.

What do you know about polyatomic ions?

Those are the ones that have more than one atom, right? They seem to be in a lot of the things we use everyday. These atoms are held together, bonded?, so that they don’t come apart when put in water. A lot of them have oxygen.

What shape do you think polyatomic ions take?

The shape? You mean how they look? Well that is going to depend on how much there is in it. The more atoms there are will determine what shape its in.

Did the computer activity help you in understanding polyatomic ions?

Kind of, but it was fun too. I like working on the computer.

The third and final interview transcript for the student participants from the treatment group is provided below and is from Jacob (ITED – low). This student appears to be brighter than indicated by regular classroom grades and his reported ITED score.
What did you know about ions before the lesson?

Nothing much. I think that they attracted each other but I can’t really tell you why this happens.

What do you know now?

They are atoms that either lost or gained electrons so that they have a charge. Then they push each other away or attract each other.

Did the lesson help you to understand ions better?

Yeah, kind of. I know a little more about them than I used to. When they were explained by (another student) it got better.

What do you know about polyatomic ions?

That there are a bunch of them with weird names. They don’t break up when in water. A lot of them have oxygen.

What shape do you think polyatomic ions take?

Well they’re not flat. Those cards had jagged edges, but I don’t think they look like that either; they are more like the balls jammed together. From the pictures, the shape is probably from how many balls there are.

Did the computer activity help you in understanding polyatomic ions?

I guess. The different pictures of the same thing were good. It might have been better if we had more time.

The first of the control group students to have the transcript of their interview reported is Carol (ITED – high). This student was one of the highest performers on the ITED. Her skills in class during the lesson were quite obvious, as they were the entire school year.
Carol is a confident student who usually prepares very well for class; she has a lot of initiative.

**What did you know about ions before the lesson?**

I knew that they were atoms that had a charge. We learned that in Physical Science and a little bit in Biology. Since they had a charge, they either repelled or attracted each other. The charges were due to gaining or losing electrons from their outer shell. Losing made them positive and gaining made them negative.

**What do you know now?**

We learned that ions can be more than one atom by itself. There can be two or more atoms that are chemically combined that have an overall positive or negative charge. These ions with more than one atom still pretty much act like the one atom ions. When these kind of ions are in compounds and the compounds are dissolved in water, the atoms don’t break-up into ions.

**Did the lesson help you to understand ions better?**

Yes it did. I learned about things I didn’t really understand before.

**What do you know about polyatomic ions?**

I know that they are made-up of more than one element and these atoms are chemically bound to each other by a bond that stronger than an ionic bond. They do not break apart when they are dissolved in water, they stay just like they are.
What shape do you think polyatomic ions take?

I believe that the shape they are going to take is going to depend on how many atoms there are in the polyatomic ion. The more atoms there are, the stranger and more complex the shape. The easiest ones will be those with just two atoms, they should just be two atoms next to each other.

The following transcript is from the interview of the second student from the control group, the middle level performer on the ITED, Andrew. This student was not exactly highly motivated.

What did you know about ions before the lesson?

Not a whole bunch. I think we did them in Physical Science.

What do you know now?

Well, they are positive or negative and they attract each other. They can be one atom or more than one atom.

Did the lesson help you to understand ions better?

I guess, I know more than I used to.

What do you know about polyatomic ions?

Those are the ones that have more than one thing? Well, they can be positive or negative too. Those are the ones that are usually non-metals.

What shape do you think polyatomic ions take?

They aren’t shaped like those card things we used, they’re more like balls.

Kyle’s interview transcript is the last from the student participants interviewed in this portion of the study. Kyle’s score placed him as the lowest level performer on the ITED in the control group. In addition, Kyle didn’t really apply himself very much during the entire
lesson or even during the school year.

**What did you know about ions before the lesson?**

Nothing. I don’t remember ever hearing about them before.

**What do you know now?**

They are atoms that are positive or negative. They make-up stuff.

**Did the lesson help you to understand ions better?**

Yeah, I kinda know what they are. I didn’t remember hearing about them before this class.

**What do you know about polyatomic ions?**

The things with more than one atom? They make-up stuff too. They have weird names that are hard to figure out.

**What shape do you think polyatomic ions take?**

I don’t know. I guess they have parts that fit together.

Interview Analysis

Upon completing the interviews and transcribing the responses, the transcripts were analyzed. There was an indication that differences in the responses of the higher level students (the students with the higher ITED scores) were extremely small to non-existent. The greatest difference in the responses to the interview questions appears to have occurred between the lower level students (students with the lower ITED scores), treatment and control. Some variation did appear to exist in the responses of the students at the middle range of ITED scores as well.

When compared to the responses on the testing instrument, the interview responses exhibited greater scientifically correct understanding of the polyatomic ion. The students
responded in such a way as to indicate that they understood the structure of polyatomic ions, even if in limited ways. Although queried on the testing instrument about the structure of the polyatomic ion, written responses that were provided by the students were far inferior to the responses provided orally by the students during their interviews.

Despite the lack of quantitative results supporting a significant improvement in student understanding of polyatomic ions and their structure, the interview results tend to indicate that some improvement in student understanding did exist. It is possible that students exhibit this improvement in ways other than those indicated by the responses provided on the traditional pencil-and-paper test that is normally administered in the classroom. Alternative assessment methods may provide superior indicators of student understanding than the use of the traditional pencil-and-paper test. Another non-traditional means of assessment may also include computer technology.

The interview analysis indicated that the students with lower scientific skills that participated in the computer-based activity had a better visualization of the structure of atomic particles than did those with lower scientific skills who did not participate in the computer-based activity. The interviewed students who received the treatment spoke with greater ease about the structure that would be exhibited by the polyatomic ions. There was more certainty in their responses that the structure depended on both the particular atoms and the number of atoms present. Those students who did not receive the treatment were more hesitant and unsure as to the particular structure that may exist and even if there were no differences in structure between the different polyatomic ions.

The same confidence in their responses was present when students receiving the treatment responded to general questions concerning the basic concepts of polyatomic ions.
The responses from students who did not receive the treatment were more hesitant and lacked confidence. The differences in the responses given by the two groups are especially evident in the students that have lower level abilities in scientific reasoning. It appears that the greater benefit was derived by those students at the lower level of scientific reasoning abilities.

When analyzing the interviews, it would appear that there is an improvement in the students’ abilities to think about the sub-microscopic particles of chemistry in a more acceptable manner. The trends which appear to exist in the interview responses seem to indicate improved cognitive abilities. These improved abilities correspond to the findings of the National Research Council’s two year study (NRC, 2000a) on cognition. The improvement may have been the result of providing students with an opportunity to observe various visual representations of the polyatomic ions. It is possible that the computer-based activity provided a more meaningful way of delivering the information than does simply lecturing. These responses also appear to agree with the characteristics of improved cognitive ability resulting from visual experiences as described by Jacob and Jeannerod (2003). The changes that seem to have occurred also correspond to the findings of Noh and Scharmann’s (1997) study in which students were provided molecular level pictorial materials.

Analysis of the interview responses appears to corroborate the increase in student ability and knowledge of polyatomic ions that are indicated by the analysis of pretest and posttest scores. An increase in student understanding is indicated by both the quantitative and qualitative results gathered during the investigation. However, there is no measurably significant increase provided.
Conclusions and Implications

Upon completion of the data gathering portion of the study, a revisit to the research questions is necessary to determine whether or not the goals of the study were reached. Using the information obtained from the analysis of the testing instruments and the answers given during the interviews, responses to the research questions may be formulated. Future uses and directions of inquiry may be guided by the outcomes of this study. It is possible that the results of the study may lead to divergent ideas and paths for additional study, as well as, means and direction for improving the method used in this particular study.

Computers and computer-based technologies are rapidly become a necessity in daily life, especially when one enters the workforce. The most common experiences students have with these technologies are for the purpose of entertainment. It is necessary to expose students to more educationally useful experiences which may be carried on into the workforce. The use modern computer technology for instructional purposes is increasing at a steady pace as various studies have determined that using computer technology does allow for conceptual change of students’ beliefs even when these incorrect beliefs are supported by past laboratory experiences (Clark & Jorde, 2004). In addition, progress is well noted in those students who fail to completely integrate accepted scientific concepts (Hoffman et al., 2003). The use of modern technology has been shown to be beneficial in many different cases and will most likely continue to be of benefit.

Conclusions

The original purpose of this study was to determine if molecular drawing software assisted students in properly envisioning polyatomic ions in order to improve their conceptual understanding of the particulate nature of polyatomic ions. The statistical
evidence obtained from analyzing pre- and posttest scores indicated that the method used in this study, in which molecular drawing software was utilized, produced no significant improvement in student understanding. The scientifically correct concept of the polyatomic ion as a discrete particle with its own identity did not appear to be improved, by the software, in student conceptual understandings of ions. There did not appear to be any improvement in the students’ understanding that the polyatomic ions do not completely dissociate into individual monatomic ions.

As stated, the belief that computer technology can be beneficial remains. The lack of statistical evidence to the contrary does not deter this idea of improving educational opportunities through the use of modern technical methods of instruction. The greater improvement shown by the students that have lower scientific reasoning skills may lead one to determine that computer technology use may prove to be of greater benefit to those with lower capabilities. It is necessary to improve scientific reasoning skills within students by whatever means work.

The question of whether or not students believe this particular methodology, the use of computer technology, adds value to the lesson was answered by responses received during the interview portion of the study assessment. Students agreed that the lesson was improved by the addition of the computer technology. The treatment group students thought the overall lesson was better when using the computer technology as opposed to being restricted to the normal lecture/discussion format.

The inclusion of the computer technology allowed students to be more actively engaged in the lesson. With the utilization of the new, unknown drawing software, students were afforded the opportunity to improve their repertoire of computer skills. The software
used was initially daunting to the students due to its unfamiliarity, yet with use, the students became more comfortable in its use which resulted in greater enjoyment of the lesson. The benefits and improvement in understanding seemed to be greater in the students at the lower levels of the ITED score range. The students at the upper range did not seem to be as influenced by the capabilities of this particular software package. It is possible that this observation, based on interview responses, indicates that students with a lower ability to visualize concepts obtain a greater benefit from the use of computer technology than those who have a greater ability to cognitively visualize concepts requiring spatial orientations.

An additional factor that may have influenced the outcomes was the limited duration of the treatment activity. Additional time may have improved the outcomes of all students. As stated previously, the time allotted for the lesson and related activities was curtailed due to pressure from the administration to complete the course of instruction mandated by the state’s Comprehensive Curriculum. An extended period of exposure may have allowed students to enhance their appreciation and understanding of polyatomic ions that the computer-based activity was attempting to deliver.

Also to be considered was whether or not student attitudes towards chemistry were affected by the particular methodology utilized in this study. The statistical analysis of the scores from the Birnie-Abraham-Renner (BAR) attitude survey indicated that there was no correlation between student contentment nor comprehension and their study participation group, treatment or control. The lack of favorable results may possibly have been due to the limitations of the instrument used. An instrument consisting of items that more closely measure the particular concepts being targeted may have provided more positive results. Despite the fact of this particular outcome from the BAR, the students appeared to take more
interest and work more diligently when provided the opportunity to use the computers to develop drawings of the polyatomic ions as opposed to being restricted to the use of the ion cards.

Although there is no direct qualitative statistical evidence to indicate that students’ attitudes improve, observation of the students and interview responses argue otherwise. The responses provided by students during the interviews indicate that the students enjoyed the computer-based activity lesson more than previous lecture-based lessons. It would also appear that more knowledge was obtained and retained based on observations made during subsequent lessons in other topics. Student behavior during the lesson as well as the interview responses appear to favor the use of computer technology for the delivery of lessons that involve visualization of concepts, particularly amongst those with lower scientific reasoning abilities in order to improve cognitive visualizations.

The question of the strategy increasing student competency to represent formula in multiple representations and increasing near transfer are not directly measured during the study. From behavior during the presentation of the lesson and from conversations with the students, some improvement may be inferred. As stated, there was no direct measurement of these particular points of interest, so the results are open to interpretation.

As to the question about whether the new strategy improves test performance in the area of chemical formula, there did appear to be some slight improvement in student performance. Test scores for the treatment group students improved slightly better than for the control group students. Test scores advances appeared to be greater when comparing the regular chemistry sections, treatment and control, as opposed to comparing the honors sections to each or when comparing the complete treatment and control groups.
Concerning the question of level of conceptual understanding correlating with attitude towards chemistry, the statistical analysis of the collected data shows no correlation. Neither of the two areas of attitude (contentment and comprehension) exhibited a correlation to conceptual understanding. This statistical lack of correlation is not quite understood as those students who performed well seemed to have a greater enjoyment of the lesson than those who performed poorly.

Implications and Possible Directions

This study was conducted using specific molecular drawing software in order to determine the benefit its use would have on student understanding of polyatomic ions. The lack of significant improvement leads to the question of what contributing factors may have affected the study in such a way as to induce this lack of improvement in student understanding. When considering the possible events and/or decisions that may have contributed to the results that were obtained, the choice of software, the limited time for the activity, and the methodology used are amongst the possible factors that had an effect on the outcomes of this study.

The particular software used in this study was one that had the basic ability to draw molecular models and represent them in three different forms. The drawings developed by the students were of polyatomic ions, but it was not possible to indicate the charges in the drawings. Newer, possibly future, superior software may be capable of indicating ionic charge hence enhancing the use of this type of software in the educational instruction of polyatomic ions. The utilization of the appropriate software package should provide a greater opportunity to prove the benefits of this particular strategy.

The software used resulted from a number of factors. The principal investigator was,
at the time, familiar only with the software that was used and as a result was comfortable with the capabilities of the software. The relative user-friendly characteristics enhanced the belief in high school students’ abilities to properly execute the software’s commands. Economic reasons also played an important role in the decision to make use of this particular software. Lack of financial assistance contributed to the decision to acquire this particular software.

The computers that were used had limitations on the software which they were capable of operating properly. Computer technology presently available to high school level educational facilities is not always up-to-date technology. A large amount of the computer technology used at the high school level consists of older, slower, less capable machines with the comparable older operating systems. The use of newer software, as stated, supported by modern hardware could possibly result in improvements in student understanding that are readily observable and significant. This modern hardware and software availability is a point that must be addressed and acted upon by those in the administrative portion of our educational system.

With the implementation of the state’s comprehensive curriculum, timelines for covering certain topics and content have been mandated by the district. Not only are limitations placed on the teachers by these timelines, but they also limited the time that could be allotted to this investigation. As has been previously reported (Berliner, 2002), the limitations that governing agencies and authorities place on free use of classroom time restricts teachers to simply deliverers of information. Without the ability to conduct research into alternate methods of instruction, there is little chance of improving educational outcomes. The mandated comprehensive curriculum imposes the will of forces outside the
classroom on those responsible for instructing students. With enough time to provide activities and instruction, the enhancement to student understanding possible through the use of computer technology should be validated.

The methodology may have also played a part in the failure to achieve the desired goals of this activity. This factor includes the specific operations that the students were to carry out and the testing instrument responsible for gauging student understanding. Of these, the activities may be altered so that students have additional opportunity to develop drawings of the polyatomic ions to provide greater chance of visualizing the ions. The testing instrument could be modified to better target the desired concepts under study. Improving the methodology is a means of attempting to show that the use of this computer technology, molecular model drawing software, is beneficial to students studying polyatomic ions.

For future studies, investigation might include a second software package that would allow for the motion of the particles. Another aspect may be an attempt to determine if the use of the software is of greater benefit to those students that have problems visualizing atomic particles. Software that would allow motion to be included could improve student understanding of the characteristics of all matter, not just polyatomic ions. This addition would create moving diagrams simulating the motion of particles. The movement of polyatomics away from the crystalline structure could enhance the idea of polyatomics as discrete particles with their own identity.

The results produced by this study seem to indicate that the students performing at the lower level of the ITED score range achieved a greater improvement than others. This leads to the question of whether or not the use of computer technology would be of greater benefit to lower achieving students. The use of computer technology may well be a means of
improving the cognitive understandings of the particulate nature of matter for students who have problems grasping these particular concepts. As has been previously reported (Long, Pence, and Zielinski, 1995), it has been suggested that a more visual approach to the teaching of chemistry would correspond to the students’ experiences with visual entertainment. It has also been suggested that the use of computer generated representations that mimic reality would be beneficial to students (Zietsman & Hewson, 1986). With positive significant results this investigation could have supported the findings of previous studies. The results, however, do not match those of other studies.

Given the results of this investigation, a future study along similar lines may be undertaken that makes use of a more versatile software package. This future study should utilize a software package that will more closely represent the characteristics of the polyatomic ions as well as a testing instrument that is more sensitive to the particular concepts being investigated. The software ideally would be capable of producing not only the polyatomic ions but also the cation to which they are attracted in order to provide a representation of the crystalline structure.

An additional study may be undertaken in order to determine the effect of animation on improving understandings of polyatomic ions and their particulate nature. It is possible that animation, which could be produced through the addition of a second software package used in tandem in order to mimic ion movement, would enhance student understandings of the particulate nature of polyatomic ions. Students’ experiences with visual computer images most commonly include movement, as opposed to static representations. Seeing that the polyatomic ion moves away from the crystalline structure intact could improve the understanding that it is a particle with its own identity.
Also to be studied might be the idea that using the computer software to enhance understanding of polyatomic ions while learning to write formulas will carry over to subsequent lessons. In particular, is it likely that enhancing the idea that polyatomic ions have a specific identity be used when the lessons move on to the balancing of equations and even into stoichiometry? Previous studies indicate that transfer may be enhanced through familiar experiences; animated computer representations may increase student cognitive understandings and also allow them to use the understandings in related new situations.

The use of computer-based instruction will increase as the tools improve and become more available to the classroom teacher. Setbacks in exhibiting the efficacy of these tools will occur, it will be necessary to determine the proper strategies for effectively using them. It will be through the efforts of practitioners and researchers to determine the proper strategies for the use of computer-based technologies that these tools will enhance student understanding. The use of computer-based technologies will not only enhance education, it will prepare students to inter into society with skills that are gained by utilizing this technology for purposes other than entertainment.


Appendix A

Concept Map
Map partitioned for detail on following pages.
Continued on page 97.
Molecular Drawing Software

Molecular 3-D
- may be downloaded
- purchase from
  - Internet
    - can then purchase
      - Registration Code
  - Software Company

Graphic Representations
- provides different
  - helps students form
    - Mental Visualizations
      - makes for better
        - Mindful Learning
  - provides three different
    - Models
      - called
        - Ball-and-stick
        - Space-filling Spheres
        - Structural Formula
Research Questions

Focus Questions

Main Question
  in the form of a
  Null Hypothesis
    stated as

There is no difference in student understanding of ionic bonding, whether computer drawing software is used or not.

Interviews
  involving students at different
  analyzed with a method called

Achievement Levels
  established by GPA

Verbal Analysis
  developed by Michelle

BAR Attitude Survey
  analyzed by e.g.
  developed by researcher

Quantitative Methods
  including a student understanding measured by pre- and post-tests
  analyzed by ANCOVA

Qualitative Methods

Data Collection
  using

used to guide

directed by the

enhanced by
Ionic Bonding

Involving

Ions
Which exist in the forms of

Cations
Polyatomics
Anions

Discrete Particles
Which are usually existing as

Solids
That have a crystalline structure
That when dissolved in water dissociate

Chemical Formulas
Produced by using

Elemental Symbols
Appendix B

Research Vee
Vee for Dissertation Research

Focus Question:
1. Does polyatomic ion nature as a particle improve with molecular drawings as a visual cue?
2. Do the high school students using selected computer drawing software perceive that this learning experience adds value to the lecture/discussion method normally used as the instructional strategy?
3. Does the use of the computer modeling software in the lesson improve student attitudes toward chemistry, as determined with the Birnie-Abraham-Renner Quick Attitude Differential, for those students using to the strategy?
4. Does the use of the strategy increase student competency to represent a chemical formula in multiple representational forms and increase near transfer?
5. Does the strategy improve chemistry test performance in the topic area of chemical formulas?
6. Does level of conceptual understanding correlate with attitude scores?

Conceptual:

Theory:
- Particulate nature of matter
- Chemical bonding
- Human Constructivist learning
- Educational Theory

Conceptual system:
- Chemical bonding
- Electrochemistry
- Ion Formation

Concepts:
- Polyatomic ions
- Bonds
- Models – representations
- Particulate nature of matter
- Chemical Formulas
- Understanding Chemistry

Event:
Students will participate in lesson on ionic compounds, take pre- and post-tests, attitude survey, and experimental group will utilize computer drawing software to produce ionic drawings.
Teachers will provide lesson on ionic compounds, administer pre- and post-tests, administer attitude survey, and provide computer tutorial on computer software to experimental group and collect student drawings.

Methodological:

Claims:
Knowledge:
The use of the computer software will assist students in learning chemical formulas as a function of the particulate nature of matter.
The use of the software will improve student attitude toward chemistry.

Value:
Improved understanding of chemical concepts will assist in discovery of additional new concepts.
Using tools as a skill in improving learning.

Transformation:
Analysis of pre- and post-test scores to determine if significant change has occurred.
Analysis of BAR results.

Records:
- Pre-test scores
- Post-test scores
- BAR results
- Interviews
Appendix C

Lesson Plan
<table>
<thead>
<tr>
<th>Day</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
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<td>Selected Chapter 8 Vocabulary words</td>
<td>Selected Chapter 8 Vocabulary words</td>
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<tr>
<td><strong>Objectives:</strong></td>
<td>TLW identify ionic compounds; TLW write ionic compound formulas; TLW identify polyatomic ions.</td>
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<tr>
<td><strong>Procedures:</strong></td>
<td>Modified Unit 4 Activity 2 to include drawing polyatomic ions on the computer</td>
<td>Unit 4 Activity 2</td>
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<td>Ion cards, worksheet, computers, drawing software</td>
<td>Ion cards, worksheet</td>
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<td><strong>Evaluation:</strong></td>
<td>Drawings will be printed and collected, post-test at conclusion</td>
<td>Post-test at conclusion</td>
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<td><strong>Use of Technology:</strong></td>
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</table>
### Determining Ionic Compound Formulas

Name _________________________________ Date ______________
Period ______________

Combine the following cations and anions to form the formulas of some ionic compounds. After determining formula, name the ionic compounds.

<table>
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<tr>
<th></th>
<th>Fluoride</th>
<th>Chloride</th>
<th>Oxide</th>
<th>Sulfide</th>
<th>Sulfate</th>
<th>Nitrate</th>
<th>Hydroxide</th>
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</thead>
<tbody>
<tr>
<td><strong>Sodium</strong></td>
<td>Na⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Potassium</strong></td>
<td>K⁺</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Iron (II)</strong></td>
<td>Fe²⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Iron (III)</strong></td>
<td>Fe³⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Copper (I)</strong></td>
<td>Cu⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Copper (II)</strong></td>
<td>Cu²⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ammonium</strong></td>
<td>NH₄⁺</td>
<td></td>
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</table>
Appendix D

Unit 4 Activity 2 of the Comprehensive Curriculum
Activity 2: Modeling the Formation of Ionic Chemical Formulas (SI GLE: 7; PS GLEs: 5, 6, 7, 16)

Preparation for the activity:
Use the patterns below to make ion cards templates. Each point on the left side represents an electron that is lost. Each indentation on the right side is an electron gained. Give each student a template of one of the patterns and one sheet of card stock. One student will need to make the + and - cards to be used later. The students are to trace the assigned patterns as many times as possible on the card stock, cut them out, and bring them to school. Place the pieces of the entire group in a baggie. They will use these cards for writing and naming compounds, writing and balancing equations and demonstrating the law of conservation of mass. Prepare a set on transparency film to be used on an overhead projector to model the activity for the students. The ion cards can be done (or outlined) with different colors for a better contrast for visual learners.

Teacher: Make a list of ions to be made into compounds such as:
1. sodium + chlorine
2. aluminum + oxygen
3. magnesium + phosphate
4. calcium + fluorine
Prepare a handout for each group of students.

Distribute a handout, a bag of ion cards, and a periodic table to each student group. Students are to use the periodic table to determine the charge on each ion in the list. They are to build each compound and name it correctly.

Samples:

- Sodium chloride
- Calcium fluoride

Once the student has mastered writing formulas and naming compounds that are ionically bonded, introduce covalent bonding.
Appendix E

Ion Cards
Al$^{3+}$

aluminum

Fe$^{3+}$

iron(III)
$\text{NH}_4^+ \quad \text{ammonium}$

$\text{Na}^+ \quad \text{sodium}$

$\text{Ag}^+ \quad \text{silver}$

$\text{K}^+ \quad \text{potassium}$

$\text{H}^+ \quad \text{hydrogen}$

$\text{Cu}^+ \quad \text{copper(I)}$
Fe$^{2+}$
iron (II)

Ca$^{2+}$
calcium

Cu$^{2+}$
copper(II)

Mg$^{2+}$
magnesium
Appendix F

Environment and Student Activity Pictures
Front of the school.

Classroom where activity occurred.
Using the ion cards.

Building structures.
Appendix G

Testing Instrument
Please answer the following items to the best of your ability. Place answers on the provided answer sheet. The scores on this test will be kept confidential. Please do not mark on this test.

1. A positively charged ion is more commonly called a(n)
   a) alloy
   b) anion
   c) cation
   d) oxyanion

2. An ionic substance that conducts electricity when dissolved in water is known as a(n)
   a) electrolyte
   b) electron sea model
   c) interstitial alloy
   d) oxidation number

3. A negatively charged ion is more commonly called a(n)
   a) alloy
   b) anion
   c) cation
   d) oxyanion

4. The force that holds two atoms together is called
   a) chemical bond
   b) ionic bond
   c) lattice energy
   d) metallic bond
5. The name used for most ionic compounds other than oxides is
   a) alloy
   b) delocalized electrons
   c) electrolyte
   d) salts

6. Ions are formed when individual atoms or groups of bound atoms
   a) lose or gain protons in order to gain stability
   b) lose or gain electrons in order to gain stability
   c) exchange protons to make new species
   d) exchange neutrons to make new species

7. The electrostatic force that holds oppositely charged particles together is called
   a) chemical bond
   b) ionic bond
   c) lattice energy
   d) metallic bond

8. The subscript that indicates the number of atoms present in a compound will appear at the symbol’s
   a) lower left
   b) upper left
   c) lower right
   d) upper right
9. A charged particle that contains more than a single atom is termed a(n)
  a) anion
  b) cation
  c) oxyanion
  d) polyatomic ion

10. Ionic compounds are formed when
  a) similarly charged particles attract each other
  b) neutral particles come together to create stable species
  c) electrons in the valence shell are shared between atoms
  d) oppositely charged particles attract each other

11. The anion that has the formula $\text{CO}_3^{2-}$ is named
  a) carbon oxide
  b) carbon trioxide
  c) carbon oxygen (III)
  d) carbonate

12. When the ions $\text{Ca}^{2+}$ and $\text{PO}_4^{3-}$ combine, they will produce calcium phosphate which has
    the formula
    a) $\text{Ca}_6\text{PO}_4$
    b) $\text{Ca}_2(\text{PO}_4)_3$
    c) $\text{Ca}_3(\text{PO}_4)_2$
    d) $\text{Ca}_3\text{PO}_4$
13. When dissolved in water, ionic compounds break up into individual ions. This process is known as dissociation. For example, when NaCl dissolves in water, the equation looks as follows: \( \text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^- \). Of the following equations, the one that best represents the dissolving of sodium hydroxide, NaOH, is

a) \( \text{NaOH} \rightarrow \text{NaH}^+ + \text{O}^- \)

b) \( \text{NaOH} \rightarrow \text{Na}^+ + \text{H}^+ + \text{O}^- \)

c) \( \text{NaOH} \rightarrow \text{Na} + \text{H}_2\text{O} \)

d) \( \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- \)

14. Explain your reason for the choice made.

15. Of the following diagrams, the best representation of the sulfate ion, when sulfur is represented by yellow spheres and oxygen by red spheres, is

a) 

b) 

c) 

d)
Appendix H

Birnie-Abraham-Renner Quick Attitude Differential
For the last few classes you have been studying a topic in Chemistry concerned with the bonding of ions in ionic compounds. We are very interested in student reaction to the approach used in your class.

**Sample:** Below you will find seven numbers between two words or phrases. You are requested to circle the number which best describes how you feel at this time. For example, if you felt very relaxed you might circle number 2.

<table>
<thead>
<tr>
<th>relaxed</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>tense</th>
</tr>
</thead>
</table>

Please tell us your reaction to the unit you have just completed by circling the appropriate number.

1. displeased 1 2 3 4 5 6 7 pleased

2. dissatisfied 1 2 3 4 5 6 7 satisfied

3. confused 1 2 3 4 5 6 7 not confused

4. unenthusiastic 1 2 3 4 5 6 7 enthusiastic

5. work is difficult 1 2 3 4 5 6 7 work is easy

6. class activities seem mixed up 1 2 3 4 5 6 7 class activities seem in order

7. I have unanswered questions 1 2 3 4 5 6 7 I understand the topic

8. I dislike this topic 1 2 3 4 5 6 7 I like this topic

9. I don’t understand the words used 1 2 3 4 5 6 7 I understand the words used

10. I can’t solve the problems 1 2 3 4 5 6 7 I am able to solve the problems

11. everything is new to me 1 2 3 4 5 6 7 I am learning nothing new

12. we are moving too quickly 1 2 3 4 5 6 7 we are moving too slowly

On the back of this sheet write what you **liked best** AND what you **liked least** about this unit.
Appendix I

Protocols for Interviews
The following questions were used to guide the semi-structured interviews of the selected students. The six selected students encompass all sections, three from the treatment group and three from the control group. One student was selected from the three levels of ITED Science scores; high, medium, and low.

1. What did you know about ions before the lesson?
2. What do you know now?
3. Did the lesson help you to understand ions better?
4. What do you know about polyatomic ions?
5. What shape do you think polyatomic ions take?
6. (Treatment only) Did the computer activity help you in understanding polyatomic ions?
Appendix J

Data Collection Form and Demographic Data Form
<table>
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<tr>
<th>Participant Identification</th>
<th>Gender</th>
<th>Treatment</th>
<th>Pretest Score</th>
<th>Posttest Score</th>
<th>ITBS Science</th>
<th>B-A-R Attitude</th>
<th>Age</th>
<th>Race</th>
<th>SES</th>
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Name ______________________________ Age _____ Gender: Female ___ Male ___
Race: African-American _____ Asian _____ Hispanic _____
          White _____ Other _____
Lunch (check one):    Free ______ Reduced _____ Full-Price _____
Extra-Curricular Activities (check all that apply):
  Athletics :  Team sports _____ Track & Field _____ Cheerleading _____
  Band :       Marching band _____ Flag line _____ Specialty band _____
  Student government : Class officer ______ Student Council ______
Appendix K

Approved IRB
Request for Exemption and
Certificate of Completion of
Human Participant Protections Education for Research Teams Course
APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

Unless they are qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

Instructions: Complete this form.

If it appears that your study qualifies for exemption send:

(A) Two copies of this completed form,
(B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts A & B),
(C) Copies of all instruments to be used. If this proposal is a part of a grant proposal include a copy of the proposal and all recruitment material.
(D) The consent form that you will use in the study. A Waiver of Written Informed Consent is attached and should be completed only if you do not intend to have a signed consent form.

to: ONE screening committee member (listed at the end of this form) in the most closely related department/discipline or to IRB office.

If exemption seems likely, submit it. If not, submit regular IRB application. Help is available from Dr. Robert Mathews, 578-8692, irb@lsu.edu or any screening committee member.

Principal Investigator: Leodore M. Amiot Jr.  Student? Y/N
Ph: 337-783-5313  E-mail: lamiot@acadia.k12.la.us  Dept/Unit: Curriculum and Instruction

If Student, name supervising professor: Dr. James Wanderee  Ph: 225-578-2348

Mailing Address: 410 Corn Street, Eunice, LA 70535-6311  Ph: 337-457-4652

Project Title: The Particulate Nature of Polyatomic Ions: An Inquiry-Based Lesson Using Molecular Drawing Software

Agency expected to fund project: self.

Subject pool (e.g. Psychology Students): High school chemistry students

Circle any "vulnerable populations" to be used: (children <18, the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature: [Signature]  Date: 8/12/05 (no per signatures)
Screening Committee Action:
Exempted ______ Not Exempted ______ Category/Paragraph ______
Reviewer ______ Signature ______ Date ______

Part A: DETERMINATION OF "RESEARCH" and POTENTIAL FOR RISK

This section determines whether the project meets the Department of Health and Human Services (HSS) definition of research involving human subjects, and if not, whether it nevertheless presents more than "minimal risk" to human subjects that makes IRB review prudent and necessary.

1. Is the project involving human subjects a systematic investigation, including research, development, testing, or evaluation, designed to develop or contribute to generalizable knowledge?

(Note: some instructional development and service programs will include a "research" component that may fall within HSS' definition of human subject research).

X YES

NO

2. Does the project present physical, psychological, social or legal risks to the participants reasonably expected to exceed those risks normally experienced in daily life or in routine diagnostic physical or psychological examination or testing? You must consider the consequences if individual data inadvertently become public.

NO Continue to see if research can be exempted from IRB oversight

YES Stop. This research cannot be exempted--submit application for IRB review.

3. Are any of your participants incarcerated?

X YES Stop. This research cannot be exempted--submit application for IRB review.

NO Continue to see if research can be exempted from IRB oversight.
4. Are you obtaining any health information from a health care provider that contains any of the identifiers listed below?

A. Names
B. Address: street address, city, county, precinct, ZIP code, and their equivalent geocodes.
   Exception for ZIP codes: The initial three digits of the ZIP Code may be used, if according to current publicly available data from the Bureau of the Census: (1) The geographic unit formed by combining all ZIP codes with the same three initial digits contains more than 20,000 people; and (2) the initial three digits of a ZIP code for all such geographic units containing 20,000 or fewer people is changed to >000=. (Note: The 17 currently restricted 3-digit ZIP codes to be replaced with >000= include: 036, 059, 063, 102, 203, 556, 692, 790, 821, 823, 830, 831, 878, 879, 884, 890, and 893.)
C. Dates related to individuals
   i. Birth date
   ii. Admission date
   iii. Discharge date
   iv. Date of death
   v. And all ages over 89 and all elements of dates (including year) indicative of such age. Such ages and elements may be aggregated into a single category of age 90 or older.
D. Telephone numbers;
E. Fax numbers;
F. Electronic mail addresses;
G. Social security numbers;
H. Medical record numbers; (including prescription numbers and clinical trial numbers)
I. Health plan beneficiary numbers;
J. Account numbers;
K. Certificate/license numbers;
L. Vehicle identifiers and serial numbers including license plate numbers;
M. Device identifiers and serial numbers;
N. Web Universal Resource Locators (URLs);
O. Internet Protocol (IP) address numbers;
P. Biometric identifiers, including finger and voice prints;
Q. Full face photographic images and any comparable images; and
R. Any other unique identifying number, characteristic, or code; except a code used for re-identification purposes; and
S. The facility does not have actual knowledge that the information could be used alone or in combination with other information to identify an individual who is the subject of the information.

☐ YES  Stop. This research cannot be exempted--submit application for IRB review.

X NO  Continue to see if research can be exempted from IRB oversight.
Part B: EXEMPTION CRITERIA FOR RESEARCH PROJECTS

Research is exemptible when all research methods are one or more of the following five categories. Check statements that apply to your study:

1. In education setting, research to evaluate normal educational practices.

2. For research not involving vulnerable people [prisoner, fetus, pregnancy, children, or mentally impaired]: observe public behavior (including participatory observation), or do interviews or surveys or educational tests:

   The research must also comply with one of the following:
   either that
   a) the participants cannot be identified, directly or statistically;
   or that
   b) the responses/observations could not harm participants if made public;
   or that
   c) federal statute(s) completely protect all participants= confidentiality;
   or that
   3. For research not involving vulnerable people [prisoner, fetus, pregnancy, children, or mentally impaired]: observe public behavior (including participatory observation), or do interviews or surveys or educational tests:

   d) all respondents are elected, appointed, or candidates for public officials.

4. Uses only existing data, documents, records, or specimens properly obtained.

   The research must also comply with one of the following:
   either that:

   a) subjects cannot be identified in the research data directly or statistically, and no- one can trace back from research data to identify a participant;
or that
b) the sources are publicly available


5. Research or demonstration service/care programs, e.g. health care delivery.

The research must also comply with all of the following:

   a) It is directly conducted or approved by the head of a US Govt. department or agency.

   and that

   b) it concerns only issues under usual administrative control (48 Fed Reg 9268-9), e.g., regulations, eligibility, services, or delivery systems;

   and that

   c) its research/evaluation methods are also exempt from IRB review.


6. For research not involving vulnerable volunteers [see 2 & 3 above], do food research to evaluate quality, taste, or consumer acceptance.

The research must also comply with one of the following:

   either that

   a) the food has no additives;

   or that

   b) the food is certified safe by the USDA, FDA, or EPA.
NOTE: Copies of your IRB stamped consent form must be used in obtaining consent. Even when exempted, the researcher is required to exercise prudence in protecting the interests of research subjects, obtain informed consent if appropriate, and must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont Report), 45 CFR 46, and LSU Guide to Informed Consent; (Available from OSP or http://aapl022.lsu.edu/osp/osp.nsf/$Content/LSU%20IRB%20Documents)

HUMAN SUBJECTS SCREENING COMMITTEE MEMBERS can assist & review:

COLLEGE OF ARTS AND SCIENCES: MASS COMMUN/SOC WK/AG:
Dr. Noell * (Psych) 578-4119  Dr. Nelson (Mass C) 578-6686
Dr. Geiselman * (Psych) 763-2695  Dr. Archambeault(Soc Wk) 8-1374
Dr. Beggs (Socio) 578-1119  Dr. Rose (Soc Wk) 578-1015
Dr. Honeycutt (Com.Stu) 578-6676  Dr. Keenan* (Hum Ecol) 578-1708
Dr. Dixit (Comm Sc./Dis) 578-3938  Dr. Belleau (Hum Ecol) 578-1535

ED/LIBRARIES/INFO SCI  BUSINESS
Dr. Kleiner (Middleton) 578-2217
Dr. Culross (Education) 578-2254
Dr. Landin* (Kinesiol) 578-2916
Dr. MacGregor (ELRC) 578-2150
Dr. Trousdale* (Currie & I) 578-2330

(* = IRB member)
Completion Certificate

This is to certify that

Leo Amiot

has completed the Human Participants Protection Education for Research Teams online course, sponsored by the National Institutes of Health (NIH), on 10/02/2005.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.
Description of Project:

During Unit 4 Activity 2: Modeling the Formation of Ionic Chemical Formulas, the investigator intends to make an addition by including the use of a computer software program which will allow the students to generate pictorial representations of polyatomic ions as well as using the ion cards as described in the activity. The study would also make use of a pretest administered approximately two weeks prior to the activity and a posttest administered at the conclusion of the activity.

During the activity, one section of chemistry would have the opportunity to use the computer to create the drawings while a second section would have no modification to the activity. The software to be used is HyperChem Lite. Students would be provided training in the use of the software in order to create the drawings of the polyatomic ions. A total of approximately 120 students would be involved in the study as either control or treatment group.

A selected few students would be interviewed to determine their overall reaction to this type of teaching strategy as well as their level of understanding of the topic of the particulate nature of polyatomic ions.
Appendix L

Consent Letter and Assent Form
Project Title: The Particulate Nature of Polyatomic Ions: An Inquiry-Based Lesson Using Molecular Drawing Software

Performance Sites: Crowley High School

Investigators: The following investigator is available for questions, M-F, 10:40 am to 12:00 pm

Mr. Leo Amiot
Crowley High Chemistry Teacher
(337) 783 – 5313

Purpose of the Study: The purpose of this study is to determine if students making use of molecular drawing software will gain a greater understanding of the particulate nature of polyatomic ions.

Inclusion Criteria: Students 16 – 18 years of age who are enrolled in high school Chemistry.

Exclusion Criteria: Students who are not enrolled in high school Chemistry or do not meet the age range.

Description of the Study: While engaged in the study of ions as described by the State’s Comprehensive Curriculum students in selected sections of Chemistry – Honors will be given the opportunity to make use of software which will allow them to create computer generated drawings of polyatomic ions. This addition to the lesson will be carried out in the classroom as a part of the overall lesson on ions. Selected students will be interviewed for their perspectives on the lesson as well as their understanding of polyatomic ions.

Benefits: Students will have the opportunity to improve their computer skills. The study could identify a teaching method that will enhance understanding of chemistry. The benefit to other teachers and students is a method that improves the learning and teaching of Chemistry.

Risks: There are no known risks.
Right to Refuse: Participation is voluntary, and a student will become involved in this method of teaching only if both student and parent agree to the student’s participation. At any point during this portion of the lesson, either the student may withdraw or the student’s parent may withdraw the student from this portion of the lesson without penalty or loss of any benefit to which they may be entitled.

Privacy: The school records of students involved in the study may be reviewed by investigators. Results of the study may be published, however no names or identifying information will be used or included for publication.

Financial Information: There is no cost to the students nor is there any financial compensation.

Signatures: The study has been explained and any questions I had were satisfactorily answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about student’s rights or other concerns, I can contact Robert C. Mathews, Chairman, Institutional Review Board, (225) 578-8692. I will allow my child to participate in the lesson described above and acknowledge the investigator’s obligation to provide me with a signed copy of this consent form.

Parent’s Signature: Date:
Agreement to Participate in Study

Student agrees to participate in the lesson while following teacher instructions and discussions concerning ions. The student will make use of the computer to create drawings of polyatomic ions if requested to do so. The student agrees to be interviewed as to understanding of the lesson if requested. All directions and tasks will be complied to in the best of the student’s ability.

Student Signature:               Date:

Student’s age:

Parent/Guardian Signature:
Appendix M

School Approval
To: Steve Duplechin  
Principal, Crowley High School

Re: Modification of Comprehensive Curriculum Activity

Mr. Duplechin;

This request is being made for the purpose of allowing the modification of the state’s Comprehensive Curriculum’s Unit 4 Activity 2: Modeling the Formation of Ionic Chemical Formulas for the purpose of gaining information on the effectiveness of a different teaching strategy. It is the intention of the chemistry teacher to add a component to the activity that involves the use of computer software to allow students to generate drawings of polyatomic ions. It is hoped that this added portion will increase understanding of the particulate nature of polyatomic ions as well as an overall understanding of one of chemistry’s most fundamental concepts.

With your permission this addition to the activity will proceed in one section while a second section will serve as a baseline group for comparison. At no time will any student be identified, privacy will be strictly enforced.

Thank you for your consideration and assistance.

Sincerely;

Leodore M. Amiot Jr.
Chemistry Teacher, Crowley High School

Approval for the modification for research purposes is granted.

Signature: [signature]  
Date: 8/22/05
Appendix N

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Appendix O

Examples of Polyatomic Ion Drawings
Stick rendering from 5E9

Ball-and-cylinder rendering from 5E9

Sphere rendering from 5E9
Stick rendering from 3E10

Ball-and-cylinder rendering from 3E10

Sphere rendering from 3E10
Stick rendering from 5E7

Ball-and-cylinder rendering from 5E7

Sphere rendering from 5E7
Appendix P

Statistical Output from SPSS
### Regression

**Variables Entered/Removed**

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a. All requested variables entered.
b. Dependent Variable: Diff_Score

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*a. Predictors: (Constant), type, treatment, ses, involve, gender, race, age, itbs*

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*a. Predictors: (Constant), type, treatment, ses, involve, gender, race, age, itbs*
b. Dependent Variable: Diff_Score

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ANOVA<sup>b</sup>

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d. Coefficients<sup>a</sup>

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a. Dependent Variable: DIFFEREN
Vita

Leo’s education includes an associate in science (May 1975) from Louisiana State University at Eunice, a bachelor of science in agronomy (May 1977) from Louisiana State University in Baton Rouge, as well as a master of education (May 1995) and master of science in chemistry (December 1998) from McNeese State University in Lake Charles. Work experience includes several years as a drilling fluids technician and nineteen years as a public school science teacher. He has served as the science department coordinator since 1990 and was once honored with the teacher of the year award at his school.

During his tenure, Leo has served on various committees at the school, parish, district, and state levels. Presently he is serving as the a mentor for new teachers under the LaTAAP program at his school. At the parish level, Leo has served on the textbook adoption committee and as a teacher representative on a school board committee. At the district level, Leo was part of the curriculum writing team for district four. He has also served on the state textbook adoption committee and is currently serving on the GEE item review committee.