Investigating Macroscopic, Submicroscopic, and Symbolic Connections in a College-Level General Chemistry Laboratory

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INVESTIGATING MACROSCOPIC, SUBMICROSCOPIC, AND SYMBOLIC
CONNECTIONS IN A COLLEGE-LEVEL GENERAL CHEMISTRY LABORATORY

by

Felicia Culver Thadison

Abstract of a Dissertation
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

August 2011
ABSTRACT

INVESTIGATING MACROSCOPIC, SUBMICROSCOPIC, AND SYMBOLIC CONNECTIONS IN A COLLEGE-LEVEL GENERAL CHEMISTRY LABORATORY

by Felicia Culver Thadison

August 2011

Explanations of chemical phenomena rely on understanding the behavior of sub-microscopic particles. Because this level is “invisible,” it is described using symbols such as models, diagrams and equations. For this reason, students often view chemistry as a “difficult” subject. The laboratory offers a unique opportunity for the students to experience chemistry macroscopically as well as symbolically. The purpose of this investigation was to determine how chemistry lab students explained chemical phenomenon on the macroscopic, submicroscopic, and representational/symbolic level.

The participants were undergraduate students enrolled in an introductory level general chemistry lab course. Students’ background information (gender, the number of previous chemistry courses), scores on final exams, and final average for the course were collected. Johnstone’s triangle of representation guided the design and implementation of this study. A semi-structured interview was also conducted to bring out student explanations. The questionnaires required students to draw a molecule of water, complete acid base reaction equations, represent, submicroscopically, the four stages of an acid-base titration, and provide definitions of various terms. Students were able represent the submicroscopic level of water.
Students were not able to represent the submicroscopic level of the reaction between an acid and a base. Students were able to represent the macroscopic level of an acid base reaction.

Students were able to symbolically represent the reaction of an acid and a base. These findings indicate that students can use all three levels of chemical representation. However, students showed an inability to connect the levels in relation to acid-base chemistry. There was no relationship between a student’s ability to use the levels and his or her final score in the course.
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by

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A Dissertation
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for the Degree of Doctor of Philosophy

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August 2011
DEDICATION
This body of work is dedicated to:

The memory of my little brother, Peyton DeJuan Culver, taken before we ever knew what he could be.

The memory of my grandfather, Israel Lee Culver, Sr., who passed away having never learned to read or write.

My son, to whom I promised that we would not be just another statistic.
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I would be remiss if I did not acknowledge my parents, Willie and Maebell Culver, for instilling in me not only a work ethic, but also a stubbornness that has allowed me to persevere no matter the odds. Thank you for all your love and support throughout my life. John, my husband, thank you for being the best friend and confidant I could ever have. The late nights have finally come to fruition. We did it!
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CHAPTER I
INTRODUCTION

In this study, students’ connections between and use of the three levels of chemical representations in a second semester general chemistry laboratory were investigated. This chapter provides background on the origin and scope of this research. The main themes of the research are student learning and chemical representations in relation to solution chemistry. In this chapter the questions, why the problem is worth exploring and what contribution to theory and practice will be made, will be answered.

Statement of the Problem

It is common knowledge that students struggle with what they perceive as the abstract nature of chemistry. Chemistry is often presented as a conglomeration of symbols, equations, and scientific measurements. Instructors attempt to use these representations to explain phenomena that occur on the molecular level and cannot be seen or easily visualized by the student. This “abstractness” makes chemistry difficult for many students to understand.

Chemical concepts can be represented at three different levels: macroscopic, microscopic, and symbolic. With microscopic and symbolic representations addressed in lecture, students experience the macroscopic level in the laboratory. Symbolic representations can often be the bridge between macroscopic and microscopic representations. However, this facility is not often achieved by students. Students on average have difficulty transitioning between representations and understanding how they are connected (Gabel, 1998).
The ability to integrate the three representational levels is important in gaining knowledge of chemical concepts such as solution chemistry (Calyk, Ayas, & Ebenezer, 2005). Prior research shows that students at various levels have incorrect knowledge of the microscopic level. This is indicated by the difficulty students have with the fundamental chemical knowledge of the particulate nature of matter. The inability to build proper mental models of the particulate nature of matter leads to misconceptions or lack of conceptual understanding (Tang, 2009). Students misconceptions about physical and chemical change at the three levels of chemical representation (macroscopic, submicroscopic, symbolic) are widespread. In a macroscopic level study by Osborne and Cosgrove (1983), 25% of students believed the bubbles in boiling water were due to air. Shephard and Renner (1982) found in the microscopic level study that students had no fundamental understanding of the particulate nature of gases, liquids, and solids.

Solution chemistry, the topic of this study, is a fundamental part of chemistry. This concept was selected because it brings together many other concepts previously covered in general chemistry. These concepts include the particulate nature of matter, solubility, and equilibrium. Whether or not the lecture or lab instructors explicitly relate the concepts for the students is highly variable. Some students possess the ability to mathematically solve problems without an understanding of the underlying concepts (Gabel, Sherwood, & Enochs, 1984). This is illustrated by the student’s lack of ability to solve word problems related to solution chemistry requiring conceptual understanding.

Purpose of the Study

The purpose of this study is to investigate second semester general chemistry students’ ability to transfer macroscopic knowledge of solution chemistry to the
microscopic and symbolic levels. The degree to which students integrate the three levels of chemical representations of solution chemistry and whether or not there is a relationship between this ability and other outcome variables was explored.

**Theoretical Framework**

The constructivist learning theory is quite familiar to most science educators. While there are many kinds of constructivism, the sense in which the term was used in this study is the building of understanding by the learner. This give and take between the environment and its representations in the human mind was expounded by Jean Piaget (Roth, 1993). Piaget is probably best known for his stages of cognitive development. Piaget believed there were distinct developmental levels based upon a child’s age. The developmental stage determines the type of learning the child is capable of demonstrating. These stages are sensorimotor, preoperational, concrete operational, and formal operational. According to Piaget, a child will pass through each stage but at their own individual rates. When a child enters the formal operational stage, they have developed the ability for abstract and symbolic thinking.

Most general chemistry college students function in the concrete level (Lawson, 1990, 1992, 1993). Functioning in the formal operational stage means experimentation can be used to solve problems (Slavin, 1988). At this stage abstract concepts which are independent of physical reality can be developed. Therefore, individuals should be able to understand abstract concepts. The fact that an individual has developed to this stage does not mean they always function at this stage. Most adults function at the concrete operational stage. This is especially true of the general chemistry college student (Gabel & Sherwood, 1980). When new concepts are introduced knowledge begins at the
concrete level. As the student’s probe the information further, they will begin to understand it at the formal level. The development of an understanding of solution chemistry requires that the student function at the formal operational stage.

While Piaget believed the stages were age-dependent, Bruner felt cognitive levels were age-independent (Bruner, 1966). Bruner’s cognitive theory describes three techniques for representing reality: enactive, iconic, and symbolic. The first level is the enactive level and involves direct manipulation of materials by the child. At this level the focus is on accomplishing or performing a task such as riding a bike or driving a car. A series of actions must be performed correctly and in order to achieve the desired result.

The second level, the iconic level, involves the child manipulating mental images of objects. These mental images stand for a concept. This level depends upon visual or sensory organization. At this level, the student has the ability to recognize paths or patterns to what they are doing. The iconic level involves making connections between ideas, discerning common and contrasting themes.

Lastly, the child moves to the third level, symbolic, where he manipulates symbols with no need for mental images or objects. At this level, concepts are represented with words or language. Abstract thoughts can be represented by the use of symbols or words.

The position of both Piaget and Bruner are connected by a common belief that students construct their knowledge when what they experience connects to or interacts with previous experience or prior knowledge to create a new knowledge. This process of connecting old experiences or knowledge with new experiences or knowledge may result in assimilation or accommodation. If the new knowledge is compatible with the prior
knowledge then the knowledge is simply integrated, or assimilated, into the existing cognitive structure of the student. Accommodation, conversely, is when the new knowledge is not compatible with prior knowledge. Under these circumstances, the student’s ideas must be restructured. Ideally, this would lead to a change in understanding for the student and a change in cognitive structure.

Dewey proposed that the way to influence the learner is by engaging them in active learning (Bransford, Brown, & Cocking, 1999). In a laboratory setting, students are involved in active learning. While most students can regurgitate definitions and understand macroscale procedures such as looking for a pale pink color, representing this with chemical symbols requires the transition to microscale thinking such as what is causing this color and why? This conceptual change, as defined by diSessi involves the cognitive reorganization of fragmented, naïve knowledge (DiSessa, 2002). The goal is to help students transition from macroscale thinking to microscale thinking. Specifically, students need to be able to connect the three representations in order to achieve meaningful learning.

Johnstone (1993) organizes conceptual understanding of chemistry into three separate levels: macroscopic, submicroscopic, and representational (Figure 1). The macroscopic understanding of chemistry is the level most often experienced in chemistry laboratory courses, dealing with observable phenomena that can be experienced via the five senses. The macroscopic level is real to the student and is comprised of tangibles. The submicroscopic level involves understanding the particulate nature of matter, including molecular, atomic, and kinetic points of view. The representational level focuses on making sense of and using representations such as chemical symbols,
equations, stoichiometry, and mathematical manipulations. According to Johnstone, students must link the three basic conceptual levels of chemistry in order to gain expertise in their field. Experts work within all three levels of understanding to think through and communicate explanations of chemical concepts and phenomena. Studies have found that students show improved performance after instruction when they are encouraged to make connections between the three levels of understanding, particularly when emphasizing learning using representations (Gilbert, 2009).

![Figure 1. Johnstone's three levels of chemical representation of matter.](image)

**Research Questions**

This study explores the following questions. How do students make conceptual sense of solution chemistry such as acid-base titration? To what extent do students use macroscopic, submicroscopic, and symbolic level conceptual thinking to explain chemical phenomena? Specific questions include the following:

1. What are students’ understandings of each level of chemical representation in relation to the chemical phenomena they experience in the laboratory?
2. Is there a relationship between a student’s final grade and that student’s ability to use the three levels of chemical representation to explain a chemical concept?
3. Is there a relationship between a student’s final grade and that student’s ability to connect the three levels of chemical representation of a chemical concept?

4. Are there differences in the final grades and explanations between students who took chemistry in high school and those who did not?

Delimitations

The following delimitations apply to this study:

1. Subjects for this study were limited to students enrolled in general chemistry at a southeastern public university.

2. The majority of the students were non-chemistry majors.

Rationale

Most studies discussed previously involved quantitative research. Data needs to be collected in the qualitative realm. The question is not about the relative strength or weakness of individual methodologies but simply one of fit. The method must be appropriate for the research question. This literature review has shown that relatively little is known about the ability of second semester general chemistry laboratory students to transition between and make connections among the different representational levels. This is what the researcher hopes to address in this study.

Preliminary Analysis of Pilot Study

Explanations of chemical phenomena rely on understanding the behavior of submicroscopic particles and because this level is “invisible” it is described using symbols such as models, diagrams and equations. How chemistry lab students explained chemical phenomenon on the macroscopic, submicroscopic, and representational/symbolic level was investigated. Two undergraduates enrolled in an introductory chemistry laboratory
were interviewed. There were distinct differences between the two students. Both students demonstrated the ability to utilize multilevel thinking. Students demonstrated the use of all three levels (macro, micro, representational or symbolic) of thinking when defining solution chemistry. However, when discussing other chemical concepts such as freezing point depression, often only the macroscopic and/or symbolic level was used. One student, with prompting, utilized all three levels to discuss acid-base titration while the second student could only discuss at the macroscopic and symbolic level. One student utilized all three levels to discuss the concept of freezing point depression but still held a misconception. This result is in conflict with the initial belief that students who could utilize all three levels when discussing a concept would understand the concept. Future work will involve discovering if there is an effect of covering the concept in class after covering it in lab. The student who was able to utilize all three levels mentioned that it was helpful in class to be able to think about the lab. This student was also a non-traditional student, meaning not in the 18 to 22-year-old age group, which will factor into future work.

Definitions and Terminology

*Macroscopic level thinking* – the ability to think spontaneously about what is observable or able to be seen or experienced. This will be evinced by the coherency of student responses.

*Submicroscopic level thinking* – the ability to think spontaneously of atoms and molecules.

*Symbolic level thinking* – the ability to think spontaneously of equations, graphs, formulas, etc.
Mental model (in general) – psychological representations of real, hypothetical, or imaginary situations.

Mental model (in chemistry) – a personal representation of the submicroscopic level of matter.

Justification

The overall motivation for this research is to gain a better understanding of how students learn chemistry. As an instructor for the general chemistry laboratory course there have been many opportunities to observe students’ struggles with chemistry. Utilizing the socratic teaching method to interact with students revealed holes in student understanding. The socratic teaching method is based on asking and answering questions to stimulate critical thinking and to illuminate ideas. Students could spout a formula or find it in the lab manual but have no concept of what it meant or how to use it. Was this inadequacy in the students due to the teaching abilities or techniques of the researcher? Why could the students not understand?

Talking to fellow general chemistry lab instructors revealed that this was not an isolated problem. Further investigation led to much literature on the actual general chemistry lecture course. However, not a great deal on information existed about the laboratory classroom. This gap is significant because labs offer a unique environment for students to experience chemistry at all three levels (macroscopic, submicroscopic, and symbolic). The majority of general chemistry labs in this public university are taught by graduate students and even some senior level undergraduates. As students ourselves, we have neither the experience nor the training a faculty member might possess. How can
we improve our understanding of student learning and thereby the achievement of our students?

The literature review has pointed out that there is no direct path from where the students are and where we want them to be. There have been no studies done at public universities exploring use of and connections among the three levels of chemical representation in general chemistry lab classes.
It is believed that the abstract nature of chemistry makes the subject difficult for students. Student learning and student understanding depend heavily on clear explanations of abstract chemical concepts. Models and chemical representations are the main tools used by instructors to explain chemistry. They are often used to develop a student’s submicroscopic level thinking ability (Johnson-Laird, 1983).

Learning can be an ambiguous term. Throughout the years terminology has been developed to address the degrees or depth of learning. Shallow learning, rote learning, instrumental understanding, passive learning, etc are all examples of learning which indicates a lack of conceptual understanding and cognition. In contrast, meaningful learning (Ausubel, 1968), relational understanding, and active learning, are examples of student focused approaches to learning and indicate greater conceptual understanding as well as higher order cognitive skills. The question of what is learning leads to another which is “how do students learn?”

According to Ausubel, the most important factor of learning is what the student already knows. This single factor is the foundation of constructivist approach to learning, a widely accepted process of knowledge construction. Having students actually actively construct their own conceptual links throughout a particular course can lead to the development of meaningful learning (Novak, 1991). While a constructivist approach increases the responsibility of the learner, the teacher still plays a role as facilitator and guide. The very nature of the laboratory environment, a place to connect concepts from
lecture with hands on activities, places this increased responsibility of constructing conceptual links on the student. In general, implementing a constructivist approach requires a change in the thinking of the teacher. It is not so much a matter of what is taught as how it is taught. Each institution has its own impediments such as time, space, curriculum, and economics. This being said, there have been numerous studies where a constructivist approach was integrated successfully (Clough & Clark, 1994; Gilmour, 2002). While the benefits of this approach to learning are recognized it must also be understood that it is not feasible to teach all topics of chemistry in this manner.

Involving students in a constructivist approach to learning affects the metacognition of the student. Metacognition has been described as thinking about your own thinking. Metacognition and mental models are closely related. The students’ mental models represent their metacognitive understanding (Hacker, 1998). It is possible to use familiar resources such as reflective questions, concept maps, Venn diagrams, and laboratory notebooks in a metacognitive manner. Metacognitive resources such as lab notebooks, already a staple in most chemistry laboratory classes, allows students to reflect on what they are doing and why, thereby giving the student a sense of control (Baird & White, 1996). Novak (1983) has successfully used both concept maps and Venn diagrams to promote meaningful learning. It may be possible to address the problem of rote memorization by focusing on using the laboratory notebook as a metacognitive resource. Students can represent their mental models in the lab notebook.

Problem Solving

Despite laboratories offering such a unique learning environment, students still have trouble solving chemistry problems present in the laboratory manual. Their
understanding of the relevant concepts is often not sufficient due to memorization of equations. Students have difficulty transferring between macroscopic and submicroscopic levels of understanding (Staver & Lumpe, 1995). Chemistry is composed of both algorithmic problems as well as conceptual problems. While students may be able to use formulas and equations to complete the algorithmic problems they often struggle with conceptual problems which require them to present their understanding. Research has shown that when faced with a conceptual problem students do not use reasoning or conceptual understanding but proceed directly to using algorithms without understanding the problem (Niaz & Robinson, 1992). To solve conceptual problems successfully students need to transfer between the three levels of chemical representation of matter and reconstruct the problems in their own words and understanding.

Much research has been conducted on problem solving and strategies to help improve this ability include analogies, models, diagrams and verbal and visual descriptions. Noh and Sharmann (1997) used pictorial models at the molecular level and saw an improvement not in problem solving ability but in the ability to construct correct scientific concepts. The advantages of integrating the three levels of chemical phenomena in problem solving were demonstrated by Gabel (1992) where students were made aware of the macroscopic properties of chemicals by using three dimensional models and diagrams to represent the submicroscopic and symbolic levels respectively.

Chemical Representations

Learning involves the process of interpreting information gleaned from many representations and internalizing it as one’s own. Representations can act as a bridge
between theoretical concepts and reality (Rosenquist, 2001). In chemistry, phenomenon can be described using three types of representations: macroscopic, microscopic, and symbolic (Johnstone, 1982). Macroscopic representations can be described as properties perceptible by the five senses in a typical laboratory classroom. These include such things as mass and color change. Microscopic representations deal with the particulate level. This includes atoms, molecules, ions, and bonding. Symbolic representations deal with coefficients, subscripts, charges, and algebraic manipulation of the chemical phenomenon. The macroscopic level of representation is most familiar to students. This is the level at which they have the most experience in everyday life. It can be difficult for students to transition to the microscopic level due to the inability to directly observe atoms. It has been indicated that simultaneous use of all three representative levels in instruction reduces students’ misconceptions in chemistry (Russell, Kozma, Jones, Wykoff, Marx, & Davis, 1997).

Chemists use a system of symbols such as reaction equations to represent the molecular phenomena observed in the laboratory. These symbolic representations are the cornerstone of communication with other science professionals (Kozma, 2000). The use of representations also comes into place when differentiating between experts and novices. Experts possess the ability to transition between multiple representations of the same phenomenon with very little difficulty. Novices, such as, students have to expend great effort in order to make the transitions. It has been shown that experts and novices in physics show considerable differences in their abilities to classify problems based upon the underlying principles (Chi, 1981). This work has been extended to chemistry (Russell, 1997). Kozman and Russel had experts and novices sort cards containing
computer generated images of chemical equilibrium into groups. The experts created groups that were larger and contained multiple representations. Novices on the other hand created groups based upon surface features alone. In addition, experts were able to utilize background knowledge more so than novices. The inability of novices to shift between different representations is typically due to their incapacity to hold large chunks of information in their working memory. Novices sort using surface features due to their incomplete knowledge of the phenomenon (Russell, 1997).

Students often see chemical structures as a collection of letters and numbers. Chemists see structures as symbols and use them to understand a chemical concept. The symbols have meaning to the expert. However, the ability to use the representations does not mean there is an understanding of how they relate to each other. Conceptual understanding involves the ability to represent and translate chemical problems using the three forms of representations. It is often a struggle for students to determine how individual representations are related to one another (Sanger, 2005). In one study by (Yarroch, 1985) secondary level students were able to write and balance chemical equations but were unable to draw representations of those balanced chemical equations. In another study by Sanger secondary students were asked to convert microscopic level drawings of a chemical reaction into a balanced chemical equation (Sanger, 2005). In both studies students had difficulty understanding the chemical consequences of superscripts and coefficients. In the previous studies macroscopic and symbolic levels were covered in a lecture course. If often falls to the laboratory to cover the macroscopic level and help students connect all three levels. The laboratory classroom is where this study was conducted.
Laboratory Work

Laboratory work is usually a required component of any chemistry course. The experiments are chosen to parallel and provide macroscopic examples of the concepts taught in the lecture course. While the microscopic and symbolic representations are covered in lecture, it is often left to the laboratory to cover the macroscopic level. Regardless, laboratory work is often criticized by student for not being relevant to the coursework, and by educators for being a recipe or cookbook activity where students simply follow instructions without understanding (Gallet, 1998). This reputation along with factors such as cost, safety, and time has caused the decline in the perceived importance of laboratory work. Computer simulations on the other hand have increased especially for dangerous or costly experiments.

Laboratory classrooms provide a learning environment where students actively complete laboratory experiments. These experiments take place under a variety of laboratory instruction styles: expository, problem-based, inquiry and discovery (Domin, 1999). The laboratory classroom allows students to work collaboratively with others in addition to providing a hands-on learning environment. The impact of laboratory instruction styles on student learning will be discussed in this section.

The first two styles of laboratory instruction, expository and problem based, are primarily deductive. In this type of lab the students apply a general principle toward understanding. The last two styles, inquiry and discovery, are inductive. This type of lab requires students to derive the main concepts. Students who complete experiments under different laboratory instruction styles will likely have different learning experiences. The
general chemistry laboratory at the university in this study primarily incorporates an expository instruction method.

The most commonly used type of laboratory instruction is expository (Domin, 1999). Students go through the steps in the manual to obtain their results. These results are primarily used for comparison to the expected results. Time constraints of the laboratory classroom rarely allow for students to do laboratory experiments that are not in the “cookbook” method. Students are not challenged to interpret their results and make sense of what they did. This is true even though educators want students to go beyond the surface and look at the concepts more in-depth. It has been shown that the expository laboratory can be modified to be more student-centered. This can encourage higher thinking about the experiment and deeper reflection on the results (Tsaparlis, 2007).

Inquiry-based laboratory experiments do not have a planned outcome. There are levels of inquiry-based instruction, from guided to open (Eick, 2005). With guided levels of inquiry teachers give students a selection of questions and procedures from which to select. In “open” inquiry the students think through the process for themselves, without any aid. Students in inquiry-based instruction have greater responsibility than in other laboratory instruction. Students are required to state the purpose of their investigation, prepare their own procedure, and predict the result.

In the discovery laboratory approach the instructor guides students so that they can obtain their desired outcome to the problem. Students are given an outline of what they are expected to do. Discovery and inquiry laboratory experiments are similar and some do not distinguish between the two (Stewart, 1988). However, discovery laboratory experiments have predictable outcomes, whereas inquiry-based laboratory experiments
have unpredictable outcomes; therefore student expectations are different for discovery laboratories than inquiry laboratories.

Unfortunately, laboratory work is not always scientifically correct. This problem is only worsened by students who are more interested in getting the “right” answer than in understanding the results. The working space in the brain is limited and the information in laboratory manuals can be overwhelming. This forces students to adopt a recipe-like procedure. The purpose of laboratory work is multifaceted: develop students’ skills in experimental technique, apply conceptual knowledge, develop procedural knowledge and apply inquiry strategy.

The laboratory is an essential part of the chemistry learning process. It helps students comprehend concepts and develop skills that cannot be accomplished by either lecture or demonstration (Abraham & Varghese, 1997). It is known that students learn more by actively doing than by simply watching. In one study, it was shown that when introductory chemistry students construct and answer questions about their own data they are more involved in the interpretation of their results. This requires students to draw upon and develop higher levels of cognitive understanding of key concepts (DeMeo, 2005). The best laboratory experiences are those that are stimulating to the student while still enhancing content learning.

Modeling

Models and modeling can be excellent tools for learners. When dealing with a model it is important that the students understand the relationship between the model and what it is supposed to represent. There has been both success and failure in research working with models (Raghavan & Glaser, 1995; Stephens, 1999). This emphasizes the
importance of how the models are used. The activities involving models must be carefully constructed so as not to mislead the student. When used correctly, model based learning where models as well as modeling by the student are included, can produce improved learning, motivation, and development of scientific knowledge (Justi & Gilbert, 2002; White, 1993).

There has been an assortment of classification methods proposed for models. One proposed method is the five categories put forth by Gilbert and Osborne (1980): scale, analogical, mathematical, theoretical and archetypal. These types of models were classified by Gilbert and Boutler (1995) based upon the way the model is used:

- **Teaching model** – A specifically constructed model used by teachers to aid the understanding of a consensus model.
- **Consensus model** – An expressed model, which has been subjected to testing by scientists and which has been socially agreed by some of them as having merit—a scientific model.
- **Expressed model** – That version of a mental model, which is expressed by an individual through action, speech or writing.
- **Mental model** – A personal private representation of the target.

In 1996, Harrison and Treagust developed a classification system based upon both how the model is used and what type of model. There were four categories:

- **Scientific and teaching models**
  - scale
  - pedagogical analogical model
• Pedagogical analogical models that build conceptual knowledge
  o iconic and symbolic models
  o mathematical models
  o theoretical models

• Models depicting multiple concepts and processes
  o maps, diagrams and tables
  o concept process models
  o simulations

• Personal models of reality, theories, and process
  o mental models
  o synthetic models

A description of a model is clearly not sufficient for the purposes of this research. It is important that the student be made aware of the role of the model. Aspects of mental models such as what they are and how they can be used were an important part of this research.

Mental models are the learners’ personal mental representation of a concept. Mental models can serve as a window into students’ understanding. Students use these mental models to make explanations. Mental models have been described as conceptual models (Young, 1983), mental representations (Duit & Glynn, 1996), and an unobservable construct (Hennessey, 2003), etc. When attempting to understand new concepts, learners look for patterns. In addition, they look for any features which are common to concepts already understood. Through the personal mental model of an individual, insight into the mental processing of information can be gained.
In chemistry, students’ mental models reflect their understanding of the submicroscopic level of chemical representations of matter. Research has shown that many students have very simplistic mental models of chemical phenomena (Chittleborough, Treagust, & Mocerino, 2002). Secondary students prefer atoms and molecules to be represented as concrete objects (Harrison & Treagust, 1996). These students are often unable to build their own mental models (Williamson & Abraham, 1995).

Given that students’ mental models are of function of experience, the teacher can have great influence as they are the ones introducing the new concepts. Learners tend to resort to simple models that work for them even when exposed to more sophisticated, abstract, and complex images (Coll & Treagust, 2001). Mental models are essential for solving problems, making predictions, and testing new ideas. All of which are necessary tasks of learning chemistry.

Conclusion

This chapter has drawn together constructs that are pertinent to learning. The abstract nature of chemistry requires the use of representations. These representations are used by students to form mental models. Learning is dependent upon clear explanations. These explanations rely upon students’ understanding of the three levels of chemical representation. Learning, problem solving, chemical representations, laboratory work and mental models have been described because they were used in this research.
CHAPTER III

METHODOLOGY

This chapter initially pertains to the legitimacy of the research method used in this research. Secondly, an overview of the type of quantitative and qualitative data sources is given. Lastly, the ethics of this research are discussed. Both quantitative and qualitative data are needed in order to obtain a holistic view of student learning. While the qualitative data was more time consuming to collect, it was necessary in order to gain insight into student understanding.

The research questions presented below are concerned with how students use and connect the three levels of chemical representation and why there are differences. Gaining insight into how and why requires a qualitative approach. Determining differences among students requires a quantitative approach.

1. What are students’ understandings of each level of chemical representation in relation to the chemical phenomena they experience in the laboratory?
2. Is there a relationship between a student’s final grade and that student’s ability to use the three levels of chemical representation to explain a chemical concept?
3. Is there a relationship between a student’s final grade and that student’s ability to connect the three levels of chemical representation of a chemical concept?
4. Are there differences in the final grades and explanations between students who took chemistry in high school and those who did not?

Design and Procedures

This research took place concurrently with teaching and learning. This study investigated the students’ abilities to integrate the three representations of solution
chemistry. Students’ knowledge of chemical concepts before and after laboratory exercises was investigated. Qualitative research methods were used in data collection and analysis. A copy of the Institutional Review Board approval for the study can be found in Appendix A.

Setting

This research was conducted at a public university in the southeastern region of the United States. The institution is a research institution with strong undergraduate programs in the sciences.

Description of Laboratory

There were 11 three-hour laboratory sessions for students during the semester. Students conducted experiments primarily of a quantitative nature in pairs. Students were expected to develop skills in the safe handling of equipment, following instructions, collecting data, processing data, interpreting data, taking measurement, accuracy, and precision. Students turned in advanced study assignments at the beginning of each session. Students then took a quiz. Following the quiz, the TA provided a brief (approximately 20 minutes) overview of the laboratory. Students then conducted an experiment and submitted data and calculation sheet from the manual for assessment.

Participants

Permission from the university’s Human Subjects Review Board was obtained before proceeding with the study. Students (20 females and 12 males) in two different sections of the second semester general chemistry laboratory participated. Each section contained approximately 20 students. Of the initial participants to complete questionnaire one, seventeen were from one section and the remaining sixteen were from
the second section. A short description of the research project and a consent form was provided to students in their respective laboratory sections.

Researcher

This researcher views learning in the constructivist point of view. Students need to construct their own knowledge through interactions with the world around them. This includes objects and people. A concept cannot be transferred exactly from one person to another. The researcher has been a TA in the general chemistry laboratories for six semesters; two semesters in this laboratory. During this study, the researcher was not the teaching assistant for the sections of the second semester general chemistry lab.

Data Collection

The research includes data collection of the students’ mental models, use of representations, and connections of representational levels. Demographic data were also collected. Questionnaire one was distributed to 41 students and 33 students responded. Of the 33 students (n=33) who consented to the study and responded to the first questionnaire, five key informants were interviewed. Twenty eight (n=28) were present for the second questionnaire.

Independent variables include age, gender (male and female) and number of chemistry courses in which participants enrolled (in high school and college levels) prior to the current lab course. Dependent variables are students’ average weekly scores, scores on quizzes, lab reports, and final exam. Each of the data sources is now described.

Quantitative Data

Questionnaire. The student questionnaire one was administered during the third laboratory class meeting. Demographic information, prior coursework in chemistry, and
sketches and explanation of the term “solution” was collected (see Appendix B).

Questionnaire two (Appendix D) was administered during the last laboratory class of the semester.

**Qualitative Data**

*Interview.* A semi-structured interview protocol was used (see Appendix C). A subset of the sample was interviewed. The individual interviews occurred in the researcher’s office. The interviews were staged in such a manner that the participant is facing the researcher across a table. Participants were informed that the interview was to be audio recorded and were reminded that they could withdraw from the interview at any time. Topics cover previous lab activities and quiz questions. Students were asked to define and describe aspects of solution chemistry in general and acid-base titration specifically. Students were given the opportunity to represent their thoughts with sketches.

**Analysis**

*Statistical Analysis*

SPSS was used for all quantitative analysis. Descriptive statistics such as frequencies, means, standard deviations, and ranges are presented. The underlying assumptions of statistical analysis such as randomness, normality, and homogeneity of variance were taken into consideration. Due to violation of assumptions, on descriptive statistics were used.

*Coding*

Interview transcripts and lab reports will also be analyzed. The data will be coded and analyzed using categorical or thematic analysis. All interviews will be transcribed by
the researcher from the audio data using inductive and deductive coding. Numerical
codes were assigned to participants to ensure confidentiality.

The interview transcripts were read by the researcher. Any statements made that
relate to the research questions were noted. The researcher examined transcripts for
common terms and terms associated with the microscopic level such as atom, molecules
and ions; the symbolic level such as chemical equations and calculations; and the
macroscopic level such as color or amount of solution. The researcher also looked for
emerging trends in the data. Through sorting and regrouping common themes became
apparent.

Credibility (internal validity) addresses the extent to which the researchers’
analysis and representation of the data relates to reality. To enhance credibility there was
triangulation among the participants’ interview transcripts, and both questionnaires. In
addition, an expert check with the laboratory teaching supervisor was done.

Ethical Considerations

All aspects of this research were dependent upon students voluntarily
participating. The laboratory coordinator was asked in writing for permission to address
the students. Consent from each student was ascertained via a written consent form. The
identity of the university as well as the students was kept confidential. Any names used
in the final product are pseudonyms.
Table 1

*Research Instruments Used to Answer Research Questions*

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What are students’ understandings of each level of chemical representation in relation to the chemical phenomena they experience in the laboratory?</td>
<td>Interview, Questionnaires 1 &amp; 2</td>
</tr>
<tr>
<td>2. Is there a relationship between a student’s final grade and that student’s ability to use the three levels of chemical representation to explain a chemical concept?</td>
<td>Interview, Questionnaires 1 &amp; 2</td>
</tr>
<tr>
<td>3. Is there a relationship between a student’s final grade and that student’s ability to connect the three levels of chemical representation of a chemical concept?</td>
<td>Questionnaire 2; laboratory report</td>
</tr>
<tr>
<td>4. Are there differences in the final grades and explanations between students who took chemistry in high school and those who did not?</td>
<td>Questionnaire 1 &amp; 2</td>
</tr>
</tbody>
</table>
CHAPTER IV

RESULTS

The purpose of this study was to answer the following research questions:

1. What are students’ understandings of each level of chemical representation in relation to the chemical phenomena they experience in the laboratory?

2. Is there a relationship between a student’s final grade and that student’s ability to use the three levels of chemical representation to explain a chemical concept?

3. Is there a relationship between a student’s final grade and that student’s ability to connect the three levels of chemical representation of a chemical concept?

4. Are there differences in the final grades and explanations between students who took chemistry in high school and those who did not?

This chapter presents the data collected during the study. Several sources of data were analyzed in order to address the research questions. This data includes student answers to open-ended questionnaire questions, student responses to interview questions, drawings completed by the students, and student writing samples.

Students answered open-ended questions on the first and second questionnaires. When answering the open-ended questions, the students showed a similar pattern in writing chemical equations or explaining chemical phenomena using their own words. Most students were able to write chemical equations; very few students were able to explain chemical concepts at the atomic and the molecular level, as they were asked to do on the second questionnaire. Questionnaire two asked students to differentiate, if possible, between end point, neutralization, equivalence point, and titration. These terms were chosen because students often confuse and misuse them. It is not always clear to
the student that the equivalence point is when the titrant and the titrand or analyte are stoichiometrically equivalent. The endpoint is the point in a titration where a color change is perceived. This requires that the student think on the submicroscopic level. Students also do not realize that a titration does not always result in a neutral pH.

The results of the water molecule drawing task and the chemical equation problem will be presented first followed by the submicroscopic drawing task, interview results and student definitions from the second questionnaire. The lab report data will be discussed last as it pertains not to acid-base chemistry per se but chemical equilibrium. The last section of this chapter is a more detailed description of one student’s data.

Participants of the Study

The study participants were undergraduate students enrolled in a second semester chemistry course. The research includes data collection of the students’ mental models, use of representations, and connections of representational levels. Demographic data were also collected. Questionnaire one was distributed to 41 students and 32 students responded. Of the 33 students (n=33) who consented to the study and responded to the first questionnaire, 5 key informants were interviewed. Twenty eight (n=28) were present for the second questionnaire.

Water Molecule Drawing Task

On questionnaire one, students were asked to (a) draw a water molecule, (b) complete an equation, (c) draw a representation of a “solution,” and (d) describe the most fascinating chemistry experiment they have ever done. As water, H₂O, is a product of the simple acid-base reaction provided in question 2, question 1 and 2 are considered linked. For the same chemical concept, water, students were asked to give two different
representations. In response to the water molecule question, most students drew a “textbook” description, oxygen bonded to two hydrogen atoms. There were 20 acceptable responses. Responses were characterized as acceptable if there were two hydrogen molecules and one oxygen molecule. Six students showed the correct response with two lone pairs on the oxygen. Four students used ball and stick representation and therefore did not show lone pairs but were still considered acceptable. Two students failed to show the lone pairs in their drawings but were still considered acceptable although not correct. Two students showed the incorrect amount of lone pairs on the oxygen yielding an incorrect but acceptable answer. Two other students drew the “Mickey mouse” version of the water molecule which was also acceptable. Two students showed full charges on the atoms, which is not correct, but given that the ratio of atoms was correct, the response was deemed acceptable. One student showed partial charges on the molecule and yet another showed hydrogen bonding, both of which were acceptable. Thirteen students gave unacceptable responses. Ten of those students used two oxygen molecules instead of two hydrogen molecules. One student had the number of atoms correct but double bonded the oxygen to each hydrogen atom. One student simply gave the formula, $\text{H}_2\text{O}$, which was not considered acceptable. There were no students who did not respond to the water molecule question; however, one student drew an unlabeled circular object.

Completion of a Chemical Equation

A chemical equation is the shorthand that scientists use to describe a chemical reaction. For example:

$$2\text{HCl (aq)} + \text{Na}_2\text{CO}_3 (\text{aq}) \rightarrow 2\text{NaCl (aq)} + \text{H}_2\text{O} + \text{CO}_2(\text{g}) \quad (1)$$
In this equation, Na₂CO₃ is mixed with HCl. The equation shows that the reactants (Na₂CO₃ and HCl) react through some process (→) to form the products (NaCl, H₂O and CO₂). Since they undergo a chemical reaction, they are changed fundamentally.

Writing a chemical equation is the first and one of the most important steps in solving all types of chemistry problems. This is true no matter what the chemistry course. If one is taking general chemistry, physical chemistry or organic chemistry, he or she will have to work with chemical equations to some extent.

Instructors often expect the students in their classes to be good at and confident with this fundamental step. Writing a chemical equation successfully often depends on the degree to which a student has rote memorized element and compound names and rules related to naming. This rote memorization skill is a low-level skill, and a lack of this sort of knowledge can easily be compensated for with access to appropriate references. For this reason, students were not allowed to use any resources while completing the questionnaire.

Like writing chemical equations, balancing the chemical equations is a very fundamental step in almost every type of chemistry problem. Until the equations are properly balanced, students cannot use the coefficients that represent the relative number of molecules of each compound. It is known, from the Law of Conservation of Mass (which states that matter can neither be created nor destroyed), that this simply cannot occur. The number of atoms of each particular element in the reactants must equal the number of atoms of that same element in the products.

Balancing a chemical equation is essentially done by trial and error. There are many different ways and systems for doing this, but in all methods, it is important to
know how to count the number of atoms in an equation. Developing a general strategy can be difficult, but here is one way of approaching a problem like this. Let us consider the following equation:

\[ \text{HCl (aq) + Na}_2\text{CO}_3 (aq) \rightarrow \text{NaCl (aq) + H}_2\text{O +CO}_2 (g) \]

1. Count the number of each atom on the reactant and on the product side.

2. Determine an atom to balance first. (Na)

\[ \text{HCl (aq) + Na}_2\text{CO}_3 (aq) \rightarrow 2\text{NaCl (aq) + H}_2\text{O +CO}_2 (g) \]

3. Choose another atom to balance. (Cl)

\[ 2\text{HCl (aq) + Na}_2\text{CO}_3 (aq) \rightarrow 2\text{NaCl (aq) + H}_2\text{O +CO}_2 (g) \]

Now, we're done, and the equation is balanced. There are several ways of balancing equations. This was a very generic method.

**Overall Results-Equation**

Students were asked to complete chemical equations on both questionnaires one and two. Although students were asked to complete three reaction equations, there were only two different reactions. Questionnaire one contained only equation 1. Questionnaire two contained both equation 1 and 2.

\[ \text{HCl} + \text{NaOH} \rightarrow \quad (2) \]

\[ \text{HCl} + \text{Ca(OH)}_2 \rightarrow \quad (3) \]

The results indicate most students (19 of 33 on questionnaire one) completed the chemical reaction equation 1 correctly by writing in the products (NaCl+H₂O). Very few students (four of 28) completed chemical equation two correctly by writing in the products (CaCl₂+H₂O). Although one student put in notations for states of matter (s, l, g, aq) this was not considered when deciding whether the equation was correct or not.
Three students wrote the products as ions (Na\(^+\), Cl\(^-\); Ca\(^+\), Cl\(^-\)). None of the students who wrote in ions correctly identified the calcium ion as Ca\(^{+2}\). The inability to recognize the oxidative state of calcium, lead students to incorrectly complete and balance the equation. It should be noted that two students gave the product for equation two as 2CaCl indicating a misunderstanding of the use of coefficients and subscripts. It is also interesting to note that student 8 was able to assign the appropriate charge to the hydroxide ion, but was not able to produce the correct product.

Table 2

Students’ Performance on Completing Equations

<table>
<thead>
<tr>
<th>Response</th>
<th>Q1E1 (n=33)</th>
<th>Q2E1 (n=28)</th>
<th>Q2E2 (n=28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>(19)</td>
<td>(19)</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td>Participants: 2, 3, 5, 7, 9, 12, 16, 17, 19, 22, 23, 26, 27, 29, 30, 31, 32, 33, 34</td>
<td>Participants: 2, 4, 5, 7, 9, 11, 12, 16, 17, 19, 21, 22, 25, 26, 27, 29, 30, 31, 32</td>
<td>Participants: 29, 27, 12, 9</td>
</tr>
<tr>
<td>Incorrect</td>
<td>(6)</td>
<td>(4)</td>
<td>(16)</td>
</tr>
<tr>
<td></td>
<td>Participants: 4, 6, 18, 21, 24, 28</td>
<td>Participants: 10, 18, 22, 28</td>
<td>Participants: 2, 4, 5, 7, 8, 11, 16, 19, 21, 22, 25, 28, 31, 32, 33, 34</td>
</tr>
</tbody>
</table>
Table 2 (continued).

<table>
<thead>
<tr>
<th>Response</th>
<th>Q1E1 (n=33)</th>
<th>Q2E1 (n=28)</th>
<th>Q2E2 (n=28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No answer</td>
<td>(8)</td>
<td>(5)</td>
<td>(8)</td>
</tr>
<tr>
<td>Participants:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8,10,11,13,14,15,20, 14, 20, 24</td>
<td>14, 17, 18, 20, 24, 26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Students’ completed chemical equations from both questionnaires were analyzed and put into one of our categories: no misconceptions, dissociation misconceptions, stoichiometry misconceptions and no understanding. A misconception in this case was considered to be the representation of a concept that is different from the known scientific understanding. For example, it is a known fact that a strong acid reacts with a strong base to produce a salt and water. Any attempt to form different products was considered a misconception.

Equations in the “no misconceptions” group showed the correct salt product, formation of water, and no extra information. “Dissociation misconceptions” group contain equations where there was a misconception regarding the dissociation of acid, base, and/or salt. “Stoichiometry misconceptions” group had misconceptions regarding formation of water, balancing of equations and representation of species present. Equations were put in the “no understanding” group if the response demonstrated no understanding. This was indicated by the student leaving the section blank or writing that they have “no idea.” The students in each category are listed in Table 3.
Table 3

Classification of Students' Equations (n=28)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Students</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Misconceptions (4)</td>
<td>9, 12, 27, 29</td>
<td>NaCl+H₂O; CaCl₂+H₂O</td>
</tr>
<tr>
<td>Dissociation Misconceptions (3)</td>
<td>8, 21, 28</td>
<td>H(OH)₂, HCl</td>
</tr>
<tr>
<td>Stoichiometry Misconceptions (16)</td>
<td>4, 2, 5, 7, 10, 11, 16, 17, 19, 22, 25, 26, 31, 32, 33, 34</td>
<td>CaCl + H₂O</td>
</tr>
<tr>
<td>No Understanding (5)</td>
<td>13, 14, 18, 20, 24</td>
<td>“no idea” or no answer</td>
</tr>
</tbody>
</table>

Four students were classified into the “no misconceptions” groups. These students demonstrated the proper dissociation of the strong acid and strong base to form the correct salt product. The equation was correctly balanced. The formation of water was shown and all compounds were correctly represented. An example can be seen in Figure 2.
Three students were in the “dissociation misconceptions” group. These students included misconceptions on the dissociation of the acid and base. One student’s response indicated that he or she did understand the acid-base reaction when it is a common acid and base such as HCl and NaOH. The problem seemed to arise when the student was confronted with Ca (OH)\textsubscript{2} as the base. Figure 3 is an example by student 21.

\begin{center}
\begin{tabular}{c}
2. Complete the following chemical equation:

$\text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{NaCl}_{(aq)} + \text{H}_2\text{O}_{(aq)}$

$2\text{HCl} + \text{Ca(OH)}_2 \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}$

\end{tabular}
\end{center}

*Figure 2.* Example of no misconceptions.

Sixteen students were classified into the “stoichiometry misconception” group. This group was the most complex. The chemical reaction shown in equation 1 appeared on both questionnaires. Some students had no trouble completing reaction equation one but were stymied by equation 2. Fifteen in this group of 16 students completed equation

\begin{center}
\begin{tabular}{c}
2. Complete the following chemical equation:

$\text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{NaCl} + \text{H}_2\text{O}$

$\text{HCl} + \text{Ca(OH)}_2 \rightarrow \text{Ca(OH)}_2 + \text{H}_2\text{O}$

\end{tabular}
\end{center}

*Figure 3.* Correct equation one; incorrect equation two of student 21.
one correctly. One student (of the 16) only missed the subscript in CaCl\(_2\). The other fourteen students presented various coefficients for water and even formed H\(_3\)O in an attempt to balance the equation. Of those fourteen students, eleven responded with CaCl instead of CaCl\(_2\) (Figures 4 and 5).

2. Complete the following chemical equation:

\[ \text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{H}_2\text{O} + \text{NaCl} \]

\[ \text{HCl} + \text{Ca(OH)}_2 \rightarrow \text{H}_2\text{O} + \text{CaCl} \]

*Figure 4. Stoichiometry misconception of student 4.*

2. Complete the following chemical equation:

\[ \text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \text{H}_2\text{O} + \text{NaCl} \]

\[ \text{HCl} + \text{Ca(OH)}_2 \rightarrow 2\text{H}_2\text{O} + \text{CaCl} \]

*Figure 5. Stoichiometry misconception of student 16.*

Five students were in the “no understanding” group. These students showed little to no understanding of an acid-base reaction. Three of the four students left both parts of the question blank. The fourth student actually wrote in “no idea.”
Sub-Microscopic Drawing Task

In this section, data from the submicroscopic titration drawing, which was completed in class by the students, is presented. Although the information could have been combined into one question, it was divided into five questions so as not to overwhelm the students. These questions can be found on questionnaire 2 in Appendix C. For the sake of simplicity a strong acid and a strong base were used instead of their weak counterparts. The drawings were analyzed for misconceptions and common themes. The drawings were first classified, then overall themes created, and finally each part (before titration, half titrated, equivalence point, endpoint, and over titrated) analyzed individually.

Categorization of Students’ Drawings

Twenty eight students were present for the second questionnaire. Although it was emphasized by the researcher that this was to be a submicroscopic drawing, no students provided answers at the submicroscopic level. Analysis of the data revealed five types of responses. Drawings of the lab setup, titration curves, random unrelated drawings, text, and no answer at all.

Overall Results- Drawing Task

In the drawing task, students were not given symbols of any kind to use. This task took place on the very last laboratory class meeting. At this point, students should have been able to voluntarily provide generic acid and base reactants. However, no students used symbols or any other representation for molecules or ions. Two students provided drawings of the actual lab setup. Seven students provided representations of titration curves. Seventeen students provided written text in response to the questions.
One student provided random smiley faces and stick people drawings. Six students left all parts of the drawing task blank. These groups are not exclusive; some students who provided text also provided drawings. Only eight students provided drawings only. The data will be presented in five sections: before titration, half-titrated, endpoint, equivalence point, and over-titrated.

Table 4

*Common Themes from Drawing Task*

<table>
<thead>
<tr>
<th>Categories</th>
<th>Before</th>
<th>Half</th>
<th>End point</th>
<th>Equiv.</th>
<th>Over</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Drawings</td>
<td>25%</td>
<td>21.4%</td>
<td>28.6%</td>
<td>32%</td>
<td>21%</td>
</tr>
<tr>
<td>a. Equipment setup</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b. Titration curve</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>c. Random artwork</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2. Text</td>
<td>39%</td>
<td>39.3%</td>
<td>42.9%</td>
<td>32%</td>
<td>43%</td>
</tr>
<tr>
<td>a. Color</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>b. Acid/base /pH</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>c. Indicator</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3. No answer</td>
<td>36%</td>
<td>39.3%</td>
<td>28.6%</td>
<td>36%</td>
<td>36%</td>
</tr>
</tbody>
</table>

*Before Titration*

Themes for the “before titration” drawings are presented in Table 4. The instructions stated that the titration was of a strong acid and a strong base. A strong acid
should be represented in its dissociated form as would a strong base. It was expected that in the “before titration” drawing only the acid or base would be present in the drawing. While the students did not draw molecules one student explicitly stated that there would be “two different solutions.” One student stated that it “depends on what kind of indicator used.” The other eight students in the text category all wrote about color or lack thereof. Only one student mentioned the terms acid or base.

_Half-Titrated_

The themes for the half -titrated drawings are presented in Table 2. The three themes are the same as for the before titrated. The distribution of students changed slightly however. At the half -titrated point, water, dissociated acid ions such as H\(^+\) and Cl\(^-\), and the cation of the base such as Na\(^+\) should be present. No students showed molecules. Six students responded with drawings of some sort. Eleven students did not respond at all. Eleven other students responded with text.

_End-Point_

The endpoint in a titration is the point where the indicator used changes color. A more formal definition is the point in a titration usually noting the completion of a reaction and marked by a change of some kind, as in the color of an indicator. The themes for the end point drawings are presented in Table 4. The majority of students’ responses were textual. For the most part, students associated the end point with a color change.

_Equivalence Point_

The themes for the equivalence point drawings are presented in Table 4. At the equivalence point, water, base cation, and acid anion should be present. There would be
equal concentrations of $H^+$ and $OH^-$, $1 \times 10^{-7}$ M, at the equivalence point of a strong acid-strong base titration. This is due to the equilibrium reaction in equation three.

$$H_2O \leftrightarrow H^+ + OH^-$$  \hspace{1cm} (3)

At this scale with so few ions, the concentration is essentially zero. It was not expected that the students would show this and they did not. The subcategory of titration curve contained the most students (seven). The color subcategory followed closely with six students. The students were required to find the equivalence point from a titration curve in the class. It is believed this is why the titration curve category is the largest. At the same time, many students believe that the end point and the equivalence point are one and the same which is why the color subcategory is also large.

**Over-Titrated**

The themes for the over-titrated drawings are presented in Table 4. Assuming the titration of a strong acid, the over-titrated drawing should have shown water, base cations and anions, and acid anions. Assuming the titration of a strong base, the over-titrated drawing should have shown, water, acid cations and anions, and base cations. Students overwhelmingly responded with text to this question. Of the 12 textual responses, 10 were related to color. Most of the students wrote that there would be a dark pink color. Phenolphthalein is the indicator most used in the class which does turn pink in a basic solution.

**Student Definitions**

Question one of questionnaire two asked students to share their ideas of the terms end point, neutralization, equivalence point and titration. Titration is a process whereby a titrant (a solution of known concentration normally in the burette) is delivered into an
analyte or titrand (unknown solution) until the unknown is completely neutralized. This will allow information about the unknown solution to be determined. An indicator is often a weak acid that is placed into the unknown solution to determine the endpoint of the titration. Indicators have distinctively different colors in acidic and basic media. Not all indicators change color at the same pH, so the choice of indicator for a particular titration depends on the strength of the acid and base. The chosen indicator should have an end point range that lies on the steep part of the titration curve. The end point pH is the pH at which the indicator changes color. The equivalence point of the titration is the point when the moles of $\text{H}^+$ are equal to the moles of $\text{OH}^-$ in a titration. The progress of an acid-base titration is often monitored by plotting the pH of the solution being analyzed as a function of the amount of titrant added. The graph produced is called a titration curve.

When titrating a strong acid with a strong base, the pH at the equivalence point will be approximately 7. When titrating a weak acid with a strong base, the pH at the equivalence point will be higher than 7. When titrating a weak base with a strong acid the equivalence point pH will be slightly lower than 7. In this section student definitions for end point, neutralization, equivalence point, and titration will be presented.

*End Point*

Twenty-two students responded with their definition of an end point. While the end point and equivalence point are similar, they are not the same. The end point refers to the point at which the indicator changes color. The equivalence point is where $\text{H}^+$ and $\text{OH}^-$ are stoichiometrically equivalent. Five students described the endpoint as the point where a color change occurs with one student identifying the color change as belonging
to the indicator. Almost half the students found it hard to describe endpoint without using the other terms neutralization and titration. Not surprisingly, some students stated that the end point and the equivalence point are equal or the same. A summary of students’ ideas about end point can be found in Table 5.

Students’ responses may not appear in two categories. For example, “Solution is neutralized when end point is reached, better known as a pale pink color” would be coded as color category.

Table 5

Students’ Ideas About End Point

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalency (3)</td>
<td>End point=Equivalence point moleA=moleB; acid=base</td>
</tr>
<tr>
<td>Destination</td>
<td></td>
</tr>
<tr>
<td>• Equilibrium(2)</td>
<td>Substance or reaction reaches equilibrium</td>
</tr>
<tr>
<td>• End of reaction(6)</td>
<td>Reaction has used up all of one reactant</td>
</tr>
<tr>
<td></td>
<td>Point when reaction is complete</td>
</tr>
<tr>
<td></td>
<td>when the pt specified has been reached in a titration</td>
</tr>
<tr>
<td></td>
<td>Equivalence pt is the endpoint of the titration meaning it is the point</td>
</tr>
<tr>
<td></td>
<td>when all of one element is used up making another element or compound</td>
</tr>
<tr>
<td></td>
<td>The end point occurs when two solutions have reached their limit of</td>
</tr>
<tr>
<td></td>
<td>titration</td>
</tr>
<tr>
<td>• Neutralization(2)</td>
<td>Solution is neutralized when end point is reached</td>
</tr>
<tr>
<td></td>
<td>The point at which a titration of an acid and a base is neutralized</td>
</tr>
<tr>
<td>Color(5)</td>
<td>Endpoint is when the titrated solution turns pink</td>
</tr>
<tr>
<td></td>
<td>Point in a titration where your indicator will change color</td>
</tr>
<tr>
<td></td>
<td>During titration a pink end point will be reached</td>
</tr>
</tbody>
</table>
Table 5 (continued).

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change(2)</td>
<td>Reaction no longer undergoes change</td>
</tr>
<tr>
<td></td>
<td>Change from acidic to basic or basic to acidic</td>
</tr>
<tr>
<td>Graphic (1)</td>
<td>Peak</td>
</tr>
</tbody>
</table>

Neutralization

Nineteen students responded with their definition of neutralization. Students were familiar with the term “neutralization” and described it as some form of interaction between an acid and a base. The most common response described neutralization as producing a solution with pH values of 7. One student described neutralization as being represented by a pale pink color. One student wrote neutralization is “the process of making a solution $[H]=[OH]$ and pH=7.” Several students described the process of neutralization as the physical mixing of an acid with a base. Most students named no products, and drew no reaction equations. A summary of the students’ ideas about neutralization is shown in Table 6.

Table 6

Summary of Students’ Ideas About Neutralization

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH= 7 (6)</td>
<td>when a solution is neutralized to a pH~7</td>
</tr>
<tr>
<td>Interaction as:</td>
<td>when a base is added to an acid</td>
</tr>
<tr>
<td></td>
<td>Physical mixing (1)</td>
</tr>
<tr>
<td></td>
<td>Chemical reaction (1)</td>
</tr>
<tr>
<td></td>
<td>Is a reaction between acid and base</td>
</tr>
</tbody>
</table>
Table 6 (continued).

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product of neutralization</td>
<td></td>
</tr>
<tr>
<td>• H₂O (1)</td>
<td>for product has self and H₂O</td>
</tr>
<tr>
<td>• neutral substance (3)</td>
<td>When you use titration to make a solution neutral</td>
</tr>
<tr>
<td>• nonreactive solution (1)</td>
<td>Experiment in which the solution becomes nonreactive;</td>
</tr>
<tr>
<td>Neutralization as a product of titration (3)</td>
<td>Neutralization requires a titration;</td>
</tr>
<tr>
<td>Equivalency (3)</td>
<td>[H]=:[OH]; acid=base</td>
</tr>
</tbody>
</table>

Equivalence Point

Sixteen students responded with their definition of equivalence point. Themes from these definitions can be found in Table 7. The equivalence point of the titration is the point when the moles of H⁺ are equal to the moles of OH⁻ in a titration. Fourteen students responded to this portion of the question. Four students defined the equivalence point in terms of where it falls on a titration curve. Only one student actually used the accepted definition above (moles H⁺=moles OH⁻). Two students described equivalence point as the point where equilibrium is reached. Three students described equivalence point as equally acidic and basic or neutral.
Table 7

*Summary of Students’ Ideas About Equivalence Point*

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal to end point (2)</td>
<td>Endpoint and equivalence point are the same thing;</td>
</tr>
<tr>
<td>Equilibrium (2)</td>
<td>Substance or reaction reaches equilibrium</td>
</tr>
<tr>
<td>End of reaction (2)</td>
<td>The end of neutralization; end of titration</td>
</tr>
<tr>
<td>Acid/base equivalency (2)</td>
<td>Acid=base;</td>
</tr>
<tr>
<td>pH (1)</td>
<td>Point in middle of change in pH of a solution</td>
</tr>
<tr>
<td>Graphic (6)</td>
<td>Point between bottom of increase in pH and when it levels out</td>
</tr>
<tr>
<td>Change (1)</td>
<td>Change has slowed</td>
</tr>
</tbody>
</table>

*Titration*

Eighteen students responded with their definition of titration. In general students described titration using the terms acid, base, and solution. In most definitions, titration was described as something that occurs between acids and bases. Titration was described as a process or act by six students. Student 2’s response, “When a titration occurs between an acid and a base then it has reached neutralization” was typical of most students. Seven students indicated that titration was a skill used to find things such as end point, neutralization, equivalence point, identity of unknown substance, and volume of a substance. Titration was also described by four students as a reaction between an
acid and a base. The responses were not as varied for this term as for the previous terms. There was one obviously erroneous response such as “amount of chemical needed to change the color of a mixture” which was given by student 20.

**Detailed Description of Student**

An in-depth description of one participant will be given in this section. Student 33 will be given the pseudonym Tom in this description. Tom, a male in the 18 to 22 age group, was a biological sciences major with plans to attend dental school. Tom had taken chemistry in 10th grade. Tom had completed the prerequisite chemistry class leading up to this one the previous semester. Tom had no community college experience, coming straight to college from high school. Tom was chosen for this detailed description because he completed all portions of the data collection and his final average for the class was only two points off from the class average of 81.3%. Tom was also well spoken in the interview, but held some misconceptions in his drawing task as well as his definitions.

The molecule of water Tom drew on questionnaire one, Figure 1, was incorrect. While the atom quantities were incorrect, it is interesting to note that he did draw a bent molecule. Tom was able to correctly complete the reaction equation for HCl and NaOH on both questionnaires. However the reaction between HCl and Ca(OH)₂ posed a problem for Tom. Tom’s response is shown in equation 4.

\[ \text{HCl} + \text{Ca(OH)}_2 \rightarrow \text{CaCl} + \text{H}_3\text{O}^+ \]  

(4)

He did not balance the equation properly. Just counting atoms and not taking into account calcium has a +2 charge makes the equation seem balanced. There are three hydrogen atoms, one chlorine atom, and one calcium atom on both sides. However, there are two oxygen atoms on the left and only one on the right.
During the interview, Tom was preoccupied with making it clear that he only remembers things long enough to complete the lab and pass the quiz. Tom stated several times that he disliked the lab manual.

I hate the lab manual. I think the lab manual should basically just be thrown away. Because half of it we don’t even do in the lab like it’s not exactly how we do it in the lab. The intros really don’t teach you much at all. You really kind of have to like decode them and I don’t like that. I feel like if it’s a book it should be there to teach you. Cause, half the time you go in the lab and you barely know how to do the advance assignment.

When Tom was asked why we perform titrations he responded,

I guess to master the concept of molarity. Understanding molarity and how it works. How to get the volumes. How to derive when you have two molarities and one volume or one molarity and two volumes or whatever, just how to use all the formulas.

During the interview Tom was asked what the term end point meant to him. In his response, Tom spoke of color and indicators, “Color. Basically it just depends on whatever indicator you’re using. Whatever the endpoint color is, each one like has different colors.” Tom proceeded to qualify this information with, “That’s what it means to me cause you’ll reach a certain like, (pauses) see, I’m not good with vocabulary I’m good with doing it.” Tom went on to say, “So I guess getting to that, whatever that point is, that’s helping you understand the volume and whatever’s in the solution.”

The researcher then asked Tom, “Do you ever think about in lab what’s going on in the flask?” Tom responded,
Somewhat, but not too much. I’m really more of like a numbers guy. I mean if it’s really explained to me very well I’ll think about it but a lot of time that’s the thing not explained as well. Its more just kind of this is what you’re doing this is how you do it; not really exactly what’s going on.

Tom then adds, “You can observe sometimes like what it’s doing but not really.”

When asked about the Ca(OH)$_2$ problem, Tom indicated that he understood that molarity of base is not the molarity of hydroxides because he and his lab partner figured it out. However, as stated before, Tom was unable to correctly complete this reaction equation on questionnaire 2. “It really depends on the question. If it’s a picture of like something being titrated I could get that because I know what the setup looks like but if it was like a picture of just like the chemical like equation that part would maybe throw me a little bit.”

Tom was asked to define equivalence point. “I think it’s like the point where the base and the acid are like equal each other. I don’t know if that’s what you really want.” Tom was then asked what he visualized to answer the question and he indicated that picturing a graph like the one made in lab. He then described that “there is a point between the two where it increased and where it stopped increasing.”

On the second questionnaire, Tom defined end point as “the point in a titration where your indicator will change color.” This is actually correct. Although he doesn’t mention pH, it is clear that he relates end point to the indicator.

Tom defined neutralization as “the process of neutralizing an acid or base by its reciprocal.” It is unclear what Tom means by reciprocal. It is this author’s opinion that Tom is speaking of neutralizing an acid with a base and vice versa. It is interesting that
Tom used the word process for neutralization. Neutralization was taught as a reaction represented by the net ionic equation $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$.

For equivalence point, Tom wrote “equivalence point is the point between the bottom increase of a pH and when it levels out.” It appears that Tom is describing the equivalence point in relation to a titration curve. Titration was defined by Tom as “when you use an acid or base to determine the volumetric or acid-base values of solutions.”

On the second questionnaire, Tom was asked to draw representations of the stages in a titration. His complete answer can be seen in Figures 6 through 10.

3. When titrating a strong acid and a strong base what would you expect to see before the titration begins?

![Figure 6. Tom's before titration response.](image-url)
4. When titrating a strong acid and a strong base what would you expect to see when half titrated?

Figure 7. Tom's half-titrated response.

5. When titrating a strong acid and a strong base what would you expect to see at the end point?

Figure 8. Tom's end point response.
6. When titrating a strong acid and a strong base what would you expect to see at the equivalence point?

\[ \text{no clue} \]

*Figure 9. Tom's equivalence point response.*

7. When titrating a strong acid and a strong base what would you expect to see when over titrated?

\[ \text{dark, dark red-pink color} \]

*Figure 10. Tom's over-titrated response.*
In the before titration box Tom drew two burettes and two beakers. One beaker was labeled HCl and the other NaOH. In the half-titrated box, Tom wrote “clear substance.” In the end point box Tom wrote “the end point.” It is interesting that Tom did not attempt more with this question as on the previous page he correctly identified the end point as the point where the indicator changes color. In the equivalence point box, Tom wrote “no clue.” In the over-titrated box, Tom wrote “dark, dark red-pink color.”

Even though Tom reported on the questionnaire that lab did not help him answer the questions, his answers all have to do with things seen or experienced in lab. He drew a version of the equipment used in a titration and his drawing task contained references to color or lack thereof.

The previous results were representative of the sample as a whole. However, to delve deeper each individual student’s questionnaire, responses were analyzed to obtain a picture of their representational ability. In order to do this, student responses were coded as macroscopic, submicroscopic, or symbolic regardless of subject matter. Each student was then assigned to a level of chemical representational ability. For this analysis, students’ representational ability were scored as (advanced=3, proficient=2, basic=1, none=0). As seen in Table 8, the majority of students scored into the proficient group.

**Table 8**

*Student Composition by Group*

<table>
<thead>
<tr>
<th>Group</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>3</td>
<td>9.1</td>
</tr>
<tr>
<td>Proficient</td>
<td>18</td>
<td>54.5</td>
</tr>
<tr>
<td>Advanced</td>
<td>12</td>
<td>36.4</td>
</tr>
</tbody>
</table>
In order to test for differences between the independent groups, a Kruskal-Wallis test was performed. A one-way, independent ANOVA could not be performed due to violation of assumptions necessary for an ANOVA statistical test. The majority of the students are in the proficient group. In a normal distribution, skewness and kurtosis should be zero. Upon testing this assumption of normality, a skewness value of -0.262 and a kurtosis value of -0.524 was found. The result of the Kruskal-Wallis test is students’ final grades were not significantly affected by the group in which they were located, $H(2) = 4.551, p = 0.103$ (Table 9). Once this was established, a test for correlation between the student’s representational ability and final grades was performed. The distribution of the final grades by ability can be found in Table 9.

Table 9

<table>
<thead>
<tr>
<th>Ability</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>0</td>
<td>6.1</td>
<td>3</td>
<td>9.1</td>
</tr>
<tr>
<td>Proficient</td>
<td>9</td>
<td>18.2</td>
<td>27.3</td>
<td>54.5</td>
</tr>
<tr>
<td>Advanced</td>
<td>15.2</td>
<td>18.2</td>
<td>3</td>
<td>36.4</td>
</tr>
</tbody>
</table>

There was no significant relationship between representational ability group and final grades, $r = .33, p < .06$. The coefficient “r” is in itself an effect size. For a Pearson correlation, $r = .30$, is considered a moderate affect size. This suggests that there may be relationship, but a larger sample size is needed. While interesting, ability does not seem to be correlated with final grade average as mentioned above.
Once students’ responses were coded according to ability, I compared students who had chemistry in high school to students who did not in terms of their ability (Figure 11). As can be seen in Figure 11, 28% of students with high school chemistry experience were in the advanced ability group, 64% were proficient and 8% were basic. In contrast, 57.1% of students without high school chemistry experience were in the advanced ability group, 28.6% were proficient, and 14.3% were basic.

Figure 11. Representational ability of students with high school chemistry experience compared to students without.

In attempt to assess whether there is a difference between high school chemistry and final grades, the mean final average for each group was calculated. The mean final grade score for students without high school chemistry was 81.97 and the mean final
grade score for students with high school experience was 82.93, with standard deviations of 7.73 and 6.42, respectively. With so little variation in the means, and such large deviations, there appears to be no difference between high school chemistry and final grades.
CHAPTER V
DISCUSSION AND CONCLUSION

Researchers such as Johnstone (1982) organize conceptual understanding of chemistry into three separate levels: macroscopic, submicroscopic, and representational. The macroscopic understanding of chemistry is the level most often experienced in chemistry laboratory courses, dealing with observable phenomena that can be experienced via the five senses. The macroscopic level is real to the student and is comprised of tangibles. The submicroscopic level involves understanding the particulate nature of matter, including molecular, atomic, and kinetic points of view. The representational level focuses on making sense of and using representations such as chemical symbols, equations, stoichiometry, and mathematical manipulations.

The overall purpose of this study was to explore students’ abilities to use and/or connect macroscopic, submicroscopic, and symbolic representations of chemical phenomena experienced in a laboratory setting. The purpose of this study was to answer the following research questions:

1. What are students’ understandings of each level of chemical representation in relation to the chemical phenomena they experience in the laboratory?
2. Is there a relationship between a student’s final grade and that student’s ability to use the three levels of chemical representation to explain a chemical concept?
3. Is there a relationship between a student’s final grade and that student’s ability to connect the three levels of chemical representation of a chemical concept?
4. Are there differences in the final grades and explanations between students who took chemistry in high school and those who did not?
To address this purpose, students were surveyed twice during the semester. In addition, a subset of students was interviewed and a different subset provided writing samples in the form of lab reports. Students’ drawings of a water molecule and of the stages of titration were analyzed. Descriptions of chemical concepts, definitions of titration concepts, and lab reports on equilibrium were analyzed for their use of the three representations and are discussed with respect to the research questions.

The study participants were undergraduates enrolled in a general chemistry laboratory course. Of the 33 initial respondents, 20 or 60.6% were female, 12 or 36.3% were males and 1 did not identify. Of the 30 participants who answered, 43.3% were biology majors, 10% were forensic science majors, another 10% were in athletic training, 6.7% each were chemistry and history majors, and 3.3% were undeclared. The remaining 20% were in other disciplines (exercise science, math, community health, exercise physiology, philosophy, and psychology).

Research Question 1

Both questionnaires as well as interview data were needed to answer this question. The fact that most students were able to represent the water molecule indicates that they realize there is a submicroscopic level and that it can be represented. The types of representations included balls as atoms, letters as atoms, sticks as bonds, and the “Mickey Mouse” molecule. Student responses contained representations of water at both the symbolic (from the equation) and submicroscopic level (from the water molecule question).

The majority of students, 18 of 32 or 56% on questionnaire one and 19 of 28 or 68% on questionnaire 2, were able to complete equation 1, a simple acid base reaction
equation. Only four of 28 or 14% were able to complete equation 2, a more complex
reaction. Completing the reaction equation is an example of symbolic representation.
The majority of students were able to combine calcium with chlorine yielding CaCl but
incapable of correctly representing the salt. The actual product should have been CaCl$_2$
and 2H$_2$O, see equation 3.

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$$

(3)

Students were able to complete the simpler equation by realizing that a strong
acid and a strong base combine to form a salt and water or by pairing the opposite
charges. Either of these two problem-solving skills would allow the students to complete
the simple reaction without really understanding how or why these compounds form.

The problem with the more complex reaction equation stemmed from balancing
the equation. If a student did not realize there needs to be two chlorine atoms per calcium
atom, they would not reach the correct product. In addition, students used coefficients
when they should have used subscripts. This indicates that students did not realize that
2CaCl is a totally different entity form CaCl$_2$. In this situation, students needed help in
order to see the connections between the sub-microscopic world and symbolic
representations.

There seemed to be no connection between the chemical reaction equation and the
drawing task to the students. Not a single student used the equations as a basis for their
answers on the drawing tasks. Instead, the students drew upon what they had
experienced in the lab. Drawings depicting the setup, and text denoting the colors that
would be seen at each stage are all macroscopic representations. The responses on the
drawing task indicated that although the students could represent a reaction symbolically
by completing an equation, they could not represent the same chemical reaction at the submicroscopic level. It must be noted that the terminology used in the drawing task question may have been confusing to the students. Perhaps the students would have given different representations if asked what would be seen at the molecular level. When asked the draw a molecule of water on the previous questionnaire students drew a molecule. Therefore it is feasible that if asked about a titration at a molecular level, the feedback may well have been different.

    All students interviewed were able to link the macroscopic properties with the symbolic representation largely as a result of their laboratory experience. However, few students felt they really understood the sub-microscopic level of chemistry.

    Research Question 2

    In general students were able to use macroscopic and symbolic representations of matter. The submicroscopic level proved to be slightly problematic for students. Throughout analysis of questionnaires one and two as well as interviews, there was a trend of inability to use submicroscopic representation in relation to chemical concepts. This finding is consistent with previous research. Most chemical explanations given to students depend heavily upon submicroscopic level of chemical representation. The knowledge that students cannot appreciably use the submicroscopic level leads to questions of student understanding at the submicroscopic level.

    This research illustrates the difficulty students have drawing and describing the submicroscopic level. This is not surprising given the lack of accurate and precise information given in the lab manual. For example the manual states that the equivalence point and the end point are the same. However, the equivalence point pertains to the
actual chemicals involved in the reaction while the end point pertains to the indicator used in the reaction. For the purposes of titration the equivalence point is where \([H^+]=[OH^-]\), while the endpoint is the where the indicator changes color. Specific indicators change colors at specific pH values. It is best if the color change pH range is very close to the equivalence point pH but they are not the same thing. Equivalence point requires students to think about what is happening at the submicroscopic level inside the flask. The endpoint is associated with a macroscopic color change.

Research Question 3

Questionnaire two was designed to investigate research question three. A connection of the three levels would be demonstrated by utilizing the strong acid and strong base given in the equation completion problem to respond to the submicroscopic drawing task. In the drawing task it was expected that students would also utilize macroscopic qualities such as color. Utilizing all three levels to describe one chemical concept would indicate an ability to connect the three levels.

None of the students connected the equation problem to the drawing task. The ability to symbolically represent an acid base reaction did not translate to a submicroscopic representation. Students gave predominantly macroscopic responses such as drawings of laboratory equipment. There were also representative titration curves. Titration curves were considered to be symbolic representations of a titration.

Research Question 4

Student demographic data and student generated definitions from questionnaire two were used to answer this question. As can be seen in Figure 11, 28% of students with high school chemistry experience were in the advanced ability group, 64% were
proficient and 8% were basic. In contrast, 57.1% of students without high school chemistry experience were in the advanced ability group, 28.6% were proficient, and 14.3% were basic. While interesting, ability does not seem to be correlated with final grade average as mentioned above. The mean final grade score for students without high school chemistry was 81.97 and the mean final grade score for students with high school experience was 82.93, however with standard deviations of 7.73 and 6.42 respectively there is essentially no difference.

In conclusion, the research results presented here agree with previous research. Most students had a good understanding of the macroscopic level. Students voluntarily provide evidence of chemical phenomena at the macroscopic level. When directed, most students could also use symbolic chemical representations. The submicroscopic level appears to be difficult for the students. With so much of chemistry instruction based on the submicroscopic level of chemical representation, this finding is significant in relation to student conceptual understanding. Emphasis on the macroscopic level in chemistry instruction may give students an anchor on which they can build their symbolic and submicroscopic understanding. This idea was brought forth by Chittleborough (2004) with the theoretical construct of the rising iceberg model.

Implications for Teaching

The results of this study show that there are varying degrees of integration of the three levels of chemical representation with respect to phenomena experienced in the laboratory. Most students could use each level individually. Based upon the students’ drawings, interview responses, verbal and written definitions, implications can be drawn.
There is a need for a different type of assessment. Large chemistry classes generally give multiple choice tests. The smaller lab class could incorporate more open-ended questions. The drawing task indicates that while students may be able to produce the correct product of a simple acid-base reaction, this knowledge is surface level. The drawings were a much better indication of student understanding. Memorization did not help the students on the drawing task. Submicroscopic drawings can be applied to many chemical concepts.

Students cannot be expected to answer these types of questions if they have never seen them before. It is up to the instructor to utilize different forms of representation in classroom instruction. Activities which require students to not only use different representation but to also convert one representation into another would prove an invaluable assessment tool.

Implications for Research

In order to help students grasp chemistry, technology could be used as a means of access to better modeling. This is especially true of the submicroscopic level. Integration of technology to improve students’ mental models would be an interesting area of research. The instructor must be careful to select technology that provides accurate models. The technology will have a significant impact on the mental models built by the student.

In addition, the relationship between cognitive development and representational ability, if it exists, could be researched. Do general chemistry students, who are normally in the 18 to 22-year-old age range, possess the cognitive ability to grasp all three levels of
chemical representation? This is important to explore, in order for educators to interact with and assess their students at an appropriate level.
APPENDIX A

IRB APPROVAL AND AUTHORIZATION FORM

THE UNIVERSITY OF SOUTHERN MISSISSIPPI
Institutional Review Board
118 College Drive #5147
Hattiesburg, MS 39406-0001
Tel: 601.266.6820
Fax: 601.266.5509
www.usm.edu/irb

HUMAN SUBJECTS PROTECTION REVIEW COMMITTEE
NOTICE OF COMMITTEE ACTION

The project has been reviewed by The University of Southern Mississippi Human Subjects Protection Review Committee in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services (45 CFR Part 46), and university guidelines to ensure adherence to the following criteria:

- The risks to subjects are minimized.
- The risks to subjects are reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered regarding risks to subjects must be reported immediately, but not later than 10 days following the event. This should be reported to the IRB Office via the “Adverse Effect Report Form”.
- If approved, the maximum period of approval is limited to twelve months. Projects that exceed this period must submit an application for renewal or continuation.

PROTOCOL NUMBER: 10091301
PROJECT TITLE: Investigating Macroscopic, Submicroscopic, and Symbolic Connections in a College Level General Chemistry Laboratory
PROPOSED PROJECT DATES: 09/22/2010 to 09/22/2011
PROJECT TYPE: Dissertation or Thesis
PRINCIPAL INVESTIGATORS: Felicia C. Thadison
COLLEGE/DIVISION: College of Science & Technology
DEPARTMENT: Center for Science & Mathematics Education
FUNDING AGENCY: N/A
HSPRC COMMITTEE ACTION: Expedited Review Approval
PERIOD OF APPROVAL: 09/27/2010 to 09/26/2011

Lawrence A. Hosman, Ph.D.
HSPRC Chair

Date
THE UNIVERSITY OF SOUTHERN MISSISSIPPI

AUTHORIZATION TO PARTICIPATE IN RESEARCH PROJECT

Participant’s Name ______________________________________________________________

Consent is hereby given to participate in the research project entitled

*Investigating Macroscopic, Microscopic, and Symbolic Connections in General Chemistry Laboratories.* All procedures and/or investigations to be followed and their purpose, including any experimental procedures, were explained by Felicia Thadison. Information was given about all benefits, risks, inconveniences, or discomforts that might be expected. The opportunity to ask questions regarding the research and procedures was given. Participation in the project is completely voluntary, and participants may withdraw at any time without penalty, prejudice, or loss of benefits. All personal information is strictly confidential, and no names will be disclosed. Any new information that develops during the project will be provided if that information may affect the willingness to continue participation in the project.

Questions concerning the research, at any time during or after the project, should be directed to Felicia Thadison at (601) 466-9830. This project and this consent form have been reviewed by the Human Subjects Protection Review Committee, which ensures that research projects involving human subjects follow federal regulations. Any questions or concerns about rights as a research participant should be directed to the Chair of the Institutional Review Board, The University of Southern Mississippi, 118 College Drive #5147, Hattiesburg, MS 39406-0001, (601) 266-6820. The University of Southern Mississippi has no mechanism to provide compensation for participants who may incur injuries as a result of participation in research projects. However, efforts will be made to make available the facilities and professional skills at the University. Information regarding treatment or the absence of treatment has been given. In the event of injury in this project, contact treatment provider’s name(s) at telephone number(s).

A copy of this form will be given to the participant.

______________________________________________ ____________________
Signature of participant Date

______________________________________________ ____________________
Signature of person explaining the study Date
APPENDIX B

QUESTIONNAIRE ONE

Name ________________________________
Phone ____________________  email _______________________
Four Digit Confidentiality Code: ___ ___ ___ ___
Year in College ____________________ (example: Freshman)
Declared Major __________________________
Current GPA ____________
Sex _____ Male _____ Female
Age _____ 18-22 _____ 23-30 _____ 31+

Previous Chemistry Courses (including High School):
________________________________________________________
________________________________________________________

Previous Chemistry Laboratories (including High School):
________________________________________________________
________________________________________________________

What do you hope to get out of this course?
________________________________________________________
________________________________________________________

What are your career goals?
________________________________________________________
________________________________________________________

Four Digit Confidentiality Code: ___ ___ ___ ___
Pleased complete the following.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoy non science classes such as English more than I enjoy science classes.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>Reading my chemistry lab manual helps me understand concepts introduced in lecture.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>When reading science textbooks I do not find pictures useful in helping me understand concepts.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>I learn a lot in general chemistry lecture.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>I learn a lot in general chemistry lab.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>I enjoy chemistry lecture more than chemistry lab.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>Reading my chemistry textbook helps me understand concepts introduced in lecture.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>I do not read my chemistry textbook.</td>
<td>SA</td>
<td>A</td>
<td>N</td>
<td>D</td>
<td>SD</td>
</tr>
</tbody>
</table>

(Kunze, 2006)
Please answer the following.

1. Draw a molecule of water in the box below.

2. Complete this equation:
   \[ \text{HCl} + \text{NaOH} \rightarrow \]
Four Digit Confidentiality Code: ___ ___ ___ ___

3. In the box provided below, please draw a diagram of what you think of when you hear the word “solution.” Please label the diagram freely and clearly. On the lines provided below, please explain your drawing. What does each component represent?

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
3. Describe the most fascinating chemistry experiment you have ever done and why you found it so interesting. Place any sketches you deem relevant in the box. You may use the back if you need more space.
APPENDIX C

INTERVIEW PROTOCOL

1. What is your definition of an acid?

2. What is your definition of a base?

3. What is your definition of pH?

4. What is your understanding of the term solution?

5. What do you think an atom looks like?

6. What would a single molecule of acid look like?

7. What is your understanding of a titration?

8. What would you expect to see when adding sodium hydroxide to hydrochloric acid?

9. What would this “reaction” look like if we zoom in?

10. What is happening to the molecule of acid during titration with a base?

11. What do you believe the purpose or role of the laboratory to be?
APPENDIX D

QUESTIONNAIRE TWO

1. Explain your understanding of the difference(s) between endpoint, neutralization, equilibrium and titration?

____________________________________________________________________________________________________________________________________________________

2. Complete the following chemical equation:

\[ \text{HCl}_{(aq)} + \text{NaOH}_{(aq)} \rightarrow \]

\[ \text{HCl} + \text{Ca(OH)}_2 \rightarrow \]
3. When titrating a strong acid and a strong base what would you expect to see before the titration begins?

4. When titrating a strong acid and a strong base what would you expect to see when half titrated?
5. When titrating a strong acid and a strong base what would you expect to see at the end point?

6. When titrating a strong acid and a strong base what would you expect to see at the equivalence point?
7. When titrating a strong acid and a strong base what would you expect to see when over titrated?

8. What do you believe the purpose or role of the laboratory to be?

9. Do you feel the lab was helpful in answering these questions?

10. What or what else helped you answer these questions?
REFERENCES


