THE EFFECTIVENESS OF PROCESS ORIENTED GUIDED INQUIRY LEARNING TO REDUCE ALTERNATE CONCEPTIONS IN SECONDARY CHEMISTRY

by

Michelle J. Barthlow

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Education

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ABSTRACT

Michelle Jones Barthlow. THE EFFECTIVENESS OF PROCESS ORIENTED GUIDED INQUIRY LEARNING TO REDUCE ALTERNATE CONCEPTIONS IN SECONDARY CHEMISTRY. (Under the direction of Dr. Scott Watson) School of Education, Liberty University, July, 2011.

A nonequivalent, control group, pretest-posttest design was used to investigate student achievement in secondary chemistry. This study investigated the effect of process oriented guided inquiry learning (POGIL) in high school chemistry to reduce alternate conceptions related to the particulate nature of matter versus traditional lecture pedagogy. Data were collected from chemistry students in four large high schools and analyzed using ANCOVA. The results show that POGIL pedagogy, as opposed to traditional lecture pedagogy, resulted in fewer alternate conceptions related to the particulate nature of matter. Male and female students in the POGIL group posted better posttest scores than their traditional group peers. African-American and Hispanic students in the POGIL group exhibited achievement gains consistent with Caucasian and Asian students. Further studies are needed to determine the value of POGIL to address achievement gap concerns in chemistry.

Descriptors: active student-centered pedagogy, alternate conceptions, chemistry education, conceptual change, cooperative learning, dynamic skill theory, guided inquiry, information processing model, POGIL, particulate nature of matter

DEDICATION

This work is dedicated to glory of God and to his son, Jesus Christ, who gave his life that I might live an abundant life. Along the way to the completion of this study, He has shown me, again, that His strength is sufficient for my needs.

I would also like to thank God for the blessing of my family who encouraged me every step of the way. To my husband and soul mate, Steve, thank you for the hours of proofreading. I cannot imagine completing this document without your editing skills. A special thank you to my sons, Wes and Derrick; your belief in me and encouragement made all the difference. Thank you, to all three of you, for being satisfied with peanut butter and jelly on so many occasions.

This work is also dedicated to the memory of the late Dr. Jill A. Jones who modeled excellence in all things. She spoke blessings into my life and shared a vision of what the Lord would have us; his dearly loved daughters, to be.

Thank you to my dissertation chair, Dr. Scott Watson, for your patience and gentle guidance. The evidence of the fruit of the spirit in your life encourages me to sow into others as you have sown into my life. Thank you to Dr. Georgann Toop who believed in my ability before this journey began. Thank you for laying the groundwork necessary for this doctoral work to be done.

Other faculty members I wish to thank are Dr. Leldon (Buddy) Nichols, my first professor at Liberty University who blessed and encouraged me. Also, to Dr. Ellen Black who, like Dr. Jill Jones, modeled for me strength and leadership as integral components of a Godly woman. Her bible study of Nehemiah blesses me still.

Finally, to the leaders of Liberty University and all who believed in the dream our Lord gave Dr. Jerry Falwell so many years ago. I thank you for walking in faith and making this unique university a reality and a blessing to so many students. My life is forever changed for the better as a result of attending Liberty University.

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List of Abbreviations

Alternate conceptions (AC)

American Association for the Advancement of Science (AAAS)

Analysis of Covariance (ANCOVA)

Cognitive Load Theory (CLT)

Dynamic Skill Theory (DST)

Information Processing Model (IPM)

No Child Left Behind (NCLB)

National Research Council (NRC)

Particulate Nature of Matter (PNM)

Particulate Nature of Matter Assessment, Version 2 (ParNoMA2)

Process Oriented Guided Inquiry Learning (POGIL)

Program for International Student Assessment (PISA)

Statistical Package for the Social Sciences (SPSS)

Trends in International Mathematics and Science Study (TIMSS)

CHAPTER ONE: INTRODUCTION

This study investigated concept mastery of secondary chemistry students under two types of chemistry pedagogy, one of which is designed to confront student alternate conceptions (AC). Student AC, also called misconceptions, have been studied for decades, but the problem of chemistry students constructing inappropriate mental models of abstract chemistry phenomena persists (Çalýk, Ayas, & Ebenezer, 2005; Chandrasegaran, Treagust, & Mocerino, 2007; Chittleborough, Treagust, Mamiala, & Mocerio, 2005; Harrison & Treagust, 2002). This study was conducted to determine if process oriented guided inquiry learning (POGIL) (Farrell, Moog, & Spencer, 1999) would reduce AC held by secondary chemistry students and therefore enhance student achievement by reducing the abstract nature of chemistry and fostering student engagement in learning.

Background

Chemistry classes are among the most challenging courses students encounter in high school and college (Johnstone, 2000; Marais & Combrinck, 2009; Passmore, Stewart, & Cartier, 2009; Taber, 2001). Students interested in high-income, high-status careers found in medicine, engineering and technology find that introductory science courses in college act as “gatekeepers” that either deny or grant access to these fields (Schwartz, Sadler, & Tai, 2008). Students who are successful in other academic courses often find chemistry courses more difficult to pass (DuBetz, Barreto, Deiros, Kakareka, Brown & Ewald, 2008; Johnstone, 2000; Nakhleh, 1992). Chemistry instructors are aware that students often struggle with the abstract concepts they are teaching, and yet, pedagogy in most chemistry classrooms does not address the students’ needs to develop appropriate mental models of abstract chemistry concepts (Chittleborough et al, 2005; Colburn, 2009; Tai, Sadler, & Mintzes, 2006; Üce, 2009). In addition, the focus of chemistry courses is on the memorization of outcomes in chemistry referred to as “declarative knowledge” (Erduran & Duschl, 2004, p. 106), rather than on developing a true understanding of the science processes and concepts which requires a correct mental framework of chemistry phenomena.

Investigations into the reasons why bright students would struggle to master chemistry concepts have revealed several areas that cause trouble for chemistry students rooted in the rigorous mental requirements of the subject matter (Bodner 1991; Johnstone, 2000; Taber, 2000). Success in studying chemistry requires sound reasoning skills, a large fundamental scientific knowledge base, the ability to work with abstract concepts, and excellent problem solving skills (Johnstone, 2000; Marais & Combrinck, 2009).

An issue involving the abstract nature of the study of chemistry is the requirement that students must be able to use and comprehend three levels of representation: *macroscopic, submicroscopic, and symbolic representations* (Chandrasegaran & Treagust, 2009; Johnstone, 2000). Macroscopic refers to what can be observed using the human senses of sight, smell, touch, and hearing. Submicroscopic refers to what scientists believe is actually taking place at the particulate level (atoms, ions, and molecules) in a chemical reaction. Human eyes cannot observe the actual breaking and forming of chemical bonds or the spreading of water molecules as they enter the gaseous state. Humans can only observe the macroscopic evidence that chemical and physical changes are occurring at the submicroscopic level. It is these changes that occur at the particulate level that students have difficulty comprehending and relating to their macroscopic observations (Çalýk, Ayas, Ebenezer, 2005; Chandrasegaran, Treagust, & Mocerino, 2007; Chittleborough et al., 2005; Ya-Wen & Hsiao-Ching, 2009). Students tend to extend macroscopic properties of a substance to submicroscopic particles (Treagust, Chandrasegaran, Crowley, Yung, Cheong, & Othman, 2010).

Symbolic representation refers to the chemical symbols found on the periodic table and other symbols used in writing chemical formulae and equations. Since students do not fully understand chemical occurrences at the submicroscopic level, the symbols and formulas in chemical equations lack sufficient meaning (Johnstone 2000).

In addition to struggling to comprehend the three levels of representation in chemistry, studies have reported that high school students hold AC in chemistry related to chemical changes in matter specific to particle theory of matter (Bodner, 1991; Chandrasegaran & Treagust, 2009; Chandrasegaran, Treagust & Mocerino, 2007; Othman, Treagust, & Chandrasegaran, 2008; Qian, 2009; Treagust et al., 2010). These AC are deeply rooted and are resistant to correction, even when students are confronted with the errors in their concept (Schwartz, Sadler, & Tai, 2008; Treagust, et al., 2010).

In an attempt to bring abstract chemistry topics into a concrete and understandable form, chemistry instructors use a variety of models to explain complex science topics. Taber (2001) does not exaggerate when he states that “the theoretical content of chemistry is best seen as a set of models” (p. 125). Models are used extensively in all science disciplines but “…they seem to present a particularly problematic nature to the learner of chemistry” (p. 125).

Investigations into the use of models in teaching chemistry have found that most traditional science classrooms do not encourage or adequately support student use of models in chemistry instruction. Teachers assume, incorrectly, that their students comprehend how the models relate to the topic studied (Chittleborough & Treagust, 2007; Chittleborough et al., 2005). Studies also show that chemistry teachers often use verbal explanations (lecture) and textbook pictures to explain abstract topics either omitting models altogether or failing to properly explain the link between the science concept and the explanatory model (Chittleborough et al., 2005; Erduran & Duschl, 2004; Treagust et al., 2010).

Research into best practices for assisting students to learn science free of AC has shown that guided inquiry learning holds great promise (AAAS, 1993; Combine Process Skills, 2009; Hansen, 2006; NRC, 1996; Nadelson, 2009). Guided inquiry assists students as they connect their understandings of macroscopic and submicroscopic chemical phenomena to their symbolic representations (Hansen, 2006). Students holding AC that hinder their understanding of chemistry confront and expose their AC and replace them with a proper understanding of scientific phenomena when engaged in guided inquiry lessons.

POGIL, which was developed for use in undergraduate chemistry classes, has proven to increase student achievement for college students (Farrell, Moog, & Spencer, 1999; Hinde & Kovac, 2001; Spencer, 1999; Hanson 2006) and has expanded to include secondary chemistry materials. This study seeks to determine the effectiveness of POGIL in teaching secondary chemistry.

Problem Statement

Current chemistry pedagogy is not producing desirable results. The research problem for this study is: How can chemistry instruction be improved so that students learn chemistry free of alternate conceptions? Studies involving conceptual change methods show that AC are difficult to change and that current teaching practices are still resulting in AC (Taber, 2001; Talanquer, 2006; Taştan, Yalçınkaya, & Boz, 2008). A method for teaching chemistry is needed that presents the content and processes of science in a way that student achievement will not be hindered by AC. This study proposes to investigate such a method, POGIL.

Inquiry science lessons have been proposed as a best practice for teaching science and for assisting students to confront their AC (AAAS, 1993; Nadelson, 2009; NRC, 1996; Combine Process Skills, 2009). Inquiry lessons require that students think and behave like scientists to develop and test their own hypotheses based on the evidence and data they generate. According to The National Science Education Standards (NRC, 1996), scientific inquiry involves the diverse ways scientists propose, explore, and test explanations for phenomena based on evidence produced by their work. Inquiry can simply be defined as a way of studying the world.

While it seems reasonable that science teaching should include methods that challenge students to think and behave like scientists, the results of inquiry learning, however, have not been what educators hoped. Students express frustration when involved in inquiry lessons. Nadelson wrote concerning attempts to teach using inquiry, “the students responded that they did not know what to do” (2009, p. 48). He also stated that the kind of inquiry teachers want for their students is a complex process and is beyond the skill set of high school students.

In order to deal with the problems inherent in inquiry lessons, science educators have turned to guided inquiry. In a guided inquiry lesson, students work in small cooperative learning groups using print materials that ask questions designed to guide students to "develop their own understanding of the concepts" (Combine Process Skills, 2009, p. 5). The teacher's role in guided inquiry lessons is to facilitate and guide students to the knowledge the lesson is designed to teach (Marshall, Horton & White, 2009; POGIL, 2010).

Guided inquiry offers a way for teachers to assist students as they develop accurate mental images of abstract chemistry phenomena. Guided inquiry also assists students to connect their understandings of macroscopic and submicroscopic chemical phenomena to their symbolic representations. In light of the difficulties many students face in high school chemistry classes, this type of pedagogy is needed to help students deal with the abstract concepts of chemistry by providing the necessary scaffolding. Students taught using a method that allows them to comprehend the three levels of representation in chemistry and how they are inter-connected should facilitate student understanding and improve achievement. Also, students holding AC that hinder their understanding of chemistry can confront and expose their own AC and replace them with a proper understanding of scientific phenomena. This study investigated pedagogy for addressing these issues.

Purpose Statement

The purpose of this study was to investigate the effectiveness of a student-centered pedagogy; process oriented guided inquiry (POGIL), to reduce AC held by secondary chemistry students in particle theory versus traditional, teacher-centered pedagogy. Abstract chemistry topics of physical and chemical changes in matter relating to particle theory, was taught to the students in the experimental group using POGIL pedagogy. Students worked in cooperative learning groups and were guided by printed POGIL student lesson documents, which include various types of teaching models, to discover chemistry concepts and processes. Their teacher acted as a facilitator.

The POGIL student lesson documents were designed to provide models of submicroscopic phenomena to address student AC and the difficulty of working in the three representational levels, by minimizing the abstract nature of chemistry studies. This pedagogy allowed students to see (macroscopic observation) into the submicroscopic phenomena of physical and chemical changes and assisted in forming accurate mental images of the concepts. The POGIL approach for conceptualizing abstract phenomena is contrasted with traditional pedagogy which is based on a lecture or a 2-dimensional image in a textbook.

Sound pedagogy provides students with opportunities to construct meaningful mental models of science phenomena that are in accordance with accepted scientific explanations by building on existing scientific schemata. Chittleborough et al. (2005) stated that knowledge acquisition is not transferred directly from instructor to student, but is constructed internally by the learner. The learner does not listen to the instructor and learn chemistry; rather, the student must process the information and mentally evaluate what has been constructed as it relates to an existing schema. By providing this type of learning experience, chemistry teachers seek to “change, develop, or modify students’ thinking and understanding to be more scientifically acceptable” (p. 197).

Significance

This study measured the effectiveness of POGIL as a pedagogy to reduce AC in secondary chemistry students. In this study, the use of POGIL allowed students to discover for themselves the fundamental laws governing physical and chemical and physical changes in accordance with particle theory. The models provided by the POGIL student learning documents enabled students to understand and apply particle theory to observed chemical and physical changes. Students formulated appropriate mental images of chemical reactions which should enable them to comprehend other related abstract chemistry concepts such as the mole and stoichiometry, which are foundational to all chemistry topics.

Particle theory is foundational to all chemistry studies (Adadan, Trundle, & Irving, 2010; Harrison & Treagust, 2002; NRC 1996). Students must master these concepts and form appropriate mental models of the submicroscopic phenomena and their symbolic representations in order to be successful in chemistry studies. In order to master these critical concepts, researchers have stated that students need classroom opportunities that provide both the time and the appropriate experiences for the building of chemistry knowledge (Adadan et al., 2010; Harrison & Treagust, 2002; Schwartz, 2009). These researchers also found that students do not have a foundation of knowledge of particle theory on which to build. They call for chemistry teachers to provide appropriate scaffolding, such as POGIL provides, for students to build their understanding of the particle theory of matter. Effective mental models of particle theory concepts must be developed over time and involve “epistemological growth and ontological conceptual change” (Harrison & Treagust, 2002, p.207).

The results of this study will assist chemistry teachers in choosing the most effective method for teaching particle theory topics. When high school chemistry students are taught using the most effective chemistry teaching methods, those students with the desire to pursue a chemistry-based career are more likely to enter college chemistry courses with the required mental framework to be successful in chemistry and their chosen science-based career.

Careers in chemistry, as in all sciences, are rewarding personally and professionally. For these reasons, many individuals choose to pursue a career in a science field, many in chemistry-related areas. Unfortunately, these ambitious students’ best plans do not come to fruition due to the very difficult nature of high school and college chemistry coursework. Pedagogy in chemistry that assists students to formulate accurate mental models of abstract topics is urgently needed.

The need for well trained scientists grows every year. Mastery of chemistry is critical not only for college chemistry majors, but also for most other science majors in college. Despite the growing need for students to be well prepared in chemistry, there is little research being conducted in the United States on improving chemistry instruction at the high school level. A review of the literature reveals that most of the chemistry education research being conducted currently is in countries other than the United States. As a leader in scientific research, the United States has a responsibility to train and prepare scientists to carry out work to improve the lives of all people.

Research Questions

This study investigated the following research questions:

Research question 1: What impact does the use of active, student centered process oriented guided inquiry learning have on secondary chemistry students' alternate conceptions in physical and chemical changes in matter related to particle theory in chemistry education when compared to traditional teacher-centered, lecture-style chemistry pedagogy?

Research question 2: Is there a difference in the achievement gains between male and female students taught using process oriented guided inquiry learning methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional teacher-centered, lecture-style chemistry pedagogy?

Research question 3: Is there a difference in the achievement gains for minority students taught using process oriented guided inquiry learning methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional teacher-centered, lecture-style chemistry pedagogy?

Research Hypotheses

The research hypotheses for this study are:

Null hypothesis 1, H_o is: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by students who were taught using active, student centered process oriented guided inquiry learning pedagogy and students taught using traditional teacher-centered, lecture-style chemistry pedagogy.

Null hypothesis 2, H_o is: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by female and male students who were taught using active, student centered process oriented guided inquiry learning pedagogy and male and female students taught using traditional teacher-centered, lecture-style chemistry pedagogy.

Null hypothesis 3, H_o is: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by minority students who were taught using active, student centered process oriented guided inquiry learning pedagogy and minority students taught using traditional teacher-centered, lecture-style chemistry pedagogy.

Identification of Variables

The independent variable was pedagogy. The pedagogical methods compared were traditional teacher-centered, lecture-style pedagogy and active, student-centered POGIL pedagogy. The dependent variable was student achievement as measured on the Particulate Nature of Matter Assessment, version 2 (ParNoMA2) (Yezierski & Birk, 2006b).

Assumptions and Limitations

Assumptions. It was assumed that all classroom environments of control and treatment groups were essentially the same. In order to control for internal validity, the same information concerning the topic of study was taught in all classrooms by veteran chemistry teachers with similar credentials and experience. The only difference between the learning environments was the participation in POGIL, which involved the use of POGIL methods and classroom materials. Teachers for the experimental group attended training sessions and fully implemented POGIL pedagogy.

Limitations. A limitation of this study was that the demographics of the participants did not include urban students, but did include students from a range of socioeconomic circumstances. Analysis of covariance (ANCOVA) was used to analyze the posttest data with pretest scores as the covariant. External validity was controlled by the number of participants. Also, all teachers involved used a common course sequence and taught the same Georgia Performance standards (Georgia Department of Education (GDOE), 2006a). This ensured that all students were being taught the same chemistry topics, based on the same standards, only the pedagogy was different.

A limitation of quasi-experimental studies is that random sampling is not possible. The students in this study, however, all attended large high schools and were scheduled into sections of chemistry by a computer and were, therefore, randomly placed in class sections of chemistry with no regard to this study.

The instrument used for the pretest and posttest was the Particulate Nature of Matter Assessment Version 2 (ParNoMA2) (Yezierski & Birk, 2006b). This assessment consists of 20 multiple choice items. Yeziershi and Birk reported a Cronbach α of .83 on the ParNoMA2. A value of .7 or larger is generally accepted as satisfactory and suggests that student responses are not random.

Definition of Key Terms

All terms are defined by the author unless otherwise designated.

Abstract mapping - the cognitive ability to link two abstract thoughts and understand their interrelatedness and is believed to emerge between 14 – 16 years of age.

Abstract model – designed to communicate theory. They can be iconic and symbolic, such as chemical formulae and chemical equations, mathematical equations or graphs, or theoretical models such as the kinetic theory of matter (Harrison & Treagust, 1998).

Abstract principles - The cognitive ability to integrate two or more related abstract systems to form abstract principles. This is the most complex form of abstract thought and is believed to develop around the age of 25.

Abstract representation - the ability to conceptualize a single abstract thought.

Abstract systems - the cognitive ability to link several abstract mappings together to form a system of related abstract ideas and is believed to develop between the ages of 18 and 20.

Alternate conceptions – in science, any belief, concept, or explanation that is different from the accepted scientific explanation of the term. Also called alternative conceptions, misconceptions, misunderstandings and children’s science.

Analogue of a model – A familiar object or occurrence used to explain abstract, submicroscopic phenomena. The concept being modeled is referred to as the target while a feature of the model is called the analogue.

Cognitive load theory – states that human memory is divided into short term memory (working memory) and long term memory (permanent). The four assumptions of cognitive load theory are: (1) working memory is limited in quantity and duration, (2) long-term memory is essentially limitless and can be used to overcome the shortage of elements held in working-memory, (3) schemata are long-term memory items that organize elements of memory, and (4) schemata from long-term memory are automatically processed and do not require conscious mental manipulation, thus reducing the working memory load.

Conceptual change theory - states that in order to correct student AC, students must first confront the flaw in their own mental model while integrating new knowledge with the purpose of constructing correct mental images of scientific phenomena.

Conceptual model - an idea proposed to explain an event in nature, often a difficult and abstract event or phenomena. Scientific models can be symbolic representations, 3-diminsional representations, equations, diagrams, analogies, metaphors, pictures, ideas and simulations (Harrison & Treagust, 1996).

Dynamic Skill Theory – a Neo-Piagetian theory of cognitive development which states that complex learning, such as chemistry, requires time and practice in which learners cycle through levels of cognition as they integrate new knowledge into existing schema (Fischer & Rose, 2001; Schwartz, 2009).

Expressed model – “A student’s expression of his or her own mental model” (Chittleborough et al., 2005). An expressed model can be a drawing, a physical model, or a verbal explanation.

Functional performance level – the lowest skill level of a task. People perform tasks at the functional level when there is no support or assistance. The functional level is observed when a student is learning in a low-support environment, such as reading from a textbook or listening to a lecture.

Guided Inquiry – an inquiry approach to teaching and learning in which teachers provide scaffolding for students as they explore natural phenomena. Teachers serve as facilitators of learning in this pedagogy. Often models and written documents are used to guide students to discover scientific phenomena.

Information processing model – a complex model of how information is handled by the human brain. Information deemed important enough to need to be learned or remembered, even temporarily, passes through a filter and is stored temporarily in the working memory and may be moved to long-term memory.

Inquiry learning – a method for teaching and learning in which students explore the world, ask questions, make discoveries, and search for understanding. This usually includes framing questions to be answered, developing a hypothesis and designing the approach or experiment to answer the questions posed by students.

Kinetic theory of matter – also known as the particle theory of matter, states that all matter is composed of particles (i.e. atoms, ions, molecules, subatomic particles) that are in constant motion. The amount of motion of the particles is determined by the energy they possess. The state of matter (solid, liquid, gas, plasma) is determined by the energy of the particles.

Learning cycle – theory that states that learning occurs in three stages: exploration, concept invention, and application.

Macroscopic observations – observations that can be made with the unaided human senses such as changes in color, odor, texture, or state of matter.

Mental model – a student’s personal knowledge. A “psychological representation of real, hypothetical, or imaginary situations” (Johnson-Laird, Girotto & Legrenzi, 1998).

Optimal level of performance - the highest performance level possible for a student. Students display their highest, best skill level when learning in a highly supportive environment.

Particle theory of matter – Also known as the kinetic theory of matter, or particulate nature of matter, states that all matter is composed of very tiny particles that are in constant motion (see kinetic theory of matter).

Particulate nature of matter(PNM) – see kinetic theory of matter definition above.

Process Oriented Guided Inquiry Learning (POGIL) – a student-centered philosophy and science pedagogy in which students work in small groups to engage in guided inquiry using carefully designed materials that direct and guide students to build and rebuild their chemistry knowledge (Boniface, 2009; Hansen & Apple, 2004; Moog & Spencer, 2008). POGIL simultaneously teaches both content and key process skills of science.

Process skills – proficiencies that are essential for success in acquiring, applying, and generating knowledge. These skills can be classified into areas of learning, thinking, problem solving, teamwork, communicating, management, and assessment (Hanson, 2004). They include, but are not limited to, critical thinking skills such as interpreting, analyzing, evaluating, and synthesizing information.

Scaffolding – support provided to a student in the form of a framework or structure to aid the student while acquiring new knowledge or practicing an existing skill. Scaffolding allows the student to perform at a higher skill level (optimal skill level) than with no support (functional skill level).

Schema – cognitive framework of understanding used to organize thoughts and ideas.

Scientific model or Conceptual model – an idea proposed to explain an event in nature, often a difficult and abstract event or phenomena. Scientific models can be symbolic representations, 3-diminsional representations, equations, diagrams, analogies, metaphors, pictures, ideas and simulations (Harrison & Treagust, 1996).

Student-centered pedagogy – characterized by students actively involved and engaged mentally, and sometimes physically, in learning.

Submicroscopic representation – used to communicate what scientists believe occur between particles at the level of atoms, ions, and molecules. A submicroscopic representation can be a sketch or drawing, computer animation, verbal analogy, or a physical model. Submicroscopic "refers to an understanding of chemistry at the particulate level—molecules, ions, atoms, subatomic particles, and so on" (Colburn, 2009). Examples are chemical equations and models of molecules.

Target of a model - The concept being modeled is referred to as the target.

Teacher-centered pedagogy – students passively listen to teacher lecture often accompanied by a PowerPoint presentation or writing on a white marker board or chalk board. Frequently used to communicate with large groups of people.

Teaching model – "a specially constructed model used by teachers to aid the understanding of a scientific concept" (Chittleborough et al., 2005, p. 196).

CHAPTER TWO: REVIEW OF LITERATURE

This chapter will review the literature on alternate conceptions (AC) in chemistry related to the particulate nature of matter (PNM) and teaching practices designed to confront these alternate conceptions. The chapter will begin with the theoretical framework for this study followed by a review of research findings in chemistry AC related to the particle theory of matter, conceptual change, multiple levels of representation, the use of models in chemistry, and Process Oriented Guided Inquiry Learning (POGIL).

Theoretical Framework

The theoretical framework for this study is constructivist in nature and includes dynamic skill theory (DST), a neo-Piagetian view of cognitive development and learning (Fischer & Bidell, 2006; Schwartz, 2009; Schwartz, Sadler, & Tai, 2008; Yan & Fischer, 2002), cognitive load theory, information processing model, and conceptual change theory.

Constructivism. Jean Piaget (1973) is considered to be the originator of the constructivist approach to education. The constructivist approach states that in order for learning to occur, a student must construct his or her own knowledge by incorporating new knowledge into existing knowledge. It is the role of the educator to provide an educational environment in which a student can construct meaning of new material learned by making a meaningful connection to prior knowledge.

Neo-Piagetian view of cognitive development. Piaget (1973) proposed that the human mind moves through predictable stages of cognitive development. Neo-Piagetian theorists have expanded and modified Piaget’s original theory (Case, 1998; Knight & Sutton, 2004; Rose & Fischer, 2009). Piaget’s core assumptions are preserved in neo-Piagetian theory. They are

- Piaget’s ‘schema’ and ‘stages’,
- learners actively build knowledge,
- cognitive development is hierarchical,
- cognitive structures grow in complexity through interactions that result in maturation and that this growth is cyclical, and
- less complex skills and knowledge are used to build more complex understandings.

Neo-Piagetian theorists have expanded Piaget’s original four stages of cognitive development (1973) to include additional stages of increasingly complex abstract thinking abilities that appear in late adolescence and early adulthood (Case, 1998). The neo-Piagetian stages beyond Piaget’s original four stages are; (1) *abstract mapping* which develops between 14 – 16 years of age, (2) *abstract systems* at 18 – 20 years, and (3) *abstract principles* emerging at 25 years of age (Knight & Sutton, 2004).

Neo-Piagetian researchers have described the hierarchical development of these stages of abstract thought (Case, 1998; Rose & Fischer, 2009; Schwartz, 2009). Abstract representation is the ability to conceptualize a single abstract thought. Abstract mapping is the ability to link two abstract thoughts and understand their interrelatedness. Abstract systems refers to the cognitive ability to link several abstract mappings together to form a system of related abstract ideas. The ability to integrate two or more related abstract systems allows the formation of abstract principles, the most complex form of abstract thought.

Neo-Piagetian theorists believe that cognitive development and learning is dynamic, cyclical, and that structures are local and domain-specific, as opposed to Piaget’s belief that mental structures were system wide (Case, 1998; Fischer & Rose, 2006; Knight & Sutton, 2004; Rose & Fischer, 2009; Schwartz & Fischer, 2004). These neo-Piagetian beliefs are key components of dynamic skill theory (Fischer & Rose, 2001; Schwartz, 2009).

Criticism of constructivism. In recent years, researchers have questioned the broad application of the constructivist view of learning in science classes (Lui & Matthews, 2005; Matthews, 2002). Constructivist learning theory led to the development of constructivist philosophy and pedagogy. The core of constructivist philosophy is that people construct their own knowledge from interactions with their environment. Implied in constructivist theory is that people construct knowledge that is correct, appropriate, and in agreement with the experts in a field. This, unfortunately, is often not the case.

Matthews (2002) wrote about the difficulty science teachers encounter when attempting to teach abstract concepts, such as chemical reactions. He found that teachers employ many constructivist strategies such as laboratory experiments, demonstrations, projects, metaphors, and discussions in an attempt to explain submicroscopic phenomena. Teachers report that even after their best efforts to explain abstract chemistry topics are exhausted, they find that many topics in chemistry are beyond the experiences of their students and that their school laboratory does not provide the experiences needed for students to truly comprehend abstract chemistry topics. Matthews wrote “it is fanciful to believe that sensory experience can, alone, be the foundation of a child's scientific knowledge" (2002, p. 130).

Glaserfeld (1989) wrote that knowledge is the ordering of an experiential reality based on one's experiences. As a chemistry student attempts to make order, or meaning, out of an experience, a laboratory exercise or some other lived reality, the student may or may not construct order and meaning that is in agreement with what the experts in the field of chemistry believe is happening at the submicroscopic level. The attempt to construct order on the part of a novice in a chemistry class often leads to AC (Fischer & Rose, 2001; Johnstone, 2000; Matthews, 2002; Schwartz, 2009).

Neo-Piagetian learning theorists consider the shortcomings of a purely constructivist view of education and propose that learning theory must include the complexity of the human brain and that the construction of scientifically sound personal knowledge takes time and effort.

Dynamic skill theory. Dynamic skill theory (DST) holds that complex learning, such as chemistry, is often difficult, requires time and practice in which learners cycle through levels of cognition as they integrate new knowledge into existing knowledge (Fischer & Rose, 2001; Schwartz, 2009). A student's knowledge level varies between learning domains and shows variation in performance abilities depending on emotional state and how much support, or scaffolding, is provided (Fischer & Rose, 2001). The construction of a particular skill requires many mental elements which must be accurately interconnected to form the new mental model. The interconnected nature of the many mental elements can be thought of as a "web of skills" (Fischer & Rose, 2001) that when properly constructed, creates new knowledge, or schema (see Figure 1). The construction of a new schema requires time and practice using and testing the new schema. Putting the schema to use over time allows the learner to create sound concepts and skills that endure in a student's memory and can be accessed in the future (Schwartz, 2009; Schwartz, Sadler, & Tai, 2008).

Web of Development of Complex Skills or Concepts

Figure 1. This spider's web represents how skills and ideas intersect and connect as a complex schema develops. Each strand in the web represents a skill or idea. The connections represent the integration of ideas or skills to form more complex skills and concepts.

Researchers have shown that as one learns a new concept, two upper limits of ability are observed, a *functional level* of performance and an *optimal level* of performance (Fischer & Bidell, 1998; Fischer & Rose, 2001; Schwartz, 2009; Schwarz & Fischer, 2003, 2004). The functional level refers to the level of skill a student displays when working alone, which is their lowest skill or ability level. The functional level is observed when a student is learning in a low-support environment, such as reading from a textbook or listening to a lecture. Conversely, students display their highest, highest skill level when learning in a highly supportive environment. This higher skill level is called the optimal level (see Figure 2).

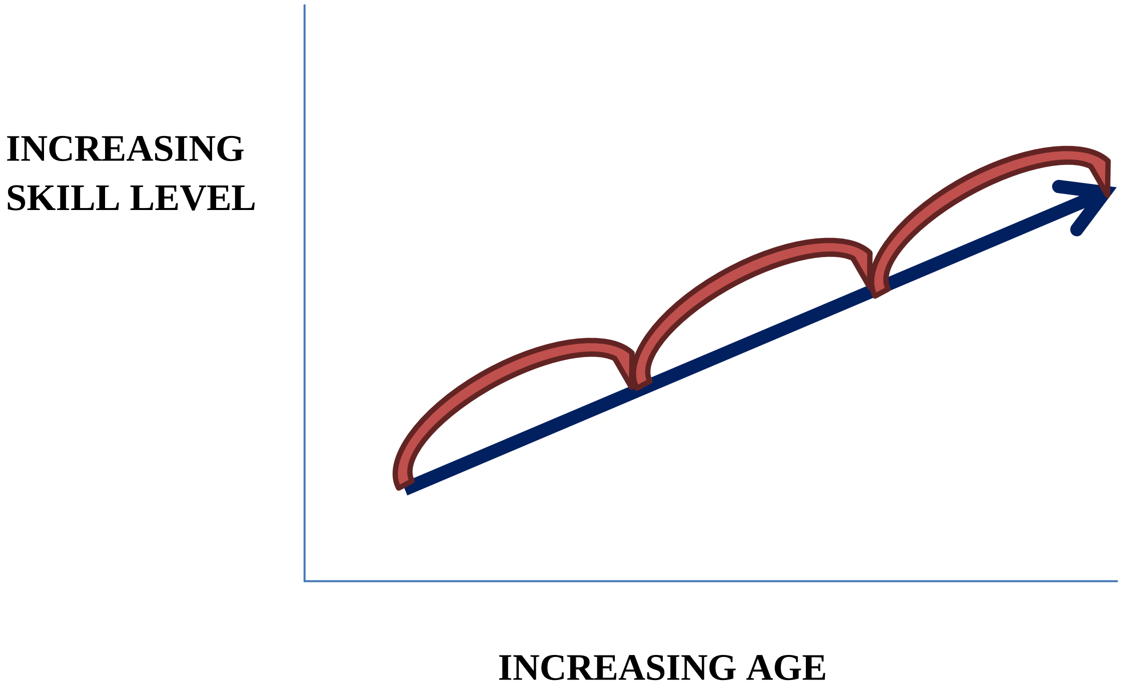

Figure 2. The red scalloping line is the optimal level. The blue line represents the functional level of ability.

A highly supportive environment is one in which the context of the learning environment provides prompts to key mental elements required for performing the task or skill. Fischer and Bidell (1998) found that a student’s optimal level of development shows spurts of growth at certain ages which correspond to brain growth and development whereas the functional level shows a slower, more continuous development that varies across domains of knowledge.

Functional and optimal levels vary across learners and domains. POGIL teaching strategies and materials provide prompts to the key mental elements required for learning a concept or performing a specific chemistry task and, therefore, supports individual student growth at the optimal level. As a student's optimal level rises, in response to a supportive learning environment, their functional level rises as well (Fischer & Rose 2001; Schwartz, 2009).

The dynamic nature of cognitive development in which a student's functional level lags behind the optimal level is built upon the work of Vygotsky (1962). Vygotsky stated that individual students have varying abilities to perform a task. The low range of ability is seen when a student works independently. The high end of the range of ability is seen when a student is working with an expert such as a parent, teacher, other adult, or a peer. He referred to the distance between the ability to work independently and with expert assistance as the zone of proximal development.

Cognitive load theory. Cognitive load theory (CLT) (Chandler, & Sweller, 1991; Aryes, Chandler & Sweller, 2003) states that human memory is divided into short term memory (working memory) and long term memory. The four assumptions of CLT are:

- Working memory is limited in quantity and duration. People hold approximately seven elements in working memory but only operate on two to four of those elements at once. Working memory holds information for only a few seconds unless refreshed by repeating the information. Without this repetition, or rehearsal of elements in working memory, the information is lost after about 20 seconds (Miller, 1956; van Merrienboer & Sweller, 2005).
- Long-term memory is essentially limitless and can be used to overcome the shortage of elements held in working-memory.

- A schema is a long-term memory item that organizes elements of memory. Lower order elements are put together and built into higher-order schema that require less working memory space.
- Schema from long-term memory are automatically processed and do not require conscious mental manipulation, thus reducing the working memory load (Pollock, Chandler, & Sweller, 2002).

When learning a complex subject such as chemistry, the demand on working memory is large (Johnstone, 1997, 2000; Taber, 2001). Teachers must find ways in which working memory space is conserved by utilizing long-term memory. Taber (2001) wrote that people process new information (in the working memory) slowly and that large amounts of information can be handled in the working memory when it fits with the student's prior knowledge, or schema, retrieved from long-term memory. Consistent with DST, CLT holds that teachers should assist students in making connections with prior knowledge and knit together the many items of information needed to successfully execute a chemistry skill, work a chemistry problem, or apply a chemistry concept to a novel situation. A deep pool of elements and schemata in memory are needed for learning chemistry concepts. Teachers need to assist students by scaffolding (Korkmaz & Harwood, 2004) the numerous pieces of information stored in students' long-term memories as they assemble these elements into a new web of understanding, as DST dictates, building, refining, and rebuilding their understanding as they put their newly formed mental models to the test (Fischer & Rose, 2001; Swartz, 2009).

Information processing model. Alex Johnstone's work (1997; 2000) refines and applies CLT specifically to the learning of chemistry. His model, the information processing model (IPM), proposes that information deemed important enough to need to be attended to, learned or remembered, even temporarily, must first pass through a person’s mental perception filter. This filter processes information, in the mind, from a person’s environment. Information can be ideas, events, or concepts that are perceived through the senses. Information that seems irrelevant or unimportant will not pass through the perception filter and is discarded mentally and forgotten (see Figure 3). Johnstone writes that “we have a filtration system that enables us to ignore a large part of sensory information and focus upon what we consider to matter” (1997, p. 262). Information that passes through the perception filter is stored temporarily in the working memory and may be moved to long-term storage for later use when needed (see Figure 3).

Johnstone's Information Processing Model

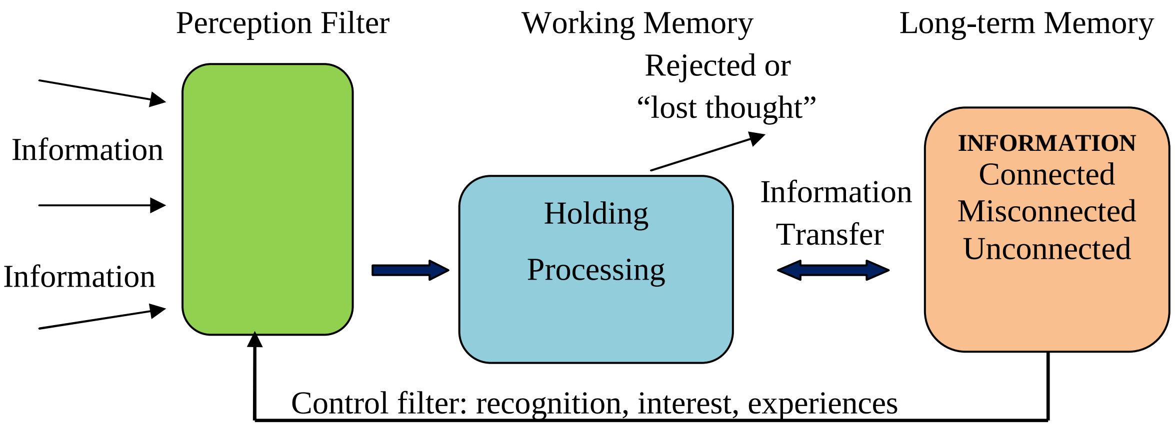

Figure 3. Information from the environment enters through the perception filter. Some information is allowed to pass to the working memory where it may be lost or moved to long-term memory. Adapted from "Chemical education research in Glasgow in perspective" by A. H. Johnstone, 2006, *Chemistry Education Research and Practice, 7* (2), p. 56. Copyright 2006 by The Royal Society of Chemistry.

Johnstone proposes that in order for students to learn the abstract concepts of chemistry, chemistry teachers should make the process more tangible (macroscopic) which results in a reduction in the load on working memory. In order for information to be moved from working memory to long-term memory, the learner must attach and incorporate the new knowledge to a schema that exists in their long-term memory. If an existing schema cannot be found to associate the new knowledge with, the learner will either try to store it unattached or will force it to fit in with an inappropriate existing schema.

In the case of storing new knowledge unattached in long-term memory, such knowledge is easily lost and not available for future use since it has not been inserted into the student's mental filing system in a manner that supports retrieval for future use. In the other case in which a student tries to fit new knowledge into an existing but inappropriate schema, the new knowledge is ‘bent’ or modified to fit, inappropriately, into an existing schema. The forcing of new knowledge to fit with inappropriate existing schema results in the formation of AC (Johnstone, 2000).

Conceptual change. Conceptual change theory states that in order to correct student AC, students must first confront the flaw in their own mental model while integrating new knowledge with the purpose of constructing correct mental images of scientific phenomena (Posner, Strike, Hewson, & Gertzog, 1982; Sandoval, 1996). Hewson (1992) states that conceptual change theory “involves changing a person’s conceptions in addition to adding new knowledge to what is already there” (p. 8). Chi, Slotta, & de Leeuw (1994) describe conceptual change theory as the repair of AC.

In order to develop a full understanding of chemistry concepts free of AC, students need educational opportunities that provide many learning situations with a range of contexts (Treagust et al. 2010). Students must experience the failure of their poorly constructed mental models, or AC, in a context that allows them to refine and rebuild their mental models. The newly constructed, more refined mental model must be tried out in a learning environment conducive to trial, error, and refinement of concept mastery, such as a POGIL environment.

Complex skills can best be learned using pedagogy that incorporates strategies that promote and support the learners’ use and application of his or her prior knowledge. Repeated practice with the new skill fosters incorporation and integration of existing knowledge with new learning. POGIL provides a supportive learning environment in which students explore models of chemistry phenomena and new knowledge is applied in exercises designed to produce higher level applications (POGIL, 2010) and fosters the growth of optimal and functional performance levels. Othman, Treagust, & Chandrasegaran (2008) wrote that students need to be given time and opportunities to practice with (teaching) models used in chemistry in order to construct their own deep understandings and appropriate mental models.

Johnstone (1997) found that when a student attempts to process too much information at once, as is common in traditional, teacher-centered classes, learning either does not occur or an AC is formed. The use of guided inquiry in POGIL instruction, divides the cognitive load inherent in a chemistry lesson into manageable 'chunks' of information that the working memory can process. The prompts provided in a POGIL lesson minimize the working memory space required by prompting the recall of already established schema in the long-term memory (Lamba, 2008). Consistent with Johnstone's IPM (1997), Lamba writes that POGIL methods facilitate the learning of complex chemistry concepts and skills by reducing the cognitive load in the working memory and moves information to long-term storage where it is more easily retrieved for future use and learning.

POGIL strategies were developed based on a neo-Piagetian theoretical framework. The focus is to provide an appropriate learning environment in which the student is supported while constructing new chemistry knowledge in the form of processes, skills and concepts.

Review of Literature

Chemistry is one of the most challenging courses offered to students. Students that wish to declare a chemistry based major in college often are unable to fulfill their dreams due to the inability to pass the necessary chemistry courses (DuBetz, Barreto, Deiros, Kakareka, Brown & Ewald, 2008; Johnstone, 2000; Nakhleh, 1992). AC held by students do not allow for success in college chemistry courses (Johnstone, 2000; Spencer, 1999).

Alternate Conceptions. Students' AC in science are well documented (Bodner, 1991; Cakmakci, 2009; Çalýk, Ayas, & Ebenezer, 2005; Cokelez, 2010; Nakhleh, 1992; Nicoll, 2001; Othman, Treagust, & Chandrasegaran, 2008; Peterson, & Treagust, 1989). Nakhleh (1992) wrote that student AC have been referred to in the literature as "misconceptions, preconceptions, alternate frameworks, children's science and students' descriptive and explanatory systems" (p.191). Çalýk, Ayas, and Ebenezer reviewed over 20 years of research conducted on AC and concluded that only "a few researchers have gone beyond documenting, categorizing, and interpreting students' ideas" (p. 45). According to Taştan, Yalçınkaya, and Boz (2008), complications for individuals holding AC arise as students attempt to incorporate what is taught in a classroom lesson with their incorrect understanding of science. Taştan et al. explained that AC affect students' learning since they interpret teachers' instruction in the light of these AC. Therefore, it is critical to identify AC held by chemistry students and their sources in order to improve chemistry instruction and student comprehension. Pedagogy is needed that will not only correct AC but, more importantly, prevent the formation of AC.

Students develop scientifically sounds mental models of the PNM over time with elements of the correct scientific explanation developing as students spend time developing their mental models (Aladan et al., 2009). Aladan et al. also pointed out that students are unaware that their understanding of the PNM is not in agreement with the scientific explanation of the behavior of atoms, ions and molecules.

Finding effective methods for dealing with AC has proven to be a difficult task (Bodner, 1991; Nakhleh, 1992; Taştan, Yalçınkaya, & Boz, 2008). Chandrasegaran, Treagust, and Mocerino, (2007) found that AC in chemistry proved resistant to change even after instruction designed specifically to challenge student misconceptions. Adadan et al. (2010) investigated the patterns of thinking exhibited by high school chemistry students as they developed concepts related to the PNM utilizing a pedagogy featuring multi-representational instruction to reduce the abstract nature of the topic studied. They found that while most students did form scientifically accurate mental models of PNM immediately after instruction, many students' accurate understandings had eroded to their previous AC after three months.

Previous studies that investigated methods for confronting and correcting AC focused on problem solving activities. What is needed, according to Schwartz, is a method to "reveal the processes by which knowledge is built" (2009, p. 199).

Particle theory alternate conceptions. The particle theory of matter, also known as the kinetic theory of matter, states that all matter is composed of particles (i.e. atoms, ions, molecules, subatomic particles) that are in constant motion. The amount of motion of the particles is determined by the energy they possess. The PNM is foundational to almost every topic studied in chemistry. Therefore, it is critical for students to gain a thorough, correct understanding of this theory in order to be successful in chemistry (Adadan et al., 2010; Harrison & Treagust, 2002; Othman, Treagust, Chandrasegaran, 2008).

AC students have in terms of the particle theory of matter include the topics of bonding and the structure of covalent molecules (Peterson & Treagust, 1989), phase changes (Coştu, 2008) , and gases (Bodner, 1991; Treagust, et al, 2010). Students memorize facts about particle theory with little understanding of the submicroscopic phenomena (Bodner, 1991; Othman, Treagust, & Chandrasegaran, 2008; Treagust et al., 2010). Spencer (1999) found that chemistry students can memorize enough information to correctly answer test questions without developing a sound conceptual understanding of chemistry. This memorization of facts as opposed to a sound understanding of the concept leads to difficulty in chemistry studies (Johnstone 2000; Spencer, 1999).

Common AC held by chemistry students is that matter is continuous (Harrison & Treatgust, 2002; Othman, Treagust, & Chandrasegaran, 2008). This belief stems from students' tendency to assign macroscopic level characteristics of matter to submicroscopic particles (Othman, Treagust, & Chandrasegaran, 2008; Taber, 2001). Among the most common AC, and one most resistant to change (Treagust et al. 2010), is the belief that a gas in not a substance, has no weight or mass. Students also hold AC regarding the bubbles that rise from boiling water. Many students state that the bubbles rising in boiling water are composed of hydrogen gas and oxygen gas (Harrison & Treagust 1998; Othman, Treagust, & Chandrasegaran, 2008). Students believe that when a substance expands or contracts, such water expanding when it freezes to form ice, the volume of the individual molecules change, as opposed to the space between them (Yezierski & Birk, 2006a).

Students' inability to comprehend electrostatic forces between particles leads to AC involving the relationships between the states of matter of a single substance. Several studies have shown that students believe that matter is continuous and smooth in the solid state based on their macroscopic observations (Cakmakci, 2009; Pozo & Gómez-Crespo, 2005; Talanquer, 2009).

Adadan et al. (2010) documented several AC relating to PNM. These researchers found that high school chemistry students hold AC that include the belief that particles in the solid state either do not move or move very fast. Students thought that solid lines exist between particles in a solid which act to hold the matter together, instead of electrostatic forces. In liquids, students stated that the particles are regularly arranged with lines between the particles maintaining the regular arrangement. For students that did believe that space exists between particles of a solid, those students expressed that air or other material occupies the space.

A thorough understanding of the PNM is essential to understanding states of matter, physical changes and chemical bonding. Students that hold AC about the PNM did not develop an accurate understanding of chemical bonding (Othman, Treagust, Chandrasegaran, 2008; Treagust, et al., 2010).

Chemical bonding alternate conceptions. Researchers have documented AC relating to chemical bonds (Adadan, 2009; Talanquer 2009). These researchers found that students do not properly distinguish between intermolecular forces and covalent bonding.

Nakhleh (1992) wrote that students hold a “static, rather than kinetic” (p.193) mental model of matter. Research has revealed that chemistry students struggle to differentiate between physical and chemical changes, that students describe chemical equilibrium as a static state instead of kinetic, and do not know that in a chemical reaction, atoms are only rearranged, (de Vos, & Verdonk, 1989; Nakhleh, 1992; Othman, Treagust, & Chandrasegaran, 2008).

Students think of chemical bonds as substantive and material (Othman, Treagust, & Chandrasegaran, 2008). They also report that students confuse the number of valence electrons with the number of chemical bonds that can be formed by an atom of an element.

Multiple Levels of Representation. One source of misunderstanding for chemistry students is the fact that chemists use three levels of representation; macroscopic, submicroscopic, and symbolic representations (Chandrasegaran & Treagust, 2009; Chandrasegaran et al, 2007; Colburn 2009; Johnstone, 2000; Taber 2001). Students conducting a laboratory exercise will report their macroscopic observations such as changes in color, odor, texture, or state of matter. Submicroscopic "refers to an understanding of chemistry at the particulate level—molecules, ions, atoms, subatomic particles, and so on" (Colburn, 2009).

Symbolic representations refer to the symbols chemists use to communicate concisely, including chemical symbols for elements, chemical formulae of compounds, and chemical equations. The use of symbolic representation allows chemists to communicate in a concise manner that is understood in all languages. For example, these symbols; $H_2\,(g) + O_2\,(g) \rightarrow H_2O\,(l)$ are used to communicate that diatomic hydrogen gas and diatomic oxygen gas react to form liquid water. This chemical equation would be written this way by scientists speaking any language. Since students lack sufficient understanding of chemistry at the macroscopic and submicroscopic levels, the significance of the symbols and formulas in chemical equations used to communicate the occurrences at the submicroscopic level lack meaning (Johnstone 2000). Students must have a sound understanding of macroscopic and submicroscopic chemical phenomena before they can use symbolic representation appropriately.

Students' difficulty in dealing with the three representational levels is complicated by the custom of chemistry teachers to change from one level of representation to another without discussing how these levels are interconnected. Chandrasegaran et al. (2007) wrote that "students are often unable to see the linkages between the three representations although they know the chemistry at the three levels. For improved conceptual understanding, it is important to help students see the connections between the three representational systems" (p. 239).

Chemists and chemistry teachers are comfortable moving between the three levels of representation, but students of chemistry find that moving between the three levels is difficult (Kozma, 2003). Marais and Combrinck (2009) wrote that students are "required to make the transition between macro and micro levels of matter, since the subject includes the study of interactions between indescribably small particles of nature which cannot be envisaged or measured by simple physical means" (p. 88). Johnstone (2000) further stated the problem students face. "It is (often) impossible for students to translate among three levels, macro-, submicroscopic, atomic, and molecular level and finally the abstract symbolic language commonly used in chemistry" (p.12).

Models in Chemistry/Science. Models in science classrooms serve as analogous representations of nature and present difficult and complex science concepts in ways that are meaningful and understandable for students (Chittleborough et al., 2005; Harrison & Treagust, 1998; Johnstone, 2000; Zare, 2002). Models in chemistry instruction are used to help students comprehend submicroscopic phenomena and to relate the submicroscopic representation to symbolic representations as they develop appropriate mental models of the phenomena (Harrison & Treagust, 1998; Taber 2001). Models are so widespread in the teaching and communication of science that Harrison and Treagust (1998) wrote that “modeling is the essence of scientific thinking…models are both the methods and products of science” (p. 420).

Model types. Scientific models take many forms including two-dimensional images, three-dimensional constructions, computer generated models, analogies, and metaphors. Regardless of the form, the purpose of a scientific model is to enable students to understand difficult, often abstract, science concepts and aid students as they form their own scientifically accurate mental models (Harrison & Treagust, 1998; Treagust et al., 2010). The concept being modeled is referred to as the *target* while the features of the model are called the *analogue.* Analogical models help and guide student understanding of abstract and difficult concepts and processes by simplifying some attributes of the target and enhancing others (Harrison & Treagust 1998). The analogues chosen are in some way familiar to students and thus translate the difficult aspects of the target into more familiar analogues. Models have been shown to assist students in both remembering as well as explaining scientific events (Harrison & Treagust, 1998)

Mental models can be thought of as the result of student learning. Chittleborough et al., (2005) wrote that teaching models and scientific models can be thought of as input for student learning and that the resulting mental model the student forms is the output of learning. They further stated that models are important in aiding students in understanding the processes of science.

Teachers use models in chemistry courses in order to attempt to bring abstract concepts into a concrete form. Models aid students to observe the unobservable. Taber (2001) wrote that many problems encountered by chemistry students are a result of not understanding the link between submicroscopic and macroscopic representations used by their teachers and the textbooks. Several studies have reported that teaching methods that stress the use of models, and explain how the models relate the submicroscopic, macroscopic and symbolic representations, improve students' abilities to understand chemistry concepts (Chittleborough & Treagust, 2007; Harrison & Treagust, 1996; Kaberman & Dori, 2009; Levy & Wilensky, 2009; Ornek, 2008; Othman, Treagust & Chandrasegaran, 2008; Taber, 2001). These researchers also found that student must be taught how to properly view scientific and teaching models. Some students were found to believe that teaching models are actual representations of submicroscopic phenomena instead of an analogous representation.

Levy and Wilensky (2009) found that students who were taught the particle theory of matter with a focused use of models, as found in this study, showed a greater comprehension of the association of submicroscopic and macroscopic representations of matter. Students in the Levy and Wilensky study also displayed an understanding that models are representations of nature rather than exact replicas of natural events. Smith, Wiser, Anderson, and Krajcik (2006) explained that the complexity of learning about PNM required time to master and nontraditional instruction. POGIL pedagogy provides both the time and nontraditional instruction proposed by many researchers (Fischer & Rose, 2001; Johnstone, 2006; Schwartz, 2009; Smith et al., 2006).

Lee, Linn, Varma, and Liu (2010) found that inquiry instruction which features computer-based teaching models designed to assist students to visualize complex science concepts were more effective than traditional lecture pedagogy. Lee et al. stressed inquiry units must be well thought out and designed for student understanding of complex topics. By well designed, the researchers were referring to teachers with strong content knowledge to act as facilitators during inquiry lessons and the quality of the guided inquiry questions and tasks. POGIL lessons provide the necessary well designed guided inquiry documents.

Process Oriented Guided Inquiry Learning. POGIL is a research-based, student-centered philosophy and science pedagogy in which students work in small groups to engage in guided inquiry using carefully designed materials that direct and guide students to build and rebuild their chemistry knowledge (Boniface, 2009; Hanson & Apple, 2004; Moog & Spencer, 2008). POGIL simultaneously teaches both content and key process skills of science. POGIL activities focus on core concepts and processes of science as it encourages and fosters a deep understanding of the course material while developing higher-order thinking skills.

The objectives of POGIL (Hanson 2004, p.1) are to

- Develop process skills in the areas of learning, thinking, and problem solving.
- Engage students to take ownership of learning.
- Increase student-student and student-instructor interactions.
- Improve attitudes toward chemistry and science.
- Enhance learning with information technology.

- Develop supporting process skills in teamwork, communication, management, and assessment that are essential for the workplace.

The development of POGIL was funded by the National Science Foundation due to the need to improve undergraduate chemistry education (Hansen, 2006). POGIL was originally developed in the 1990’s for undergraduate chemistry courses (Boniface, 2009; Moog & Spencer, 2008; POGIL, 2010) and has now spread to secondary chemistry and biology classrooms. College chemistry professors in the 1990’s found that the lecture based teaching methods, referred to as “teaching by telling” (Bressette, 2008, p. 51), in which an instructor attempts to pass knowledge from his or her brain to the students’ brains, was not working. What was needed was a pedagogy that promoted greater student engagement (Boniface, 2009; Hansen, 2006). A thorough review of the literature on best teaching practices revealed that active, student-centered practices were more effective in building enduring understandings of difficult science topics than traditional, teacher-centered, lecture style pedagogy.

Active, student-centered POGIL lessons were first developed for introductory general chemistry college courses. Quantitative studies report positive gains in achievement for students and qualitative studies revealed that students preferred POGIL pedagogy over traditional teacher-centered instruction (Farrell, Moog, & Spencer, 1999; Hinde & Kovac, 2001; Lewis & Lewis, 2005). College students taught using POGIL in general chemistry wrote that they wished they had been taught using POGIL methods in high school (Hanson, 2006). Hence, POGIL for high school chemistry materials were developed under an American Chemical Society-Hach grant funded by the Hach Scientific Foundation for the support of high school chemistry teaching.

Traditional teaching versus active, student-centered instruction. Traditional classroom instruction is defined as one in which the teacher is in control while the students are passive, recipients of information. The power and responsibility for learning are teacher centered. The teacher makes all decisions as to what is studied and how the instruction is to take place. A traditional classroom can be competitive in nature which leads students to resent others using their ideas. Coverage of the content is a primary concern in a traditional classroom. Content is transferred to the students from the textbook or from the teacher through lecture. This practice is referred to as '"teaching by telling" (Bressette, 2008, p. 51) and is not effective. The oral presentation of information in the lecture and can be aided by PowerPoint presentations, educational videos, or other media. Students attempt to acquire mastery of the topic through drill and practice. Higher order thinking skills are usually not required as memorization of facts is common (Triangle Coalition for Science and Technology Education, 1993).

In contrast, an active, student centered classroom, is one in which students do not sit passively in desks listening to a lecture. Active, student-centered pedagogy involves engaging students in the learning process by first moving students from passive recipients of a lecture, to active constructors of knowledge. Cooperative learning and scientific inquiry are often aspects of active student-centered learning, as in this study. Materials such as teaching models, laboratory materials, computer software, computers with internet access, and other resources for learning are usually provided for student use.

Differentiation. As classrooms in America become more diverse, the need for differentiation of instruction has become clear (Tomlinson, 1995, 2009). Differentiation of instruction is defined by Tomlinson and Allan as:

> a teacher's reacting responsively to a learner's needs….attending to the learning needs of a particular student or small group of students rather than the more typical pattern of teaching the class as though all individuals in it were basically alike. (2000, p. 4)

A teacher devoted to providing the optimal learning experience for all students will seek to differentiate instruction, which means that she must begin instruction where the student is, not on page one of the textbook or at the beginning of a curriculum guide (Tomlinson, 1999). Students arrive in the classroom each with his or her own unique set of life experiences on which knowledge may be built. The wise teacher must determine what prerequisite knowledge the student possesses or lacks, as well as what special gifts, talents and abilities the student has. Then the teacher may prepare to move the student forward from that student's own, unique starting point.

Once a student's starting point is determined, the task for the teacher is to determine what classroom experiences can he or she provide that will offer the optimal learning experience for that child, based on the unique needs and talents of each student. In other words, how should the lesson be differentiated for a student in order for him or her to learn as much as possible?

Classroom instruction can be differentiated in any of three ways: process, product and content. Process differentiation refers to *how students will learn* the content. Tomlinson and Allen (2000) define process differentiation as "how the learner comes to make sense of, understand, and "own" the key facts, concepts, generalizations, and skills of the subject." (p. 8). Product differentiation refers to *what students will produce* to demonstrate mastery of a topic. Product differentiation could include portfolios of work, an exhibition of solutions to problems, or a pencil-and-paper test. Content differentiation refers to the specific content students will learn (Tomlinson & Allan, 2000). Content differentiation is applicable to highly capable students who need an accelerated curriculum or students in a classroom that lag behind their peers and are learning content the others have mastered.

POGIL is an example of process differentiation, as the “P” in POGIL is, indeed, process. POGIL utilizes guided inquiry set in cooperative learning groups where students actively build on their previous knowledge while giving to and receiving from their group mates learning support as needed. Students in a POGIL lesson evaluate the learning model provided and move from their own unique cognitive starting place, based on their personal prior knowledge. This active process of POGIL differs from the traditional passive lecture pedagogy, which provides only one lesson for all listening to the lecture. The active involvement in a POGIL lesson results in process differentiation from traditional lecture.

POGIL lessons also offer product and content differentiation. As teachers rotate past each cooperative learning group, informal assessments of how students process and apply knowledge of differentiated instruction can easily be accomplished by the teacher posing questions to gauge the students’ understandings. Content differentiation could be accomplished by selecting students for groups based on the topic (content) they need to master. All POGIL groups would not have to be utilizing the same student learning documents or be studying the same topic.

Also, POGIL lessons include questions that students typically complete individually as homework or class work which is collected by the teacher for assessment. Student products may include sketches, verbal explanations, quizzes, and formal exams. Compared to lecture-style pedagogy, a typical POGIL lesson will include more informal assessments both by the students in their cooperative learning groups and from the teacher. Teachers have the opportunity to informally assess student learning as they pass by the cooperative groups or when calling for summaries from each group's spokesperson during the course of the class period. Formal, graded assessment occurs after students have had the opportunity to experience and grow from several informal assessments.

Guided inquiry learning, the heart of POGIL. The G and the I in POGIL stand for guided inquiry. Guided inquiry learning is a central tenet of POGIL philosophy and pedagogy because guided inquiry has been shown to be a more effective pedagogy than traditional lecture teaching. Minner, Levy and Century's (2010) meta-analysis of studies of inquiry-based science teaching found that students showed greater science achievement when involved in guided-inquiry lessons than when involved in traditional lecture classrooms. Minner et al. reported that guided inquiry can be defined many ways. They chose to define inquiry as hands-on activities used to "motivate and engage students while concretizing science concepts" (p.475). They also stressed that learners involved in inquiry lessons will communicate to others and evaluate their explanations of scientific phenomena as well as justify proposed scientific explanations, as all POGIL lessons do. Students in inquiry lessons that provided both hands-on opportunities and time for discussion posted the greatest gains. Students were observed to benefit from having time provided to "process for meaning through class discussions of the reasons behind what they observed" (p. 491).

Inquiry learning in the United States dates back to Dewey's (1897, 1938) call for educators to provide learning opportunities in which students could seek knowledge for themselves in interactive and social environments. In 1961, the Educational Policies Commission stated that students in American schools should be developing certain thinking and learning skills which included: recalling and imagining; classifying and generalizing; comparing and evaluating; analyzing and synthesizing; and deducing and inferring (Educational Policies Commission, 1961). The development of these skills and abilities are central to inquiry learning. Piaget (1973) wrote concerning the need of students to have opportunities to develop their cognitive abilities through challenging and thought provoking activities now referred to as constructivist learning activities. From this constructivist perspective, inquiry learning has grown in use and importance, especially in science classrooms (Matthews, 2002).

More recently, Wilson, Taylor, Kowalski and Carlson (2010) reported an important and promising finding from their study of inquiry pedagogy as opposed to traditional lecture teaching. Wilson et al. reported that the students in their study who were taught using inquiry-learning posted greater achievement than students taught using traditional lecture methods. Of particular interest was the absence of an achievement gap between students of different races. In the Wilson et al. study, minority students posted similar gains to their Caucasian and Asian peers. They also reported similar learning gains for male and female students.

A critical component of successful guided inquiry learning is the cooperative learning group (Lee et al., 2010). Students discuss with their cooperative learning group peers the content being investigated in an inquiry lesson. Cooperative learning is a key to the success of guided inquiry learning and is discussed in the next section.

POGIL and cooperative learning. Students in a POGIL environment work in cooperative groups to solve problems, work on a project, or research a topic. In the context of a cooperative learning community, students are less competitive and are more likely to share ideas and support classmates as they work together to solve common problems. An aspect of cooperative learning in a POGIL session is that students engage in conversations as they discuss and debate their answers to questions or explore possible answers. In these discussions, students are found to employ higher order thinking skills as they engage in critical thinking, discovery learning, and inquiry (P. Brown, 2010; S. Brown, 2010).

Cooperative learning is rooted in the work of Vygotsky (1962) and Dewey (1897, 1938) each of whom wrote on the social nature of learning and the necessity for the learner to interact with his or her environment when engaging in a learning activity. Recent studies of cooperative learning in science classes have shown improved student achievement when compared to less social learning environments (Bilgin & Geban, 2006; Johnson & Johnson, 1999, 2010; Köse, Şahin, & Gezer, 2010). Studies have found that cooperative learning groups in which students interacted with peers increased conceptual learning more than when students worked alone with no peer interaction (Lumpe and Staver 1995; Marinopoulos and Stavridou, 2002). POGIL pedagogy was specifically designed to incorporate cooperative learning since cooperative learning has been shown to improve process skills and results in higher order thinking (Bilgin & Geban, 2006; Johnson & Johnson, 1999, 2010).

***POGIL pedagogy*.** POGIL is active and student-centered and is based on the learning cycle (Moog & Spencer, 2008; Hansen, 2006). POGIL instruction utilizes carefully written guided inquiry student learning documents available at http://www.pogil.org, with each document offered as a free download. Embedded in the POGIL student learning documents are models designed to help students visualize abstract concepts and submicroscopic phenomena. POGIL student learning documents are thoughtfully and intentionally developed with the purpose of each student experiencing the learning cycle.

Learning cycle. The learning cycle is a pedagogy which states that learning occurs in three stages: exploration, concept invention, and application (Atkin & Karplus, 1962). Atkins & Karplus (1962) and Abraham (1982) offered explanations of the stages of the learning cycle. They wrote that in the exploration stage, students explore a topic or phenomena using their senses as much as possible and interact with their environment (which can include other students or their teachers). Observations are made and questions usually arise from the exploration.

The next phase in the learning cycle is concept invention. Students utilize prior knowledge along with the newly acquired information from the exploration phase to begin making a series of statements of conjecture concerning the concept being studied. Students frequently refer back to the model or materials utilized in the exploration phase as they work to formulate their concept.

The final stage of the learning cycle is application. In this phase, students apply their newly formed concept to a situation to test the validity of their concept. If their concept is faulty, they cycle back to the previous two stages and continue refining and developing their concept.

In the exploration stage of a POGIL lesson, students examine a teaching model along with a series of questions relating to the model. The questions, along with the lesson objectives, lead students to explore the model and execute certain tasks that lead to a full understanding of a concept. The model could be any number of things including a diagram, a computer simulation, a table of data, graphs, a teacher demonstration or a combination of these experiences. As the students work in their cooperative learning group to examine and explore the model, they engage in conversations as they attempt to explain and understand the model. Their conversations include statements of conjecture and the formation of hypotheses.

The concept invention state occurs as a result of the exploration phase and the conversations that occur in this first stage. Students will ‘invent’ the concept featured in the lesson. The questions and tasks provided in the POGIL student documents lead the students to logical conclusions, which are the concepts featured in each lesson.

The final stage of the learning cycle is the application stage. Students are provided with opportunities to apply their newly invented concept to chemistry problems. If their concept needs refining, the cycle returns them to the exploration stage where the learners can explore and refine their new knowledge. In their discussions, students contemplate and discuss the strengths and weaknesses of their hypotheses and work toward understanding and mastery of the topic for every group member.

Abraham (1982) pointed out that the learning cycle pedagogy emphasizes and employs the use of active student investigation of phenomena to produce evidence, or data, to back up student conclusions. The ability of students to explain newly acquired knowledge is critical. Abraham also stated that this type of pedagogy is in contrast with traditional approaches in which the student is a passive receiver of knowledge and has knowledge of the expected outcome of an experiment before performing it.

Abraham and Renner (1986) applied the learning cycle in secondary chemistry and found that students involved in lessons built upon the learning cycle exhibited greater achievement gains, better mastery and retention of concepts, and developed better process skills when compared to students taught using traditional lecture-based pedagogy.

To support student exploration, concept invention, and application, all POGIL lessons feature two dimensional models (figures or diagrams) that have been carefully chosen to aid in the conceptual understanding of the topic and guided inquiry questions referring to the model which have been carefully written to develop scientifically sound understandings of chemistry fee of AC. Research confirms that students form correct, strong conceptual understandings of science topics when relevant analogical models are used in a context where students are interacting socially and discussing the model's meaning and applications (Harrison & Treagust, 1996, 1998). Most POGIL student activities also utilize computer animation models that are available on-line, free of charge. These computer animations provide students with macroscopic views of submicroscopic phenomena. For the study of the particle nature of matter, computer animations are superior to static models since animations allow students to observe the constant movement of the particles, which is the basis for the particle theory of matter. With static physical or paper models, students cannot see the movement of the particles.

POGIL pedagogy is multirepresentational since a typical POGIL lesson involves the use of verbal definitions and descriptions, two-dimensional models and computer animations. Aladan et al (2010) found that multirepresentational pedagogy aided students to form more scientifically accurate mental models of PNM phenomena. Based on their findings, these researchers encouraged classroom teachers to incorporate many types of models, or representations, of PNM phenomena in order to facilitate student understandings of abstract phenomena. These researchers also pointed out that encouraging students to create their own sketches of what they believe is happening at the particulate level and then verbally explain what they have drawn, fosters concept development. POGIL lessons provide this type of opportunity to develop and express a student's mental model. In doing so, peers in a POGIL learning community can discuss each student's drawing, explanation and understanding. The discussion which accompanies these acts is a vital part of the learning cycle in which the student tests a mental model and is allowed to make corrections as needed in a nonthreatening, supportive environment.

A common initial concern of individuals considering a change to student-centered pedagogy away from the traditional lecture methods, common in most science courses, is that active student-centered pedagogy does not allow time for both lecture and student activities. Concerns have been raised over the amount of content that can be covered in a term when using POGIL methods. Lecture has been the pedagogy of choice in science courses for decades because it allows the instructor to move steadily ahead whether students comprehend the material or not. When contemplating a move away from the traditional, lecture format in science courses to active, student-centered pedagogy, tertiary and secondary schools have expressed concerns that students will not learn as much in classes that employ POGIL pedagogy as they do in traditional, lecture-format classes. Several studies have found that these concerns are groundless: Students in classes that employ POGIL pedagogy score at least as well as students in traditional teacher-centered, lecture courses (P. Brown, 2010; S. Brown, 2010; Farrell, Moog & Spencer 1999; Lewis & Lewis, 2005). Research has also found that the students who achieve in lecture based course do equally well in POGIL classes and that students who perform less well in lecture courses achieve higher scores in POGIL classes (P. Brown, 2010; S. Brown 2010; Lewis & Lewis, 2005).

Effectiveness of POGIL. After the initial success of POGIL in undergraduate chemistry (Farrell, Moog, & Spencer, 1999) classes, POGIL methods have been successfully implemented in several other college courses as well, including organic chemistry (Schroeder & Greenbowe, 2008), physical chemistry (Spencer & Moog, 2008), biochemistry (Minderhout & Loertscher, 2007), medicinal chemistry (S. Brown, 2010), mathematics (Rasmussen & Kwon, 2007) and anatomy and physiology (P. Brown 2010).

Patricia Brown (2010) and Stacy Brown (2010) each studied the effectiveness in college science courses using POGIL methods. Both reported that they had found test grades and overall test grades were positively affected by POGIL. They found that the number of students failing chemistry or making a “D” fell and that students reported more confidence in what they had learned. Students reported that they felt as if they had learned a great deal and understood the material as opposed to memorized necessary facts to pass a test.

P. Brown (2010) studied the effectiveness of POGIL methods in an anatomy and physiology course at King College. Brown stated that King College, like many other tertiary institutions, chose to implement POGIL methods in order to make their courses more student-centered, active learning experiences since lecture methods were not producing the desired learning outcomes in science classes. She stated that “only a small fraction of students in introductory science classes are served by a traditional didactic approach” (p. 4).

P. Brown’s study reported higher achievement of students on summative tests which lead to significantly better grades in the course for students. Brown’s study covered three semesters and student grades in the course improved over all three semesters from a mean of 76% to 89%. The mean score on the final exam during this period improved from 68% to 88%. Of particular interest is the decrease in the percentage of students earning a grade of D or F in the course. P. Brown reports that the percentage of students earning a D or an F was halved in the first two semesters and dropped to 0% in the third semester. Qualitative data from this study reported that almost all of the students regarded POGIL instruction as very beneficial and highly effective.

S. Brown studied the effectiveness of POGIL methods in a one semester medicinal chemistry course in the doctor of pharmacy program at East Tennessee State University. S. Brown reported four positive aspects of utilizing POGIL methods in the course. POGIL improved grades in the course, encouraged active engagement with the material in the class, provided immediate feedback to the instructor concerning student deficits and misunderstandings, and created a positive classroom environment where students enjoyed learning very difficult material.

S. Brown reported that the grade distribution shifted upward due to the POGIL methods. What had been a B-C distribution in this course became A-B centered after POGIL implementation. S. Brown wrote,

> to truly appreciate the significance of this grade distribution shift, one must consider the high competency level of these students. As professional school students, they underwent a rigorous admissions process that resulted in 3 groups with no significant differences in PCAT composite scores or GPAs. Nevertheless, they showed that differences in their mastery of medicinal chemistry course content depend on how the material was delivered. (p. 6)

S. Brown also wrote that the students felt confident in what they were learning in a class that had historically been known as a most abstract and difficult course. What could be seen as a shortcoming of this study might, indeed, be an asset. The instructors in the various sections of the courses in this study changed their summative assessments each year. These documents were analyzed to determine the Bloom’s taxonomy level of each question. The examinations given in the POGIL sections consisted of fewer questions from Bloom’s level 1 (knowledge) and more questions from level 2 (application). The students in the POGIL sections were taking more difficult exams than the exams given to the students in the non-POGIL sections of the course and yet, were earning better scores. The average scores on summative exams shifted from 86% of students scoring in the B-C range in the non-POGIL sections to 82% of students scoring in the A-B. This shift is remarkable when considering how similar these groups are in regard to aptitude for the subject matter being taught and tested.

POGIL in high school chemistry. The development of POGIL for high school chemistry grew out of the frustration of science educators with their failed attempts to teach using inquiry methods in secondary classrooms. The *National Science Education Standards* (NRC, 1996) and *Project 2016* (AAAS, 1993) each called for science to be taught using inquiry though most science teachers rarely use them (Hermann & Miranda, 2010; Kuhlthau & Maniotes, 2010). In an open inquiry lesson, students come up with their own question to research, design their own investigation, conduct the investigation, and report their findings (Hermann & Miranda, 2010). This type of inquiry, open inquiry, has not proven to be an effective method for teaching as students report being frustrated and confused (Colburn, 2009; Kirschner, 2008). Students simply do not have the experience or the knowledge base to engage in open inquiry as scientists do (Colburn, 2009; Kirschner, 2008).

Guided inquiry, such as POGIL, differs from open inquiry in that the teacher provides the question and other supports needed to investigate the question, such as models, and personal guidance. The promotion of inquiry learning in science is consistent with conceptual change theory and dynamic skill theory, as they all trace their origins to constructivism and share a common ideology that the learner must be actively engaged in the teacher's lesson and construct knowledge personally. Guided inquiry requires students to draw on their previous knowledge as they incorporate new learning by thinking critically about the situation that is presented. Chiappeta & Adams (2004, p. 47) identified five reasons guided inquiry lessons are superior to traditional lecture instruction. They wrote that guided inquiry science instruction promotes:

- understanding of fundamental facts, concepts, principles, laws, and theories;
- development of skills that enhance the acquisition of knowledge and understanding of natural phenomena;
- cultivation of the disposition to find answers to questions and to question the truthfulness of statements about the natural world;

- formation of positive attitudes toward science; and
- acquisition of understanding about the nature of science.

Guided inquiry lessons allow teachers to engage their students in both the content (what) and the process (how) of science. Traditional lecture teaching consists of students passively listening to content being delivered by the instructor. The student in a traditional class is not actively involved in the process of learning as they are in an inquiry lesson.

In order for conceptual change to occur where AC exist, students need to explore complex tasks, as found in chemistry, in various contexts (Schwartz, Sadler, & Tai, 2008). The POGIL method provides such opportunities for in depth exploration of complex topics. Students have a platform for discussing their ideas and for testing their own mental models of submicroscopic phenomena in chemistry as well as their understanding of symbolic representation. POGIL guides students to reconstruct their mental models into forms consistent with those held in the scientific community.

Few empirical studies are available that have examined science achievement and in-depth studies of complex science skills, as POGIL provides. One rare study found a positive association between high school science experiences that provided in depth study of at least one topic in high school science classes and college science course grades (Schwartz, Sadler, & Tai, 2008). This study also found a negative correlation between college science grades and high school experiences where material was “covered” and not studied in depth. POGIL lessons call on students to process the information, not merely “cover” the material by memorizing a few isolated facts.

Summary

This chapter has offered a review of the literature related to the difficulties teachers and students encounter when teaching and learning chemistry. The neo-Piagetian theoretical framework for this study was presented which incorporates dynamic skill theory, cognitive load theory, Johnstone's information processing model, and conceptual change theory.

The review of literature included many research studies of chemistry AC, and specifically those studies related to AC in relation to PNM. Teaching practices designed to address AC and their implications for student achievement were considered. The research reviewed has reported that the struggles students encounter when studying chemistry has been traced to the mental demands of such an abstract subject and to the formation of alternate conceptions. The issue of students struggling to comprehend the three levels of representation in chemistry was reviewed as was the use of models in science teaching.

The need for more effective chemistry pedagogy led to the development of the POGIL philosophy, pedagogy and teaching materials at the college level which has spread to the secondary chemistry classroom. The use of teaching models to help form appropriate mental models is a key component of the POGIL classroom while the cooperative learning groups provide a non-threatening environment in which students can build and rebuild their mental models of chemistry concepts.

POGIL allows teachers to engage their students in both the content (what) and the process (how) of science. POGIL provides opportunities for in-depth exploration of complex topics through the use of models and carefully ordered questions that guide and focus student learning. Students have a platform for discussing ideas and testing their own mental models of submicroscopic phenomena in chemistry as well as their understanding of symbolic representation. POGIL guides students to reconstruct their mental models into forms consistent with those held in the scientific community. POGIL as a differentiation tool was discussed.

The effectiveness of POGIL in college classes is evident in the literature, but the effectiveness of POGIL in the secondary chemistry classrooms has not been researched. This study was conducted to provide information concerning the effectiveness of POGIL in secondary chemistry education.

CHAPTER THREE: METHODOLOGY

Introduction

In this chapter, the participants, setting, instrumentation, procedures, research design, and data analysis plans are described. The independent and dependent variables are defined and assurances of content validity and reliability are shared. This study utilized a nonequivalent control group, pretest-posttest design to investigate student achievement in secondary college preparatory chemistry. This study investigated the effect of using student-centered process oriented guided inquiry learning (POGIL) on high school chemistry achievement in particle theory versus traditional, teacher-centered lecture-style pedagogy. The research question for this study is: What impact does the use of process oriented guided inquiry learning have on student achievement in explaining physical and chemical changes in matter related to particle theory in secondary chemistry? The research hypothesis is that student alternate conceptions related to particle theory in secondary chemistry will be reduced by the use of process oriented guided inquiry lessons.

Participants

The population studied was college preparatory chemistry students enrolled in large (1700 – 2000 students), suburban high schools. Most of students were either in the 10th or 11th grade with some students in the 12th grade, ranging in age from 15 to 18 years. Participants in the study were all college prep high school students taking chemistry as a requirement for graduation and as a prerequisite for admission to a four-year college.

Instructors. The teachers involved all have completed graduate work and earned at least a master's degree in science education or a related field and are broad-field science certified by the State of Georgia to teach grades 7 – 12. All have a minimum of 7 years experience teaching high school chemistry. The instructors involved in this study followed the Georgia chemistry curriculum map (GDOE, 2006d) and taught the same chemistry topics during the second semester of the 2010-2011 school year. All topics were taught in the same order, as listed on the curriculum map**.** The teachers involved in the experimental group of this study were trained in POGIL instructional methods.

Participant groups. Entire classes taught by a total of eight chemistry teachers were randomly assigned a teaching method with each teaching all of his or her chemistry classes using one of the two teaching methods; POGIL or traditional pedagogy. All students were taught the same topics related to particle theory. The control group was taught using traditional, teacher-centered lecture-style pedagogy. The experimental group was taught using POGIL documents and methods. A total of 318 students completed this study with 169 students in the control group and 149 in the treatment group.

***Experimental group teacher training*.** Experimental group teachers (EGT) met with the researcher to be trained in POGIL philosophy, methods, and use of the guided inquiry materials provided through the POGIL project (POGIL, 2010). The focus of the training session for the EGT was to explain and share POGIL methods, philosophy, and teaching materials.

The researcher also provided each teacher participant a notebook containing POGIL documents, correlation maps, the timeline for the study, and contact information for the researcher (see Appendices A and B). The POGIL documents used by students and the teacher support documents, all retrieved from http://www.pogil.org, and were included in the notebook. The study timeline listed a window of time to administer the pre-test and posttest. The test dates offered a window of one week which allowed the teachers some flexibility to administer the assessments at the time most appropriate for their students. The correlation map shows where each POGIL student activity fits into the Georgia curriculum map for chemistry, thus, the teachers knew the appropriate POGIL activity to use with each chemistry topic. The contact information for the researcher ensured that participants could communicate quickly and easily with the researcher if they had any questions during the period of the study.

The researcher provided all materials the participants needed for the study including the pretest/posttest ParNoMA2 documents, Scantron answer sheets, and number 2 pencils for use with the Scantron sheets. The pretest and posttest ParNoMA2 documents, Scantron answer sheets and pencils were delivered to each teacher the week before the administration of these assessments.

The POGIL classroom materials were matched to their corresponding topics in the Georgia Performance Standards Framework for Science-Chemistry documents for the 3rd and 4th quarters of chemistry instruction (GDOE, 2006b, 2006c). POGIL activities were correlated to the sequence of chemistry topics specified by the Georgia Department of Education Year Curriculum Map (GDOE, 2006d). This correlation was included in the teacher participant notebook (see Appendix A).

The researcher provided the POGIL materials and shared at the training session how each POGIL activity should be integrated into their units of study during the second semester of the school year. The POGIL activities for this unit are; *Kinetic Molecular*

Theory, Vapor Pressure Curves, Phase Changes, Collision Theory – Impact for a Chemical Reaction. The researcher followed up with the experimental group teachers throughout the semester.

Training for POGIL lessons. The training session focused on preparing the experimental group teachers to utilize POGIL strategies which include cooperative learning in small groups, student discussion of ideas, and guided inquiry learning. The POGIL philosophy as well as methods and materials were discussed and provided and is explain here.

The philosophy of POGIL is that students learn complex concepts best when they are actively engaged in the learning process. This philosophy is expressed in the POGIL objectives which are accomplished during POGIL activities designed to focus on core concepts and processes of science that encourage a deep understanding of course material while developing higher-order thinking skills. The objectives of POGIL (Hanson 2004, p.1) are to;

- develop process skills in the areas of learning, thinking, and problem solving,
- engage students to take ownership of learning,
- increase student-student and student-instructor interactions,
- improve attitudes toward chemistry and science,
- enhance learning with information technology, and
- develop supporting process skills in teamwork, communication, management, and assessment that are essential for the workplace.

Experimental group teachers were trained to place their students in cooperative work groups to solve problems, work on a project, or research the topic of each POGIL lesson.

Teachers always reserved the right to change the make-up of groups in order to maximize the learning opportunities for all students. Groups were comprised of three or four students, each with an assigned role. The roles are defined as follows (Hanson, 2006).

- The *manager* is responsible for ensuring that all members of the group participate and stay focused on the task. He or she assigns the work and responsibilities as they arise in the work session and resolves disputes within the group. The manager is also responsible for ensuring that all members of the group understand the topic being studied.
- The *spokesperson* may also be called the presenter. This person reports the group's findings to the class.
- The *recorder* keeps all records during the work session and prepares a report of the group's discussions and findings.
- The *strategy analyst* may also be called the *reflector*. He or she records the strategies and methods utilized by the group to solve problems. Careful attention is paid to identifying strengths and weaknesses in the group. The strategy analyst prepares a report of his or her observations.

These roles should be rotated with each new POGIL lesson. If a group has only three members, the roles of spokesperson and recorder can be combined.

An aspect of cooperative learning in a POGIL session is that students engage in conversations as they explain their answers to questions or explore possible answers. In these discussions, students are found to employ higher order thinking skills as they engage in critical thinking, discovery learning, and inquiry (P. Brown, 2010; S. Brown, 2010). Teachers were trained to encourage such student-to-student conversations.

The role of the teacher in a POGIL work session is to act as a monitor, a facilitator, and evaluator of student engagement and learning. This is accomplished by monitoring and assessing individual and team performance as the teacher circulates around the room listening to each group's conversations. When needed, the teacher can facilitate student-to-student conversation by asking a critical thinking question. All teacher interventions focus on the process of learning that leads to content comprehension. At the end of a POGIL work session, the teacher will ask the spokespersons from each group to report on their group's findings. The teacher provides a closing to the lesson by summarizing the groups' findings or by having a student summarize the class findings.

Typical POGIL lesson. Instead of the lengthy lecture about a chemistry topic that is the norm in traditional chemistry pedagogy, a typical POGIL lesson consists of a brief introductory lecture which lasts 5 to 10 minutes. After the introduction, students break up into their assigned work groups to examine the model provided in the POGIL documents and answer the guided inquiry questions associated with that model for 15 minutes. The teacher will call for the spokespersons to give a brief report their group's progress after the prescribed time for that lesson. The brief progress reports of all groups should take no more than 5 minutes. The groups will begin working on the Exercises and Problems in the guided inquiry documents for 15 to 20 minutes. The final 5 to 10 minutes of class is used to bring closure to the lesson by the spokespersons reporting findings followed by the preparation of final written reports from the strategy analysts and recorders.

The teacher circulates around the room listening in on each group and offering assistance only when necessary. The guided inquiry exercises and problems on the

POGIL documents begun in class may be finished for homework or the teacher may choose to continue the discussion of questions in POGIL work groups the next day.

As students work in their groups, they will be discussing the model provided in the POGIL documents and also, in some cases, a computer-based model available on-line. All POGIL lessons feature two dimensional models (figures or diagrams) that have been carefully chosen to aid in the conceptual understanding of the topic and guided inquiry questions referring to the model which have been carefully written to develop scientifically sound understandings of chemistry free of AC. Research confirms that students form correct, strong conceptual understandings of science topics when relevant analogical models are used in a context where students are interacting socially and discussing the model’s meaning and applications (Harrison & Treagust, 1996, 1998).

Settings

All schools in the study are located in a northern suburb of metropolitan Atlanta, Georgia and are fully accredited by the Southern Association of Colleges and Schools Council on Accreditation and School Improvement (SACS-CASI). This region is marked by rapid growth and is populated by middle class through lower income residents. As a result of the recent economic downturn, many jobs formerly held by middle class workers have been lost and families in the area have suffered significant financial difficulties.

Pseudonyms have been given to all participating schools. With assistance from the school district involved, the demographics of four high schools were compared. High School A (HAS) and High School B (HSB) share similar demographic data as do High School C (HSC) and High School D (HSD).

High School A and High School B. The school district's data management offices reports that HSA and HSB each have approximately 1700 students enrolled. HSA reports an ethnic distribution of approximately 80% Caucasian, 10% Hispanic, 8% African American, 1.6% Asian, and <1% Indian American. The population is approximately 50% female and 50% male. Specific demographic data for HSB was not available to the researcher, but the data management office of the school district involved confirmed that the HSA and HSB demographics are similar and distinct from the other schools involved socioeconomically.

High School C and High School D. The school district's data management office reported that HSC and HSD have approximately 2000 students each coming from diverse communities that are changing demographically. While the populations are currently predominately Caucasian, the Hispanic population is growing. HSD reports an ethnic distribution of 73.2% Caucasian, 11.7% Hispanic, 9.7% African American, 2.8% Asian, and 2.7% multiracial. The population is 49.8% female and 50.2% male. The ethnic distribution of HSC is 77.2% Caucasian, 10.5% Hispanic, 8.8% African American, 2.3% Asian, 2.4% multiracial, and <1% Indian. The population is 48.1% female and 51.9% male.

Instrumentation

One instrument was used as a pretest and posttest, the Particulate Nature of Matter Assessment Version 2 (ParNoMA2) (Yezierski & Birk, 2006b). This instrument consists of 20 multiple choice items carefully written to assess common AC held by chemistry students related to the particulate nature of matter. Yezierski and Birk (2006a) report a Cronbach alpha score of 0.83.

Yezierski and Birk developed the ParNoMA2 to expose AC held by students enrolled in introductory chemistry courses. Yezierski and Birk used Treagust's (1988) guidelines to develop the ParNoMA. These guidelines include:

- examine the literature for confirmed AC in a particular topic,
- conduct informal student interviews to investigate AC,
- developing multiple choice content items and free response diagnostics,
- develop 2-tier diagnostic test featuring a (tier 1) multiple choice question followed by a (tier 2) multiple choice item stating the reason for the 1st answer. The reasons listed are derived from common AC.
- refine the assessment developed.

Using these guidelines, Yezierski and Birk searched the literature on AC relating to PNM. They conducted informal student interviews of undergraduate chemistry students to confirm the presence of the suspected AC based on the review of literature. Based on the literature review and the response of student interviews, they found these topics relating to the PNM to be commonly misunderstood by students: size of particles, weight of particles, phases and phase changes, composition of particles, and the energy of particles (2006a; 2006b). They then began to develop their multiple choice content items.

For the AC tested in the multiple choice items, Yezierski and Birk turned to the work of several researchers. Osborne and Cosgrove (1983) described AC relating to the composition of bubbles rising in boiling water and the descriptions of the particle behavior during evaporation and condensation (see Figure 4, item 2). Griffiths and Prestons (1992) and Garnett, Garnett and Hackling (1995) published works exposing student AC relating to energy, shape, arrangement, and weight of atoms and molecules in various phases. From the work of these researchers, items were written to probe student conceptual understanding of these topics and multiple choice distracters were written to reflect common AC. Benson and Wittrock (1993) reported AC related to the size of gas molecules under different pressure.

ParNoMA was reviewed by college chemistry researchers found to be appropriate. Sample items are found in Figure 4.

Sample item 1: Which of the following processes will make water molecules larger?

A. freezing
B. melting
C. evaporation
D. condensation
E. none of the above

Sample item 2. A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear. What are the bubbles made of?

A. heat
B. air
C. gaseous oxygen and hydrogen
D. gaseous water
E. none of the above

Figure 4. Sample items from the ParNoMA2. Used with permission. Sample item 1 is the work of Garnett, Garnett and Hackling (1995). Sample item 2 is the work of Osborne and Cosgrove (1983).

The ParNoMA2 was reviewed and approved by experienced chemistry teachers in the district where this study was conducted to ensure validity with the chemistry course content as specified in the Georgia Performance Standards for chemistry (GDOE, 2006a) used in the classrooms participating in this study.

Procedures

After submitting an internal review board (IRB) packet and gaining approval from Liberty University IRB and the participating school system's review committee in January, the researcher began to execute the research. Pretests were copied and delivered to the participating schools along with Scantron sheets. Participating teachers in both the control and experimental groups were notified that permission to collect data had been secured from the school district office and from Liberty University IRB and that they could administer the pretest during the prescribed testing window.

Data gathering. Data were gathered by the participating teachers and picked up by the researcher from the participating schools. Each teacher administered the ParNoMA2 as the pretest and posttest with student multiple choice answers recorded on Scantron sheets provided by the researcher.

Sampling procedures. Intact classes of students enrolled in chemistry classes were used. Ary, Jacobs, Razavieh and Sorensen (2006) wrote, "In a typical school situation, schedules cannot be disrupted nor classes reorganized to accommodate a research study. In such a case it is necessary to use groups as they are already organized into classes" (p. 341). The teachers employing POGIL method at HSA and HSC taught all of their chemistry classes using POGIL methods and materials. Teachers participating in the control and experimental groups were all similar in education and years of experience teaching chemistry. A total of 318 students completed the study by taking both the pretest and posttest.

Pretest. The ParNoMA2 was administered early in the 3rd nine weeks (second semester) of the school year as a pretest. The results were utilized to determine the similarity of the control and experimental groups. Ary *et al.* (2006) states “The pretest enables you to check on the equivalence of the groups on the dependent variable before the experiment begins…and use ANCOVA to statistically adjust the posttest scores for the pretest differences.” (p. 342).

Research Design

This study utilized a nonequivalent control group, pretest-posttest design to investigate student achievement in chemistry. This design is modeled after studies of the effectiveness of POGIL at the college level carried out by Lewis and Lewis (2005) and P. Brown (2010). Both of these studies compared student achievement, as in this study, under POGIL method versus traditional, lecture-based chemistry instruction. In the studies mentioned, student achievement, as measured by the semester final exam and course grades, were compared using ANCOVA. These studies did not administer a pretest as was used in this study.

The pretest and posttest results of the two treatment groups in this study were compared using ANCOVA. ANCOVA was chosen to compare the control and experimental groups in order to control for the possible existence of an extraneous variable that could differ between the control and experimental groups. The use of ANCOVA adjusts the mean scores of the control and experimental groups for differences between the groups that exist. Thus, the part of the variance in the scores between the experimental and control groups not caused by the treatment was removed (Ary, Jacobs, & Sorensen, 2010). ANCOVA analyzed the posttest scores of the experimental and control groups in light of their performance on the pretest. Each null hypotheses that states that there is no statistically significant difference in the alternate conceptions in chemistry held by students who were taught using active, student centered POGIL pedagogy and students taught using traditional, teacher-centered pedagogy, was rejected at $p < 0.05$ significance level.

Two teaching methods were compared; traditional teacher-centered lecture-style approach versus student-centered POGIL. The independent variable is teaching method and the dependent variable is student alternate conceptions in chemistry as measured on the PaNoMA2. Since it is not possible to randomly assign students to the control and experimental groups, intact chemistry classes were randomly assigned to either the control or experimental group. Some degree of random assignment had occurred in that students were placed in their classes with no consideration of this proposed study. Students were enrolled in their classes by computer with no consideration made as to assigning classes as control, treatment, or non-participating classrooms prior to student enrollment.

Teachers participating in this study met for training with the researcher during the weeks leading up to the unit of study to ensure that all procedures are understood and carried out correctly. All participants in the study had experience with inquiry learning and only needed to be trained in using the POGIL documents and methods.

Data Analysis

The independent variable in this nonrandomized pretest-posttest design is pedagogy (traditional method versus POGIL). The dependent variable is student alternate conceptions in particle theory. All data were analyzed using Statistical Package for the Social Sciences (SPSS) Version 19.

Similarity of groups. ANCOVA was used to compare the pretest and posttest results. ANCOVA was chosen to analyze the data since differences between the control and experimental groups can be controlled using this method.

Achievement. ANCOVA was used to analyze the data collected from the pretests and posttests for the control and experimental groups. Each null hypothesis, which states that there is no difference in the mean scores on the posttest for the groups, was considered at a significance level of $p < 0.05$.

CHAPTER FOUR: RESULTS

This chapter reports the results of the statistical analysis performed using IBM® SPSS version 19 on the data collected. As stated in Chapter One, the purpose of this study was to examine the effectiveness of process oriented guided inquiry learning (POGIL) in reducing alternate conceptions (AC) in the particulate nature of matter in secondary chemistry students. The independent variable was pedagogy, either traditional passive, teacher-centered lecture-style pedagogy or active, student-centered POGIL. The dependent variable was performance on the Particulate Nature of Matter Assessment, version 2 (ParNoMA2). The research questions and null hypotheses for this study are:

> *Research question 1*: What impact does the use of active, student centered process oriented guided inquiry learning (POGIL) have on secondary chemistry students' alternate conceptions in physical and chemical changes in matter related to particle theory in chemistry education when compared to traditional teacher-centered, lecture-style chemistry pedagogy?
>
> *Null hypothesis 1, H_o*: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by students who were taught using active, student centered process oriented guided inquiry learning (POGIL) pedagogy and students taught using traditional teacher-centered, lecture-style chemistry pedagogy.
>
> *Research question 2:* Is there a difference in the achievement gains between male and female students taught using process oriented guided inquiry learning (POGIL) methods and materials to teach physical and chemical changes in matter related to

particle theory in secondary chemistry when compared to traditional teacher-centered, lecture-style chemistry pedagogy?

Null hypothesis 2, H_o: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by female and male students who were taught using active, student centered process oriented guided inquiry learning (POGIL) pedagogy and male and female students taught using traditional, teacher-centered pedagogy.

Research question 3: Is there a difference in the achievement gains for minority students taught using process oriented guided inquiry learning (POGIL) methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional teacher-centered, lecture-style chemistry pedagogy?

Null hypothesis 3, H_o: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by minority students who were taught using active, student centered process oriented guided inquiry learning (POGIL) pedagogy and minority students taught using traditional teacher-centered, lecture-style chemistry pedagogy.

Approval to execute the research was received in January, 2011, from both Liberty University IRB and the school district in which the study was conducted (see Appendices C and D). The researcher informed the teacher participants that final approvals had been received and that they could administer the pretests when ready. The pretest Scantron answer sheets were returned to the researcher in early to mid February.

The data were analyzed using IBM SPSS version 19 (for complete data table, see Appendix E). ANCOVA was used to determine whether the posttest results for the control and experimental groups were different after the pretest scores were considered as a covariate. The assumption of equal regression slopes was confirmed by a between-subject test in which the interaction of the covariate (pretest) and the independent variable (group) was found to not be significant ($F(1,313) = 7.210$, $p > .05$). The Levene test of equality of variance indicates that the assumption of homogeneity of variance is tenable ($F(18,294) = 1.458$, $p > .05$).

Descriptive statistics were collected and an ANCOVA statistical test was used to determine if there was a significant difference in the performance on the posttest between the control and treatment groups with the pretest as a covariate. Differences in performance based on gender and race were investigated. Descriptive and inferential statistics were used to compare the outcomes for the control and treatment groups and are reported in this chapter.

Descriptive Statistical Analysis

Three hundred eighteen students completed this study, with 169 in the control group and 149 in the treatment group. Three students, of the original 321 who took the pretest, left their schools and did not complete the study. The sexes were each equally represented with 154 males and 159 females, which is 50.8% female and 49.2% male with five students not reporting their sex. Students who identified themselves as racial minorities made up 18.2% of the study. Three participants did not report their race.

Descriptive statistics for the ParNoMA2 pretest and posttest results by variable are listed in Table 1. The ParNoMA2 consists of 20 multiple choice questions designed to determine what, if any, AC students hold in regard to the PNM in secondary chemistry. Pretest and posttest means are out of a possible 20 correct answers.

The control group had a mean pretest score of 11.49 (*SD* = 4.298) and a posttest mean of 11.64 (*SD* = 3.798) which is an increase of .15 out of 20. The experimental group had a mean pretest score of 11.85 (*SD* = 3.868) and a posttest mean of 14.60 (*SD*=3.573) which is an increase of 2.75 questions answered correctly out of a possible 20. Descriptive statistics for pretest and posttest results are found in Table 1 which shows all groups with posttest scores higher than their pretest scores.

Table 1

Descriptive Statistics: Pretest and Posttest

	Pretest			Posttest		
Variable	*N*	*M*	*SD*	*N*	*M*	*SD*
Group						
Control	171	11.49	4.298	169	11.64	3.798
Experimental	150	11.85	3.868	149	14.60	3.573
Total	321	11.66	4.100	318	13.03	3.975
Gender						
Female	162	10.94	3.870	159	12.43	3.836
Male	156	12.44	4.205	154	13.68	4.065
Race						
African American	13	11.150	4.018	13	15.31	2.750
Asian	20	11.65	4.043	20	14.05	4.850
Hispanic	15	12.000	4.018	14	13.29	4.393
Caucasian	259	11.67	4.146	256	12.91	3.909
Other	12	11.17	4.398	10	11.00	4.163

Analysis of Covariance Results

An ANCOVA was conducted to examine the effect of POGIL on AC secondary chemistry students hold in relation to the PNM with a significance level of 0.05 for this analysis. The ANCOVA examined these effects:

(a) group (control vs. experimental)
(b) gender (female vs. male)
(c) race (African-American, Asian, Hispanic, Caucasian, other)
(d) interaction of group and gender
(d) interaction of group and race
(e) interaction of group, race and gender

Table 2 reports the findings of the ANCOVA in which the posttest was the dependent variable and the pretest results were entered as a covariate to correct for any differences in the control and experimental groups. Gender, race, and group (control or experimental) were entered as fixed factors.

Table 2

Test of Between Subject Effects with Dependent Variable: Posttest

Source	Type III Sum Of Squares	df	Mean Square	*F*	Sig	Noncen	Power
Corrected Model	2373.132	19	124.902	14.068	.000	267.297	1.00
Intercept	1212.290	1	1212.290	136.546	.000	136.546	1.00
Pretest	1235.323	1	1235.323	139.140	.000	139.140	1.00
Group	135.163	1	135.163	15.224	.000	15.224	.973
Gender	.104	1	.104	.012	.914	.012	.051
Race	58.484	4	14.621	1.647	.163	6.587	.504
group*gender	16.050	1	16.050	1.808	.180	1.808	.268
race*group	17.571	4	4.393	.495	.740	1.979	.168
gender*race	27.782	4	6.946	.782	.537	3.129	.250
group*gender*race	32.725	3	10.908	1.229	.299	3.685	.328
Error	2601.328	293	8.878				
Total	58210.000	313					
Corrected Total	4972.460	312					

Note. [a]R Squared = .477 (Adjusted R Squared = .443). [b]Computed using alpha = .05

As seen in Table 2, pretest scores were significantly related to posttest scores (F(1,312) = 139.140, $p < .0001$, *partial* $\eta^2 = .322$). Power was found to be 1.00 (very high) which indicates that the sample size is large.

Null hypothesis and research question one. This study was conducted to determine if POGIL helped students to learn chemistry in a way that reduced the number of AC they commonly hold related to particle theory in secondary chemistry. Research question one asked what impact does the use of active, student centered POGIL have on secondary chemistry students' AC in physical and chemical changes in matter related to particle theory in chemistry education when compared to traditional teacher-centered, lecture-style chemistry pedagogy? The first null hypothesis states that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by students who were taught using active, student centered POGIL pedagogy and students taught using traditional teacher-centered, lecture-style chemistry pedagogy.

Inferential statistics were used to test hypothesis one. The main effect for Group was significant (F(1,3132= 15.224, $p < .0001$, *partial* $\eta^2 = .049$) (see Table 2) with the POGIL group posttest estimated marginal mean of 14.866 (Std. error = .419) significantly higher than the lecture group posttest mean of 11.923 (Std. error = .569) (see Figure 5). Power was .973. The *partial* η^2 value of .049 indicates that 4.9% of students' gains were related to the teaching method.

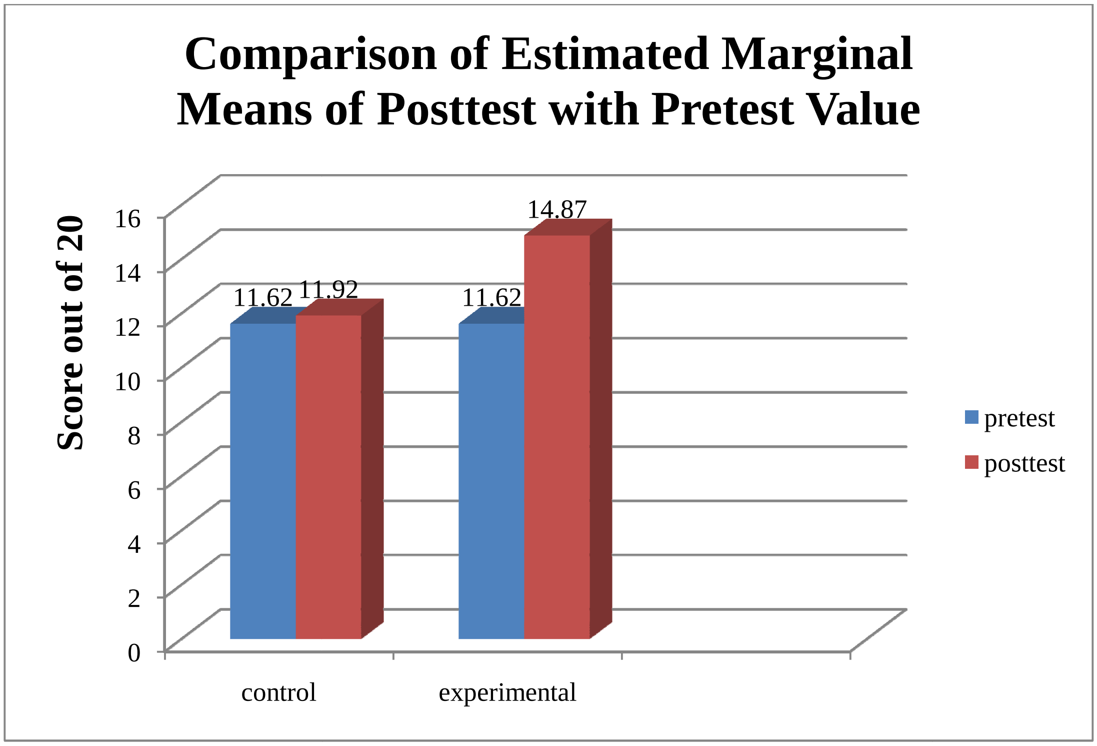

Figure 5. Comparison of Estimated Marginal Means of Posttest with Pretest Value. Pretest score as a covariate evaluated as 11.62.

Figure 5 shows that the experimental group's estimated marginal mean was greater on the posttest than the control group's. Figure 5 also shows that the control group made very little gain on the posttest as a result of the traditional teaching which is in sharp contrast to the gain made by the experimental group as a result of the POGIL pedagogy. Based on the results of the ANCOVA reported here, null hypothesis one, which stated that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by students who were taught using active, student centered POGIL pedagogy and students taught using traditional, teacher-centered pedagogy, was rejected.

Null hypothesis and research question two. Research question two considers the learning gains by gender and asks if there a difference in the achievement gains between male and female students taught using POGIL methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional chemistry pedagogy? The second null hypothesis states that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by female and male students who were taught using active, student centered POGIL pedagogy and male and female students taught using traditional, teacher-centered pedagogy. The main effect of gender was not significantly related to posttest scores (F(1,312)= .012, $p > .05$) with females having an estimated marginal mean of 13.270 (std. error .511) and males having a similar estimated marginal mean of 13.360 (std. error = .509) (see Table 3). Thus, student gains on posttest scores were not due to gender.

Table 3

Gender Posttest Estimated Marginal Means

			95% Confidence Interval	
Gender	Mean	Std. Error	Lower Bound	Upper Bound
Female	13.270^{a,b}	.511	12.265	14.276
Male	13.360^{a,b}	.509	12.359	14.361

Note . ^{a}Covariant, Pretest = 11.62. ^{b}Based on modified population marginal mean.

In order to determine if the gains made by the experimental group were greater for one gender than the other, the interaction of gender and group was tested and was not found to be significant (*F*(1,312)) = 1.808, $p > .05$) (see Table 2). The estimated marginal mean scores for males in the treatment group was higher than for females in the treatment group and higher than the estimated marginal mean for males in the control group (see

Table 4), but the difference was not statistically significant at the $p < .05$ level (see Table 2).

Table 4

*Group*Gender Posttest Estimated Marginal Means*

				95% Confidence Interval	
Group	Gender	Mean	Std. Error	Lower Bound	Upper Bound
Control					
	female	12.525^{a}	.774	11.001	14.048
	male	11.322^{a}	.837	9.674	12.969
Experimental					
	female	$14.202^{a,b}$	.617	12.988	15.416
	male	15.398^{a}	.572	14.272	16.524

Note . [a]Covariant, Pretest = 11.62. [b]Based on modified population marginal mean.

Figure 6 shows the effect of the interaction of gender and group on posttest scores. The gains of both male and female students in the experimental group can be seen in contrast to the lack of increase in posttest scores by both genders in the control group. In particular, the gain for male students in the experimental group is visible (see Figure 5).

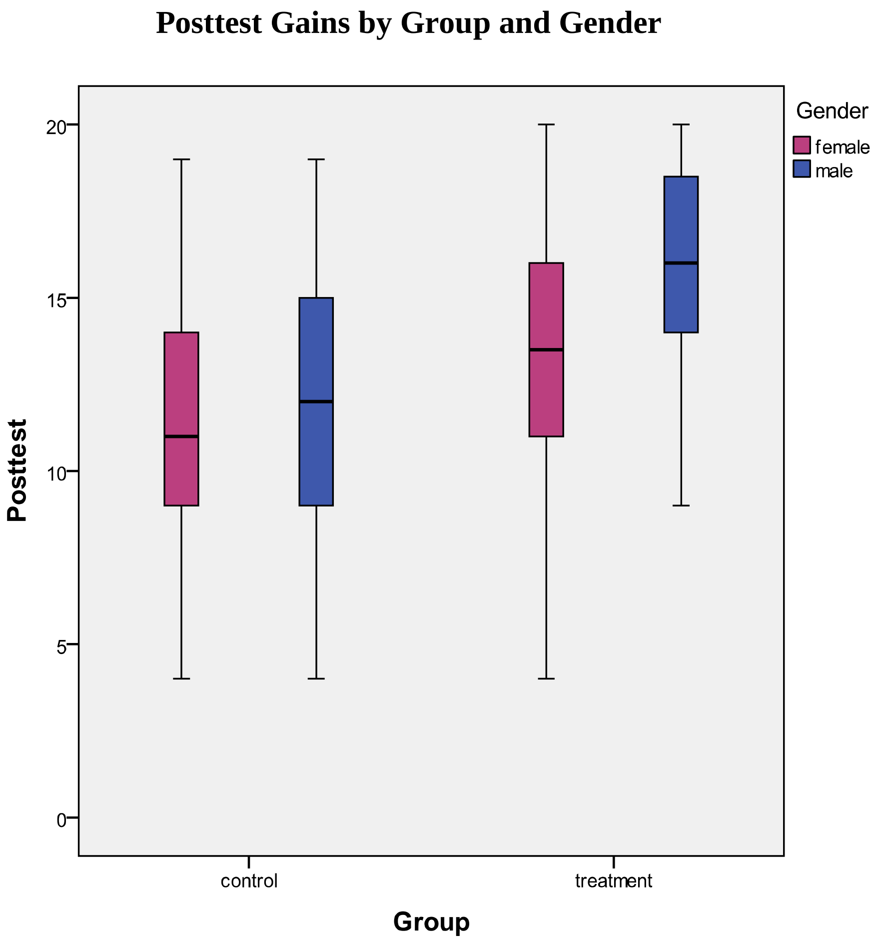

Figure 6. Posttest Gains by Group and Gender. The estimated marginal means of the control group males and females and experimental group males and females are shown.

Null hypothesis two which states that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by female and male students who were taught using active, student centered POGIL pedagogy and male and female students taught using traditional, teacher-centered lecture-style pedagogy was not rejected since the interaction of gender and group was found not to be significant at the $p < .05$ level.

Null hypothesis and research question 3. Learning differences between racial groups is considered in research question three. Hispanic and African-American students' academic achievement has been shown to be lower than their Caucasian and Asian peers

(Johnson, 2009). Research question three: Is there a difference in the achievement gains for minority students taught using POGIL methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional teacher-centered lecture-style chemistry pedagogy? The third null hypothesis states that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by minority students who were taught using active, student centered POGIL pedagogy and minority students taught using traditional teacher-centered, lecture-style chemistry pedagogy. The main effect of race was not significantly related to posttest scores (*F*(4,312) =1 .647, *p* >.05) (see Table 2). The estimated marginal means for each race subgroup are listed in Table 5. Differences in posttest scores are, therefore, not due to race.

Table 5

Race Posttest Estimated Marginal Means

			95% Confidence Interval	
Race	Mean	Std. Error	Lower Bound	Upper Bound
African American	15.042^{a,b}	1.032	13.012	17.073
Asian	14.019^{a}	.749	12.545	15.492
Hispanic	12.644^{a}	.860	10.951	14.337
Caucasian	13.124^{a}	.189	12.753	13.495
Other	11.239^{a,b}	.951	9.367	13.110

Note . [a]Covariant, Pretest = 11.62 [b]Based on modified population marginal mean.

The between-subjects effect of group*race was not significant (*F*(4,312) = .495, *p* >.05) (see Table 2). Table 6 lists the estimated marginal means for each group by race.

Table 6

*Group*Race Posttest Estimated Marginal Means*

Group	Race	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control					
	African American	13.778[a]	1.828	10.181	17.375
	Asian	12.951[a]	1.247	10.497	15.405
	Hispanic	11.575[a]	1.361	8.896	14.253
	Caucasian	11.834[a]	.246	11.350	12.319
	Other	9.478[a]	1.140	7.234	11.722
Treatment					
	African American	16.307[a]	.963	14.411	18.203
	Asian	15.087[a]	.829	13.455	16.718
	Hispanic	13.713[a]	1.054	11.637	15.788
	Caucasian	14.413[a]	.286	13.850	14.975
	Other	14.761[a,b]	1.728	11.360	18.161

Note . [a]Covariant, Pretest = 11.62. [b]Based on modified population marginal mean.

Table 6 shows that each racial subgroup in the experimental group posted higher estimated marginal mean scores than their peers in the control group on the posttest. These higher scores, however, were not statistically significant at the $p < .05$ level.

Table 2 shows that the interaction of group, gender, and race ($F(3,309) = 1.229$, $p > .05$) was not significant. Thus, there is no subset of participants defined by group, gender and race that produced results on the posttest that were significantly different from any other subset of participants.

Based on this evidence, null hypothesis 3, which states that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by minority students who were taught using POGIL pedagogy and minority students taught traditional teacher-centered, lecture-style chemistry pedagogy, was not rejected.

Summary

Chapter Four has presented a detailed report of the statistical analysis of this study. Data were analyzed using SPSS version 19 to perform an ANCOVA. Descriptive and inferential statistics were reported. The use of POGIL pedagogy to reduce the alternate conceptions held by chemistry students was supported and null hypothesis one was rejected. Students of all racial subgroups benefitted from POGIL instruction as did both male and female students, however, null hypotheses 2 and 3 were not rejected as the results were not significant at the $p < .05$ level.

CHAPTER FIVE: DISCUSSION

This chapter summarizes the study presented in the previous chapters and discusses the results. The chapter is divided into the following seven sections: summary, discussion, limitations, implications, Christian perspective of findings, recommendations for future research, and conclusion.

Summary

The purpose of this study was to investigate the effectiveness of POGIL pedagogy to reduce AC in particle theory held by secondary chemistry students when compared to AC held by students taught using traditional, teacher-centered lecture pedagogy. This study included over 300 high school chemistry students enrolled in four large suburban high schools and utilized a nonequivalent, control group, pretest-posttest design. The data were analyzed using ANCOVA and revealed that POGIL is effective in reducing the AC related to particle theory commonly held by secondary chemistry students.

Research question one and null hypothesis one. Research question one asked: What impact does the use of active, student centered POGIL have on secondary chemistry students' alternate conceptions in physical and chemical changes in matter related to particle theory in chemistry education when compared to traditional teacher-centered, lecture-style chemistry pedagogy? The null hypothesis stated: There is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by students who were taught using active, student centered POGIL pedagogy and students taught using traditional teacher-centered, lecture-style chemistry pedagogy. Based on the results of the ANCOVA, null hypothesis one was rejected. Students in the experimental group who were taught using POGIL documents and methods earned statistically significant higher posttest scores than the control group who were taught using traditional lecture pedagogy. Figure 5 clearly shows the statistically significant gain of the POGIL group as opposed to the very minimal gain of the traditional group.

Research question two and null hypothesis two. Research question two asked: Is there a difference in the achievement gains between male and female students taught using POGIL methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional teacher-centered, lecture-style chemistry pedagogy? The null hypothesis stated that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by female and male students who were taught using active, student centered POGIL pedagogy and male and female students taught using traditional, teacher-centered pedagogy. Based on the results of the ANCOVA, null hypothesis two was not rejected. The mean posttest scores for males and females in the POGIL group were higher than the mean posttest scores in the control group, but they were not statistically significant at the $p < .05$ level. POGIL methods did not appear to aid either sex more than the other.

Research question three and null hypothesis three. Research question three asked: Is there a difference in the achievement gains for minority students taught using POGIL methods and materials to teach physical and chemical changes in matter related to particle theory in secondary chemistry when compared to traditional teacher-centered, lecture-style chemistry pedagogy? Null hypothesis three stated that there is no statistically significant difference in the alternate conceptions related to particle theory in secondary chemistry held by minority students who were taught using active, student centered POGIL pedagogy and minority students taught using traditional teacher-centered, lecture-style chemistry pedagogy. Based on the results of the ANCOVA, null hypothesis three was not rejected. POGIL did not result in greater achievement for any racial group.

Discussion

A review of the literature reveals a dearth of information concerning effective secondary chemistry pedagogy. Conversely, numerous studies have been conducted over several decades on AC in science held by students. Despite the abundance of studies on AC in science, little progress has been documented in the struggle to rid students of AC. Of the many studies on AC, most have documented specific AC in chemistry held by students and some investigated conceptual change methods of teaching designed to correct AC. These studies have shown that AC are difficult to correct. Few studies exist which offer a pedagogical strategy for confronting AC specific to chemistry as this study has investigated. Recently, studies have been conducted to investigate the effectiveness of POGIL in college classes, but very few studies exist that examined secondary chemistry students. This study was conducted in order to add to the literature related to this important area of educational research.

This study found that POGIL methods were successful in reducing AC held by high school students. The *partial* η^2 value indicated that 4.9% of the difference between the experimental and control groups was due to pedagogy. This difference, while small, could be the beginning of greater chemistry achievement and understanding.

Consistent with previous studies on AC, this study found AC to be resistant to change. While students in the POGIL group showed greater achievement than their peers in the traditional group, all AC were not eradicated. The persistence of AC in particle theory for high school chemistry students is consistent with tenets of the neo-Piagetian theoretical framework for this study.

Theoretical framework. Consistent with dynamic skill theory, the study of the PNM in chemistry involves manipulating many ideas and concepts. As students learn, they weave together many elements from long-term memory and working memory, to create new mental models of abstract chemical phenomena. These abstractions cannot be observed, only modeled on paper, on a computer screen, by using analogies, or some other modeling technique. This process requires time and hard work by the student that is lacking in traditional pedagogy but is present in a POGIL classroom experience.

Johnstone's IPM explains that students must properly filter out extraneous information and focus on the pertinent facts concerning particle theory when learning chemistry. IPM and CLT hold that a person can mentally manipulate a limited number of ideas at once. Comprehending the behavior of atomic and molecular particles requires many abstract concepts to be manipulated in the working memory by the student. It is critical that students properly connect (as per DST and IPM) appropriate ideas to form schema that are stored in long-term memory, thereby reducing the working memory load.

Students in high school chemistry courses are still developing their abstract thinking abilities and are in need of the development of chemistry schemata. Understanding the behavior of particles at the level of atoms, molecules and ions requires abstract thought that neo-Piagetian theory suggests is still developing for students in their mid-teens. DST states that between the ages of 14 and 16 years, the age of most secondary chemistry students, humans are in the cognitive ability stage called abstract mappings. In this cognitive stage, students are able to link together separate abstract ideas and comprehend relationships between these connected thoughts. These connected abstract thoughts are then meshed to form a complex mental model, such as is required to comprehend the behavior of molecular and atomic particles that are changing phase. In order for students to fully comprehend, manipulate and use the particulate theory of matter, students must be able to form multiple abstract mappings to create systems of abstractions. This ability to form complex systems of abstract mappings does not fully emerge until the late teens.

Secondary chemistry students need the mental stimulation and practice of thinking about and forming systems of abstract mappings but they will not fully develop this ability for several more years. The persistence of AC in chemistry, as in this study, may be due to the fact that students are still developing the mental capabilities necessary to form the complex schemata required for abstract systems thought. This study has shown that POGIL lessons provide an appropriately supportive environment for the hierarchical development of the stages of abstract thought: abstract representation, abstract mapping, abstract systems and ultimately, the integration of abstract systems into abstract principles.

DST states that appropriate science schemata are built through active mental engagement of learners over an extended period of time during which the student must build, test, rebuild and retest their mental models. Furthermore, students must attach new learning to existing knowledge. This study has shown that the models provided in POGIL lessons provide familiar images that aid students in attaching new knowledge to existing knowledge while developing new, scientifically accurate chemistry schemata.

The support offered in the POGIL lesson documents, the discussions between students as they work through the models in the lessons, and the scaffolding offered by the teacher, provided the appropriate level of support necessary for students to operate at their optimal level, instead of struggling at their lower, functional level, which is typical of traditional classroom experiences. The process of building a mental model, testing it, refining it, rebuilding, and retesting by individual students takes time and effort. Schwartz (2009) stated that learning is slow and hard work, even in supportive environments. This study found that POGIL pedagogy provides the appropriate learning support to foster the development of scientifically accurate mental models of abstract chemistry concepts in secondary students.

In order for an AC to be corrected, students must confront a situation in which their AC-laden mental model fails. Due to the active participation required of students in the POGIL lessons involved in this study, students had the opportunity for their AC to be discovered and for their new knowledge to be constructed free of AC. Teachers act as facilitators in POGIL lessons. The teacher participants in this study had the opportunity to discover and address students' AC and assist students to form new mental models. Also, as students discussed the questions in the POGIL lesson documents and observed the models provided in the student lesson documents, participants were able to discuss their individual understandings of chemistry and work to correct their peer's AC.

Current findings and previous studies. Consistent with the findings at the college level, secondary students who were taught in POGIL classrooms performed better on chemistry assessments than their peers who were taught using traditional pedagogy in this study. Several studies report an upward shift in student test scores corresponding to one letter grade for students taught using POGIL instead of traditional pedagogy in college chemistry courses (P. Brown, 2010; S. Brown, 2010; Ferrell, Moog, & Spencer, 1999; Ruder & Hunnicutt, 2008). The similarities in those studies to this present study are presented in the following paragraphs.

Ferrell, Moog, and Spencer (1999) reported their study of undergraduate chemistry achievement at Franklin and Marshall College. They compared the grades earned by undergraduate students in general chemistry taught using POGIL pedagogy (fall 1994 – spring 1997) to students enrolled in previous years (fall 1990 – spring 1994) who were taught using traditional pedagogy. The instructors remained constant throughout the study. Their findings are presented in Table 7.

Table 7

Distribution of Undergraduate Chemistry Grades: POGIL vs. Traditional Pedagogy

Pedagogy	n	Percentage of Students Earning Grade						
		A	B	C	D	W	F	D+W+F
Traditional (F’90 – S’94)	420	19.3	33.1	25.7	9.0	9.3	3.6	21.9
POGIL (F’94 – S’97)	438	24.2	40.6	25.6	7.1	2.3	0.2	9.6

Note. Comparison of student course grades in undergraduate general chemistry taught using traditional pedagogy from fall 1990 until spring 1994 versus POGIL methods used from fall 1994 through spring 1997. Adapted from “A guided inquiry general chemistry course” by J.L. Farrell, R.S. Moog and J.N. Spencer, *Journal of Chemistry Education, 76*, 570 – 573.

As can be seen in Table 7, the percentage of students earning scores of D, W, and F decreased while the percentage of students completed the course with grades of A or B increased in response to POGIL. In the Ferrell, Moog and Spencer study, student achievement over the years was compared and the findings are similar to the findings in this current study of secondary chemistry students. Students taught using POGIL methods are more successful than students taught using traditional lecture pedagogy.

Hinde and Kovac (2001) applied POGIL strategies in physical chemistry courses at a large regional university. They found, as does this study, that students learned the material “more thoroughly” (p.93).

S. Brown (2010) reported moving away from traditional lecture pedagogy (fall 2007) to POGIL methods in the fall of 2008 and 2009 in the medicinal chemistry courses she taught. She reported an upward shift from most students earning course grades of B-C to the majority of students earning in the A – B range. This upward shift in achievement for POGIL students is similar to the findings in this study.

P. Brown (2010) utilized POGIL methods to teach an undergraduate anatomy and physiology course at a small liberal arts college. He reported an increase in students’ scores on chapter exams, the comprehensive final and overall course grades. Three semesters after implementing POGIL, the mean course average rose 23%. The results of this present study are less dramatic, but are consistent with the positive findings reported by P. Brown. Of particular interest is that P. Brown describes the institution where his study was conducted as a diverse student population. Like the secondary school study presented here, he reported achievement gains for students of all races.

Another study featuring a diverse student population is the Ruder and Hunnicutt (2008) study. These researchers utilized POGIL to teach both general chemistry and organic chemistry at a large, ethnically diverse suburban university with results similar to this present secondary chemistry study and the P. Brown study. Ruder and Hunnicutt compared pre-POGIL chemistry student achievement (fall 2002) to post-POGIL implementation (fall 2003 and fall 2004) achievement. They reported improvement in test scores and greater retention of material.

The result of this present study of secondary chemistry achievement reveals results similar to the college studies mentioned in which greater achievement is observed for all students, regardless of gender or race, when POGIL instruction replaces the traditional lecture format. Figure 7 illustrates the gains made by all races in each group. It is interesting to note that all races, regardless of group, posted higher posttest scores, but some were only slightly higher. Hispanic and Caucasian students showed very little gain in the traditional group while all races showed greater gains in the POGIL group.

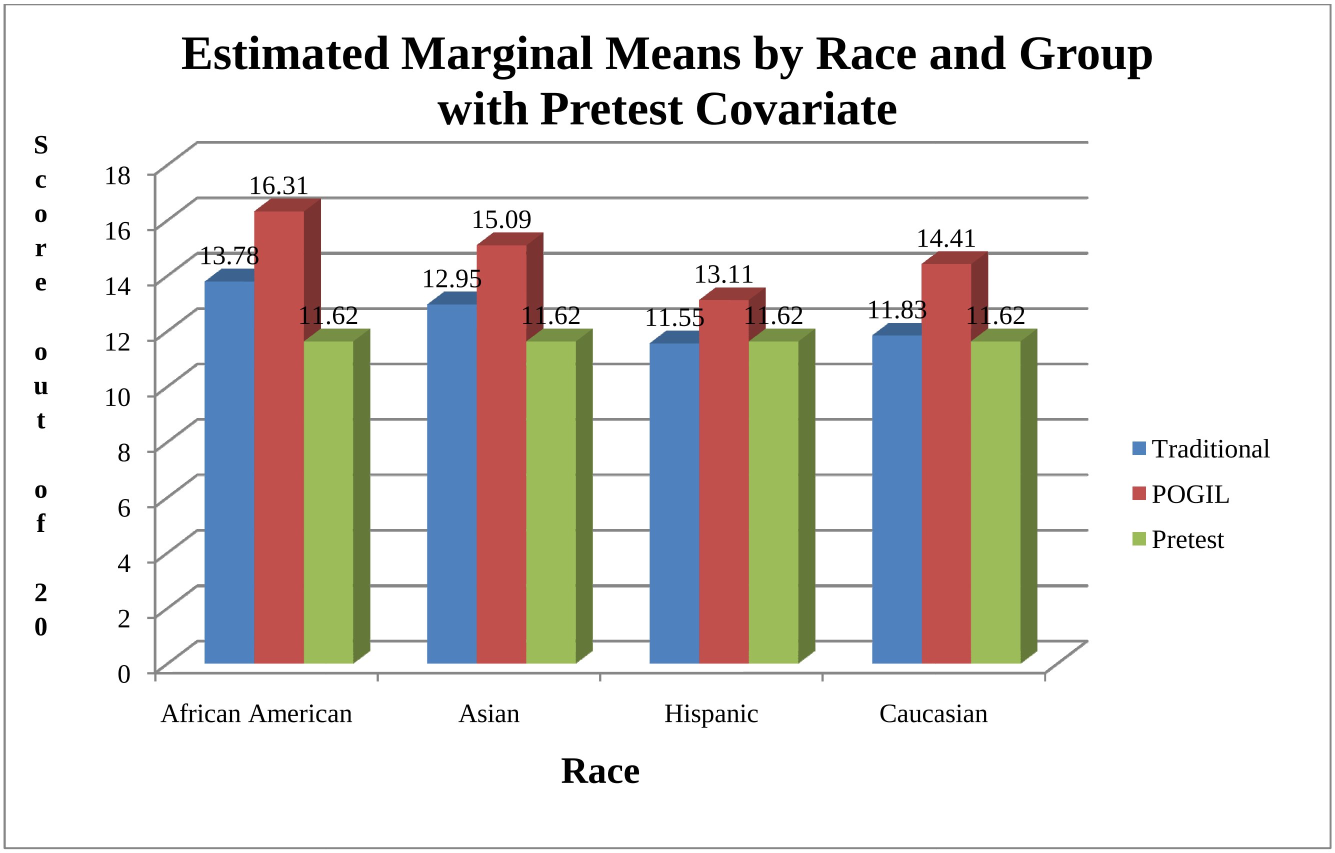

Figure 7. Estimated Marginal Means by Race and Group with Pretest Covariate. The pretest covariate estimated value is 11.62.

Figure 7 shows that all students, regardless of race, posted gains in the POGIL group that were greater than the traditional group, even though they were not statistically significant at the $p < .05$ level. Of particular interest is the gain posted by the African-American group. The African-American students, when compared to the other races, recorded the highest mean in both the traditional and POGIL groups, compared to the pretest estimated covariate model of 11.62. African-American students in the POGIL group posted the highest posttest estimated marginal mean. This finding indicates that POGIL could provide a conduit for addressing the racial achievement gap.

The mean score for all students in the POGIL group for this study was 14.8% higher than the posttest mean for the traditional group. This increase equates to approximately one letter grade higher for the POGIL group than the grade earned by the traditional group students, which is in agreement with the college studies mentioned.

The findings of this study are consistent with previous college POGIL studies in that POGIL proved effective for all subgroups. Both female and male students and all racial groups studied showed gains. No one subgroup showed a greater gain than any other group. This finding suggests that POGIL could be effective in addressing the racial achievement gap. Currently, Hispanic and African-American students' academic achievement lags behind their Caucasian and Asian peers. Further studies addressing the use of POGIL methods to address this achievement gap are needed.

Cooperative learning, models, and guided inquiry. POGIL is based on cooperative learning strategies. This study found, as many other studies of cooperative learning have found (Bilgin & Geban, 2006; Köse, Şahin & Gezer, 2010) that this particular cooperative learning approach had a more positive impact on student achievement than did a traditional lecture approach. The extent to which the cooperative learning aspect of POGIL was responsible for student gain is difficult to determine. Cooperative learning is an integral aspect of POGIL pedagogy, as is the use of models to reduce the abstract nature of the topics and guided inquiry to stimulate high order thinking. The strength of the POGIL approach is that it incorporates all of these critical components; cooperative learning, guided inquiry, and the use of models, to support student learning.

Students in the POGIL cooperative learning groups worked as a team to learn chemistry. Communication among the members of the team was an integral part of every lesson. By working as a team, students grew in their abilities to manage their time and interactions with each other in order to optimize learning. Each group knew that the teacher would soon be calling on their group to summarize their findings. Students were internally motivated to self-assess and check their understandings of the topics being studied during the lesson in order to be prepared to provide an accurate summary of their group's work. With each member of the POGIL group assigned a role, students were accountable to each other and grew in their ability to function as an important member of a team.

Limitations

This study utilized a nonrandomized pretest-posttest design. The lack of randomization is a limitation of this study. Lack of randomization was controlled for by selecting schools which register students by computer. Students were placed in their respective classes with no regard to participation in this study. Since each participating school had other science classes which did not participate in this study, students were equally likely to be excluded from this study as included. In addition, differences in the control and experimental group were controlled by the use of ANCOVA in which a pretest was used as the covariant. External validity was controlled for by the large number of participants.

This study had limited participation by African-American, Hispanic, and Asian students. The percentages of student participants in each racial subgroup were similar to the local population which has a smaller minority population than in some other regions of the country. Another limitation of this study is that no completely urban or rural schools were studied. The schools studied were all suburban schools. Although many students in this study are from formerly middle class families, a broad range of socioeconomic situations permeate the area at this time due to recent economic issues.

This limitation necessitates further studies of students in urban and rural areas as well as economically disadvantaged students.

The length of time teachers and student used POGIL methods was limited to less than one semester of the school year. POGIL methods were used to teach concepts related to the PNM only. The full impact of POGIL methods would be better measured if students had been taught the entire school year using POGIL pedagogy in the experimental group over all chemistry topics. Further studies of the use of POGIL in secondary chemistry classrooms for a larger percentage of the school year are needed.

Implications

In light of the findings of this study, POGIL is an effective method for teaching concepts related to the PNM and was shown to reduce the number of AC held by secondary chemistry students. All students, male and female, benefited from POGIL methods.

POGIL methods were effective in reducing the achievement gap between racial subgroups. In stark contrast to most studies of academic achievement, POGIL provided the same, or greater, achievement gain for African-American and Hispanic students as were seen in Caucasian and Asian students.

It is important to note that all alternate conceptions held by secondary students in this study were not eradicated. Like other AC studies, this present study found AC resistant to change, but progress was made. The number of AC held by students in the POGIL group was found to be 14.8% fewer than for the traditional group. For this reason, POGIL offers a method for teaching chemistry to students that reduces AC.

Some of the AC held by students that were resistant to change in this study, despite the use of POGIL methods, can be explained by DST. Some students might still be developing the cognitive ability to develop the abstract mappings chemistry studies require. The ability to manipulate abstract thought and develop appropriate schemata in chemistry requires that students have an emotionally safe environment in which to build, test, and solidify their new chemistry schema. The cooperative nature of a POGIL learning group provides the appropriate environment for students to develop these cognitive skills.

An integral aspect of POGIL pedagogy is cooperative learning which has been shown to be more effective in improving student achievement than traditional pedagogy in science classes. The gains shown by the students in the POGIL group in this study could be the result of the cooperative learning and not POGIL. Since it is impossible to extract cooperative learning from POGIL pedagogy, this study, at the very least, has shown that POGIL pedagogy is an effective vehicle for creating a cooperative learning environment. The other aspects of POGIL, such as the use of guided inquiry and the incorporation of models of many types to reduce the abstract nature of chemistry, have also been shown to aid student achievement. POGIL, therefore, brings together best practices of science teaching for students in secondary chemistry classes.

In light of the findings of the few studies on POGIL in science classrooms, POGIL methods should become a part of science teacher preparation programs in colleges of education. Aspiring science teachers need to be trained in POGIL philosophy, methods and lesson development. POGIL training workshops for in-service teachers is currently offered on a limited basis and needs to be expanded to professional development workshops available to more teachers.

Christian Perspective and Theory of Mind

The neo-Piagetian understanding of the development of abstract thinking abilities over time is in keeping with Paul’s observation in 1 Corinthians when he wrote “When I was a child, I talked like a child, I thought like a child, I reasoned like a child. When I became a man, I put childish ways behind me” (1 Corinthians 13:1, NIV). Clearly, there is an understanding that humans develop the ability to think and reason over time, thus not reaching maturity in thinking or reasoning ability until adulthood. Students must have opportunities to put away their childhood understandings of science and develop mature, scientifically accurate understandings of chemistry. Since the ability to think abstractly and to function at the abstract mapping level, is domain specific, it is critical that students have multiple opportunities spread over time, to develop their science process skills and content knowledge.

In the United States, students are not exposed to science lessons as early or as often as in other nations. In the U.S., science instruction usually does not begin in earnest until after elementary school (Appleton, 2003; Century, Rutnick, & Freeman, 2008; USDOE, 1999). This delay to begin teaching science is in sharp contrast with Finland, Japan and China, countries which consistently post the highest science achievement scores on international comparison tests such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) (Lavonen & Laaksonen, 2009). From 2002 until 2006, only reading and math were required to be tested by No Child Left Behind (NCLB) legislation in the United States.

Due to the high-stakes nature of NCLB accountability testing, many schools began focusing their efforts on teaching reading and math, at the expense of other subjects. Time spent teaching science in elementary schools decreased, and in some cases, was eliminated (Gunzenhauser, 2003; Levy, Pasquale & Marco, 2008; Winters, Trivitt, & Greene, 2010). The Center on Education Policy reported that since NCLB took effect in 2002, the time spent on English Language Arts (ELA) and math has increased by an average of 43 percent. Fifty-three percent of the districts that reported increasing time for ELA or math, also reported that they decreased the amount of instructional time spent on science by an average of 75 minutes per week. Some elementary school teachers report that their principals told them not to teach science at all but to focus on reading and math (Winters, Trivitt, & Greene, 2010).

Students who have no science instruction in elementary school do not have an adequate skill set from which to pull when they reach high school chemistry. Educators in the United States have known for some time that students in countries that value science education in the elementary and middle school years are producing students who perform well on the PISA and TIMSS science tests. As stewards of the trust God has given Christian adults as parents, teachers, and educational policy makers, Godly men and women must provide appropriate opportunities for children to develop science process skills and content knowledge. Isaiah 48:17 says, “I am the Lord your God who teaches you what is best for you, who directs you in the way you should go” (NIV). This verse considered along with Proverbs 16: 22 which states “understanding is a fountain of life to those who have it” (NIV) indicate that Christian leaders in education have a responsibility to provide appropriate educational opportunities for students in light of what is now understood about how children learn and how abstract thinking skills develop over time. Advances in mind, brain, and education research now allow educators to know that students must have time and practice to develop science skills. It is not wise to ignore this need of students if the Christian community is to heed Proverbs 22:6 which states we are to "train a child in the way he should go" (NIV).

It is interesting to note that the understanding that knowledge is domain specific is accepted by philosophers who specialize in the theory of mind. Peter Carruthers, a professor of philosophy and chair of the department of philosophy at the University of Maryland has written extensively on the theory of mind. He states that, "...(the mind) can take any content as *input*, but it cannot, in the course of processing that input, draw on anything other than the contents of its own proprietary domain-specific memory store" (p. 80). He further states that comprehending the human mind and how it functions is a difficult task. He asks, "…who ever thought that the architecture of the mind could be conquered in a day?" (p.87). Carruthers statements are in complete agreement with dynamic skill theory. In the field of science education, educators should learn from leading scholars in other fields. In this case, educators and philosophers alike must accept that comprehending how the human mind learns is very difficult, after all, the human mind is "fearfully and wonderfully made" (Psalm 139:14, NIV).

Another noted philosopher and theory of mind scholar, David Papineau (2003), wrote "the standard metaphor is that of the human mind as a Swiss Army knife, containing a number of tools each designed to perform some definite task" (p.161). The human mind is indeed created to perform many specific tasks. One of the most exciting and fulfilling tasks the human mind can pursue is the study of God's creation, which is the study of science. The attempt to gain understanding of the natural laws God ordained for this temporal world is both difficult and fulfilling. Throughout Proverbs, Godly men and women are encouraged to search for truth and gain understanding. The study of chemistry is a specific task, which the mind of man was created to comprehend. It is imperative that Christian educators continue to search for the most effective methods to teach what is understood about God's laws in science. Preparing educational opportunities that are in accordance with what is understood about the human brain and mind is wise and prudent as well as obedient to God's teachings.

Psalm 85:13 states that "righteousness goes before him and prepares the way for his steps" (NIV). Just as God's righteousness goes before the Godly man and woman to prepare the way, Christian educators should go before their students to prepare the way as students step into science knowledge and understanding. POGIL lessons provide necessary components for students to better be able to develop chemistry understandings free of alternate conceptions.

Recommendations for Future Research

Students in this study were taught using POGIL methods for a part of the school year. During that limited time, their achievement increased due to the pedagogy. Future studies are needed to determine if POGIL methods utilized over the course of the year would increase student achievement due to AC being confronted and corrected.

Further study is needed to determine if the gain on the ParNoMA2 will persist over time. Studies have found that AC that were thought to be corrected can return for some students after a period of time (Çalýk, Ayas, & Ebenezer , 2005). The question of the durability of the accurate mental models created in the POGIL environment should be investigated.

This study investigated AC related the particle theory of matter. Further studies of the reduction of AC in chemistry topics other than particle theory are needed. POGIL documents for secondary biology are being developed and studies are needed to determine the effectiveness of these materials and methods in biology classes.

POGIL pedagogy began in college classrooms and spread to the high school due to the frequency of students in college POGIL courses who stated that they believed they would be more successful in college chemistry courses if they had been taught in a POGIL environment in their high school chemistry courses (Hanson, 2006). Further studies are needed to determine whether students taught in POGIL environments in high school are more successful in college chemistry than students who were taught high school chemistry by the traditional method. Several studies (Schwartz, 2009; Schwartz, Sadler & Tai, 2008; Tai, Sadler & Mintzes, 2006) indicate that students taught using POGIL should perform better in college chemistry, but studies are needed to determine if POGIL does provide a superior foundation for future chemistry studies.

The active engagement of students in POGIL pedagogy provides unique opportunities for students to develop the process skills of science. A study of the development of process skills utilized in POGIL is needed to determine the level of growth in process skills experienced by students in POGIL based classrooms as opposed to traditional classroom experiences. An investigation into the development of those process skills and how they enhance other academic endeavors beyond the acquisition of chemistry knowledge is needed.

Conclusions

This study found that POGIL pedagogy resulted in fewer AC in secondary chemistry students as compared to students taught using traditional methods. POGIL pedagogy is a promising option for chemistry teachers searching for effective teaching methods which result in a reduction of AC held by their chemistry students in regard to particle theory. The literature available offers few insights on effective methods for improving achievement in high school chemistry.

This study indicates that POGIL methods could prove to be effective in addressing the achievement gap often seen between African-American and Hispanic students and their Caucasian and Asian peers. Both male and female students benefitted from POGIL instruction as opposed to traditional pedagogy.

Theory of mind philosophers, scholars in education, and the ancient writers of the Bible agree that that human mind is a complex and magnificent creation. Only now in the 21st century are experts beginning to understand how the human mind matures, functions and learns. Christian educators must avail themselves of all possible resources and information related to teaching and learning in order to properly prepare students to study complex subjects such as chemistry. Dynamic skill theory explains that students must have long-term exposure to complex science skills in order to develop their own mental models of science concepts free of AC. This study shows that POGIL provides a superior learning environment for the development of science concepts free of AC when compared to lecture pedagogy.

POGIL pedagogy brings together several best practices in science and chemistry teaching. Every POGIL lessons engages students in these best practices for learning chemistry:

- a cooperative learning environment where students discuss their ideas, confront their lack of understanding, and negotiate meaning as concepts are discovered and personal mental models are being formed;
- structured use of many types of teaching models;
- consistent use of higher order thinking skills;
- integration of process skills into the acquisition of chemistry content;
- differentiation of instruction from the traditional lecture method to an active, student centered approach, which allows for differentiation of content, product and process, and
- teachers facilitate content mastery as opposed to content coverage.

This study was conducted to provide much needed information to assist high school chemistry teachers as they plan for effective teaching. Further studies of the effectiveness of POGIL in teaching topics other than particle theory are needed at the secondary level. The results of this study suggest that POGIL pedagogy provides appropriate learning support to foster the development of scientifically accurate mental models of abstract chemistry concepts in secondary students. This study also suggests that POGIL pedagogy could be effective in reducing or eliminating achievement gaps frequently found between racial groups and the gender achievement gap.

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APPENDICES

Appendix A: Correlation of POGIL materials to Georgia Department of Education Chemistry Curriculum Map

Appendix B: Study Timeline

Appendix C: Local Consent Form

Appendix D: Liberty University IRB Approval

Appendix E: Data Table

Appendix A: Correlation of POGIL materials to Georgia Department of Education Chemistry Curriculum Map

GDOE Chemistry Curriculum Map 3rd and 4th Quarter, Chemistry Standards	**POGIL High School Chemistry Classroom Activities**
SC1 Students will analyze the nature of matter and its classifications. c. Predict formulas for stable ionic compounds (binary and tertiary) based on balance of charges. d. Use IUPAC nomenclature for both chemical names and formulas: •Ionic compounds (Binary and tertiary)	Chemical Formulas and Names of Ionic Compounds
SC2 Students will relate how the Law of Conservation of Matter is used to determine chemical composition in compounds and chemical reactions. a. Identify and balance the following types of chemical equations: • Synthesis • Decomposition • Single Replacement • Double Replacement • Combustion	Shall We Dance?—Classifying Types of Chemical Reactions Balancing Chemical Reactions
SC6. Students will understand the effects motion of atoms and molecules in chemical and physical processes. a. Compare and contrast atomic/molecular motion in solids, liquids, gases, and plasmas. b. Collect data and calculate the amount of heat given off or taken in by chemical or physical processes. c. Analyzing (both conceptually and quantitatively) flow of energy during change of state (phase). **SC5. Students will understand that the rate at which a**	Kinetic Molecular Theory Vapor Pressure Phase Changes

chemical reaction occurs can be affected by changing concentration, temperature, or pressure and the addition of a catalyst. a. Demonstrate the effects of changing concentration, temperature, and pressure on chemical reactions. b. Investigate the effects of a catalyst on chemical reactions and apply it to everyday examples. c. Explain the role of activation energy and degree of randomness in chemical reactions.	Collision Theory – Impact for a Chemical Reaction Dynamic Equilibrium: Which Way Do We Go?

Appendix B: Timeline

Pre-test in January

POGIL lessons-January – May

Posttest, week of May 9 - 13

Appendix C: Local Consent Form

REQUEST FOR PERMISSION TO CONDUCT DATA COLLECTION ACTIVITIES WITHIN THE SYSTEM

Name_______Michelle J. Barthlow__________________
CCSD Employee: Yes _X__ No ____ If ***NO***, list employer: ______________________
College/University Supervising Activities___Liberty University____________________
Degree in Progress(Level/Area)_Doctor of Education, Teaching and Learning_______
Locations for Data Collection __High Schools A, B, C, and D
Date of Request_Dec. 1, 2010 Requested Dates for Data Collection January 2010 and May 2010
Professor's Name _Dr. Scott Watson_____________ Phone #/Email _swatson@liberty.edu
Phone/email for M. Barthlow: 770 926-4411 (work), 770 833-6657 (cell)
michelle.barthlow@cherokee.k12.ga.us

Include with this request:

- A letter from your supervising professor on college or university letterhead indicating support for your research and his/her confirmation of data collection validity.
- A brief summary of the issues being researched and the type of data collection you are requesting to conduct. (Page 2 of this form).
- Method of data collection assessment (Page 2 of this form); Number of respondents, etc.
- Copy of interview questions, surveys, etc. that will be used. If student data is used, a notarized "Release of Educational Records for Research Purposes Confidentiality Statement" will be required.
-

I,__Michelle J. Barthlow___ do hereby submit to **not** hold the Cherokee County School System liable for any findings, or commentary involved in this research. I understand that without the express written permission of the Cherokee County Board of Education, I am not authorized to conduct any data collection involving system employees or students and/or any other information that is protected by Federal or State Law. **Furthermore, a copy of all findings and data collection instruments will be made available to the Cherokee County Board of Education. All research is to be sent to the Office of Assessment upon completion of the project.**

Signature____ Date Dec. 1, 2010
Send completed form to: Dr. Susan Padgett-Harrison, Director, Office of Assessment, ESA, Building G, 1010 Keeter Road, Canton, GA 30114 (770 721-6206)

Staff Use Only

____ _________ Permission given
_________ Permission denied
Office of Assessment

Conditions of Permission: Denied due to:

Please write a brief summary of the issues being researched and the type of data collection you are requesting to conduct.

______ The study proposed is a nonequivalent control group, pretest-posttest design to investigate student achievement in high school college preparatory chemistry. This study will investigate the use of Process Oriented Guided Inquiry Learning (POGIL) in the teaching of secondary chemistry. Students at Millard, Rogers, Taylor and Orion High Schools will take the Particulate Nature of Matter Assessment (ParNoMA) version 2 as a pretest before being taught concepts relating to the kinetic theory of matter as indicated in the Georgia Department of Education Chemistry Georgia Performance Standards (pseudonyms will be used for participating schools). The GPS states that inquiry methods should be utilized to teach chemistry, and yet, many teachers do not have access to high quality guided inquiry materials. This study will provide participating teachers with the training and materials needed for students in high school chemistry courses to experience quality, guided inquiry lessons. One chemistry teacher at each high school will participate and give the ParNoMA as a pretest and a posttest in the second semester. Only students in the treatment groups (Woodstock High and Sequoyah High) will utilize the POGIL methods and materials. Students taking the pretest and posttest as Cherokee High and Creekview High will serve as the control groups and will not utilize the POGIL materials (see sample materials attached).

_____ All POGIL documents have been correlated to the Chemistry GPS (see attached correlation document attached).

___Since this study is designed to only measure the effectiveness of guided process oriented guided inquiry in groups of students (not individual students), individual student identities will be strictly guarded as will the names of the participating schools. The statistical analysis will be ANCOVA to determine student gains for the experimental and control groups.____

Indicate your method of data collection assessment (surveys, interviews, and/or test data)
_____________ Students will take the Particulate Nature of Matter Assessment (ParNoMA) version 2 as a pre-test and posttest (see attached).____

Check the appropriate box(s) which indicate respondents:

☐ Administrators

☐ Teachers/Certified Personnel

☐ Classified Personnel

X Students

Note the number of data collection instruments being used (i.e., number of expected respondents)
_Approximately 200.____

Appendix D: Liberty University IRB Approval

IRB Approval 1044.012711: The Effectiveness of Process Oriented Guided Inquiry Learning to Reduce Alternate Conceptions in Secondary Chemistry Education

IRB, IRB
Sent: Thursday, January 27, 2011 11:34 AM
To: Barthlow, Michelle Jones
Cc: Watson, Scott; IRB, IRB; Garzon, Fernando

Attachments: Annual Review Form.doc (34 KB); Change in Protocol.doc (32 KB)

Good Morning Michelle,

We are pleased to inform you that your above study has been approved by the Liberty IRB. This approval is extended to you for one year. If data collection proceeds past one year, or if you make changes in the methodology as it pertains to human subjects, you must submit an appropriate update form to the IRB. Attached you'll find the forms for those cases.

Thank you for your cooperation with the IRB and we wish you well with your research project. We will be glad to send you a written memo from the Liberty IRB, as needed, upon request.

Sincerely,

Fernando Garzon, Psy.D.
IRB Chair
Associate Professor
Liberty University
1971 University Blvd.
Lynchburg, VA 24502
(434) 592-4054

Appendix E: Data Table

Student	Gender	Pretest	Posttest	Race	School	Group
1	2	15	17	5	1	2
2	1	15	13	4	1	2
3	2	19	19	4	1	2
4	1	10	13	4	1	2
5	2	16	19	3	1	2
6	2	5	10	4	1	2
7	1	18	15	1	1	2
8	2	7	12	4	1	2
9	2	19	18	4	1	2
10	1	15	19	1	1	2
11	1	11	11	4	1	2
12	2	10	10	4	1	2
13	2	12	13	4	1	2
14	1	12	17	4	1	2
15	1	7	12	4	1	2
16	2	13	14	4	1	2
17	1	11	12	4	1	2
18	2	11	14	2	1	2
19	2	14	13	4	1	2
20	1	13	13	1	1	2

Student	Gender	Pretest	Posttest	Race	School	Group
21	2	16	14	3	1	2
22	1	19	20	4	1	2
23	2	14	12	4	1	2
24	1	9	9	4	1	2
25	1	15	19	4	1	2
26	2	15	17	3	1	2
27	2	9	11	4	1	2
28	2	18	15	4	1	2
29	2	13	14	4	1	2
30		5	9	5	1	2
31	2	16	17	4	1	2
32	1	6	9	4	1	2
33	1	8	13	4	1	2
34	2	14	17	4	1	2
35	1	13	16	4	1	2
36	1	15	15	4	1	2
37	11	13	5	1	4	2
38	2	16	18	5	1	2
39	1	11	15	1	1	2
40	2	16	16	4	1	2
41	1	6	12	1	1	2
42	1	11	16	4	1	2

Student	Gender	Pretest	Posttest	Race	School	Group
43	2	9	12	4	1	2
44	1	7	11	4	1	2
45	2	9	11	3	1	2
46	2	14	15	4	1	2
47	1	14	15	4	1	2
48	1	13	14	4	1	2
49	1	10	11	4	1	2
50	2	8	12	4	1	2
51	1	5	11	4	1	2
52	2	12	14	1	1	2
53	2	8	16	4	1	2
54	1	8	9	4	1	2
55	2	11		3	1	2
56	1	13	13	4	1	2
57	2	14	15	3	1	2
58	1	9	9	3	1	2
59	1	10	12	4	1	2
60	2	18	19	4	1	2
61	1	8	10	4	1	2
62	1	8	9	4	1	2
63	2	17	17	4	1	2
64	1	11	10	4	1	2

Student	Gender	Pretest	Posttest	Race	School	Group
65		14	10	4	1	2
66	2	17	17	1	2	1
67	2	16	16	4	2	1
68	2	14	14	4	2	1
69	2	19	13	4	2	1
70	1	14	14	4	2	1
71	2	13	4	4	2	1
72	1	9	12	4	2	1
73	1	17	17	4	2	1
74	1	11	16	4	2	1
75	1	17	7	4	2	1
76	1	17	10	4	2	1
77	2	12	10	4	2	1
78	1	19	11	4	2	1
79	1	14	14	4	2	1
80	1	13	11	4	2	1
81	1	7	7	4	2	1
82	1	17	16	4	2	1
83	1	11	16	4	2	1
84	1	11	7	4	2	1
85	2	10	4	2	2	1
86	2	13	7	5	2	1

Student	Gender	Pretest	Posttest	Race	School	Group
87	1	7	7	5	2	1
88	1	8	15	4	2	1
89	2	7	7	4	2	1
90	2	13	5	4	2	1
91	1	15	17	4	2	1
92	1	12	16	4	2	1
93	1	19	15	4	2	1
94	1	19	17	4	2	1
95	1	16		4	2	1
96	2	11	12	4	2	1
97	2	10	8	4	2	1
98	2	7	8	4	2	1
99	2	11	13	4	2	1
100	2	15	11	4	2	1
101	1	6	12	4	2	1
102	1	10	12	4	2	1
103	1	16	15	4	2	1
104	1	14	14	4	2	1
105	1	13	11	4	2	1
106	1	5	9	5	2	1
107	1	9	11	4	2	1
108	2	11	9	4	2	1

Student	Gender	Pretest	Posttest	Race	School	Group
109	2	6	9	4	2	1
110	1	10	10	4	2	1
111	1	7	6	4	2	1
112	1	10	9	4	2	1
113	2	17	9	4	2	1
114	2	16	8	5	2	1
115	2	13	10	5	2	1
116	2	8	11	4	2	1
117	1	12	9	4	2	1
118	2	5	6	4	2	1
119	2	10	7	4	2	1
120	2	10	11	4	2	1
121	1	12	17	4	2	1
122	1	10	16	4	2	1
123	1	11	9	4	2	1
124	1	13	8	4	2	1
125	1	13	16	2	2	1
126	1	14	13	4	2	1
127	1	13	10	4	2	1
128	1	14	14	4	2	1
129	1	9	8	4	2	1
130	2	16	17	4	2	1

Student	Gender	Pretest	Posttest	Race	School	Group
131	2	10	14	2	2	1
132	1	11	14	4	2	1
133	2	10	16	4	2	1
134	2	7	9	4	2	1
135	2	19	17	4	2	1
136	2	14	18	4	2	1
137	1	16	17	4	2	1
138	2	20	4		2	1
139	1	6	13	3	2	1
140	1	5	4	4	2	1
141	2	12	13	4	2	1
142	2	14	14	3	2	1
143	1	11	10	4	2	1
144	2	13	16	4	2	1
145	2	10	12	4	2	1
146	1	11	11	5	2	1
147	2	4	16	4	2	1
148	2	12	16	4	2	1
149	2	7	8	5	2	1
150	1	9	7	4	2	1
151	2	18	17	4	2	1
152	2	19	1	7	4	1

Student	Gender	Pretest	Posttest	Race	School	Group
153	2	10	9	4	2	1
154	2	18	16	4	2	1
155	2	3	13	4	2	1
156	2	1	15	4	2	1
157	2	17	17	4	2	1
158	1	12	15	4	2	1
159	1	12	10	4	2	1
160	1	13	10	4	2	1
161	1	3	8	4	2	1
162	2	10	10	4	2	1
163	2	16	17	4	2	1
164	1	8	9	4	2	1
165	2	13	7	4	2	1
166	1	11	11	1	2	1
167	2	16	7	4	2	1
168	2	8	6	4	2	1
169	1	9	9	4	2	1
170	1	16	16	4	2	1
171	1	6	6	4	2	1
172	1	8	11	4	2	1
173	2	14	15	4	2	1
174	2	12	12	2	2	1

Student	Gender	Pretest	Posttest	Race	School	Group
175	2	4	11	4	2	1
176	2	16	11	4	2	1
177	2	7	12	4	2	1
178	2	15	13	4	2	1
179	2	6	12	4	2	1
180	2	10	13	4	2	1
181	2	18	13	4	2	1
182	1	6	13	4	3	2
183	1	13	13	1	3	2
184	2	19	17	4	3	2
185	2	14	15	4	3	2
186	1	10	17	4	3	2
187	1	15	16		3	2
188	2	12	16	4	3	2
189	2	4	14	1	3	2
190	2	14	15	4	3	2
191	1	7	9	3	3	2
192	2	12	14	4	3	2
193	1	10	10	4	3	2
194	1	10	9	4	3	2
195	2	10	10	4	3	2
196	1	7	12	4	3	2

Student	Gender	Pretest	Posttest	Race	School	Group
197	1	6	16	4	3	2
198	1	14	19	4	3	2
199	2	19	20	4	3	2
200	1	18	15	2	3	2
201	2	15	16	4	3	2
202	1	12	11	4	3	2
203	2	11	13	4	3	2
204	1	6	9	4	3	2
205	2	17	20	4	3	2
206	2	13	19	4	3	2
207	1	11	19	4	3	2
208	2	15	18	4	3	2
209	2	9	17	4	3	2
210	2	10	13	2	3	2
211	2	13	19	4	3	2
212	2	18	19	3	3	2
213	1	8	19	1	3	2
214	1	9	11	4	3	2
215	2	17	18	4	3	2
216	2	14	19	4	3	2
217	2	18	20	2	3	2
218	1	16	14	4	3	2

Student	Gender	Pretest	Posttest	Race	School	Group
219	1	14	15	4	3	2
220	2	9	9	4	3	2
221	1	10	14	4	3	2
222	2	9	10	4	3	2
223	1	2	4	4	3	2
224	1	16	14	4	3	2
225	1	8	9	2	3	2
226	1	7	15	2	3	2
227	1	12	11	4	3	2
228	2	12	20	4	3	2
229	2	18	18	4	3	2
230	2	10	15	4	3	2
231	1	11	11	4	3	2
232	1	11	11	4	3	2
233	2	6	11	2	3	2
234	1	11	9	4	3	2
235	2	15	20	4	3	2
236	2	15	15	5	3	2
237	1	11	17	2	3	2
238	1	18	20	4	3	2
239	2	15	20	2	3	2
240	1	7	7	2	3	2

Student	Gender	Pretest	Posttest	Race	School	Group
241	2	10	14	4	3	2
242	2	18	19	4	3	2
243	1	9	12	4	3	2
244	2	10	11	4	3	2
245	2	18	17	4	4	1
246	1	16	18	4	4	1
247	2	19	19	4	4	1
248	1	13	10	4	4	1
249	1	9	13	4	4	1
250	2	13	14	4	4	1
251	1	19	19	4	4	1
252	1	12	8	4	4	1
253	1	10	10	4	4	1
254	1	12	13	4	4	1
255	1	11	12	4	4	1
256	1	17	18	2	4	1
257	2	19	19	4	4	1
258	1	8	12	4	4	1
259	2	18	18	4	4	1
260	1	16	12	4	4	1
261	1	7	11	4	4	1
262	2	6	14	4	4	1

Student	Gender	Pretest	Posttest	Race	School	Group
263	1	10	10	4	4	1
264	1	17	10	4	4	1
265	1	17	18	4	4	1
266	1	11	15	4	5	2
267	1	3	17	4	5	2
268	1	7	19	4	5	2
269	2	9	17	4	5	2
270	1	12	16	4	5	2
270	2	9	19	4	5	2
272	1	10	15	4	5	2
273	2	20	20	4	5	2
274	2	10	15	1	5	2
275	2	18	20	2	5	2
276	2	12	18	2	5	2
277	2	12	16	4	5	2
278	1	14	20	2	5	2
279	2	10	15	4	5	2
280	1	15	19	4	5	2
281	2	13	18	4	5	2
282	2	9	20	1	5	2
283	1	8	14	4	5	2
284	1	16	20	4	5	2

Student	Gender	Pretest	Posttest	Race	School	Group
285	1	11	18	4	5	2
286	1	8	14	4	5	2
287	1	16	20	3	5	2
288	2	11	12	2	4	1
289	2	7	8	4	4	1
290	1	8	13	4	4	1
291	1	15	14	4	4	1
292	2	8	10	4	4	1
293	2	14	12	3	4	1
294	1	7	12	4	4	1
295	2	8	9	4	4	1
296	2	18	14	4	4	1
297	1	5	8	4	4	1
298	2	3	4	4	4	1
299	1	8	8	4	4	1
300	2	5	6	2	4	1
301	2	9	11	4	4	1
302	1	2	6	4	4	1
303	1	8	7	4	4	1
304	1	9	12	4	4	1
305	1	8	7	3	4	1
306	2	16	12	4	4	1

Student	Gender	Pretest	Posttest	Race	School	Group
307	2	10	8	4	4	1
308	1	7	8	4	4	1
309	2	12	19	4	4	1
310	2	12	12	4	4	1
311	1	7	7	3	4	1
312	1	11	15	1	4	1
313	2	11	11	4	4	1
314	2	15	16	4	4	1
315	1	7	5	4	4	1
316	2	8	7	4	4	1
317	1	8	9	4	4	1
308	2	15	14	4	4	1
319	1	8	10	4	4	1
320	2	11	9	4	4	1
321	1	2	4	4	4	1