EFFECTS OF USING LOGIC AND SPATIAL CYBERGAMES TO IMPROVE STUDENT SUCCESS RATES IN LOWER-DIVISION CHEMISTRY COURSES

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Dissertation Prepared for the Degree of

DOCTOR OF PHILOSOPHY

UNIVERSITY OF NORTH TEXAS

May 2011

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A study was conducted to investigate the relationships between cybergaming treatment groups and the control group ($N = 99$: $n_{\text{control}} = 8$; $n_{\text{logic}} = 29$; $n_{\text{spatial}} = 30$; $n_{\text{combination}} = 32$) with success in the organic chemistry I course as measured by achievement over a 10-week period. The treatment groups included logic training, spatial training, and combination logic-spatial training. Students' ability was measured by pre/post exams using the Group Assessment of Logical Thinking (GALT) to measure logic ability, Purdue Visualizations of Rotations (ROT) test to measure spatial skills, and the General-Organic-Biochemistry (GOB) Exam to measure content attainment. Finally, students’ responses about participation in this experience were evaluated using open- and closed-ended questions on a self-developed survey.

A second study was conducted to evaluate the relationship between the cybergaming treatment and control groups ($N = 88$: $n_{\text{experimental}} = 27$; $n_{\text{control}} = 61$) with success in the general chemistry I course as measured by achievement and final course averages and grades. The cybergaming treatment group underwent intensive combination logic-spatial training for 10 weeks. Students’ progress was measured using three pre/post instruments: Group Assessment of Logical Thinking (GALT) measured logic ability, Purdue Visualizations of Rotations (ROT) Test measured spatial skills, and the California Chemistry Diagnostic Exam measured content attainment. Finally,
students’ responses about their participation in this experience were evaluated using open- and closed-ended questions on a self-developed survey.

Analyses of the data were performed to determine the relationships between cybergaming treatments and control groups in organic chemistry I and general chemistry I courses. In organic chemistry I results showed no statistical or practical significance as to students' success. In general chemistry I results indicated statistical significance and medium practicality for students with an average grade of C and for females over males as to improvement of spatial skills.
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ACKNOWLEDGEMENTS

I would like to thank the chemistry faculty at the University of North Texas (UNT) for their support. Dr. Diana Mason has been a mentor and positive force that has challenged and guided me every step of the way. I appreciate Professor Robin Henson for support and encouragement. I enjoyed each professor in my academic classes and the invaluable information I learned from them.

I appreciate the support from my husband, Alex Manrique, and my dog Elle, both offered the emotional reinforcement needed to achieve my goals. Also, to my parents Mike and Carla Smith, who taught me to fight for my goals and never give up. I want to also take time to offer thanks go my extended family that were always willing to give positive encouragement through the process.
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CHAPTER I

INTRODUCTION

The following investigation used a mixed methods design to evaluate how student academic success in lower-level college chemistry courses using repetitive practice of logic and spatial skills presented in a cybergaming format can be improved. Practicing logic and spatial skills was promoted by experiencing knowledge improvement courses published on the commercial Lumosity™ Website dedicated to using cutting edge science to develop tools to exercise the brain and enhance learning (Hardy, 2010). Also described are student evaluations using nationally recognized logic, spatial and chemistry content tests and self-reported data from Institutional Review Board (IRB)-approved questionnaires. (See Appendix A for IRB consent forms.) This chapter presents the statement of the problem, research questions, an overview of the methodology, limitations to the research and definitions of the technical terms used in this study.

Statement of the Problem

In 2000, 56% of students in China were getting science degrees compared to 17% of American students (Wallace, 2005). David Baltimore, president of the California Institute of Technology and Nobel laureate, stated, "We can't hope to keep intact our standard of living, our national security, our way of life, if Americans aren't competitive in science. Period" (Wallace, 2005, p. 30). In January 2001, the Hart-Rudman Commission found that our failures in mathematics and science education in the United States (US) are a greater threat than any war (Wallace, 2005).
Currently, the U.S. education is in the “No Child Left Behind” era. President Bush signed this act in 2001 with strong bipartisan support. The purpose is to ensure all students have an equal chance to attain a minimum academic proficiency (Conchran-Smith, 2005). Though at first glance this act seems ideal, it has left our country in academic disarray. Some critics have claimed it should be called “no student left untested” or “no student gets ahead.” According to Cochran-Smith (2005), this act has failed to reach its ultimate goal of improving academic success of U.S. students. Others claim it has even negatively affected teachers by enticing them teach to the test consequently limiting their pedagogical creativity. Something needs to change in our education system; we cannot wait for another Sputnik-like event to occur before we reassess our education system.

If you compare how the U.S. high school students rank nationally to other countries around the world, the results are surprisingly devastating. A study done in 2009 tested how well 15-year-old high school students from many nations could apply their science and mathematics skills. The study found that U.S. students tested near the bottom of the 29 participating countries. When comparing science and mathematics bachelor degrees to other nations, the U.S. has dropped from 3rd in 1975 to 18th in 2009 (U.S. Department of Education Institute of Education Sciences, 2010). According to this report, the U.S. needs to better prepare students in science and mathematics to continue to compete globally. The disconnect between high school and college chemistry courses can be documented by noting the overall success rate (i.e., grades of A, B or C) in the general chemistry I class selected for this study at the University of
North Texas (UNT) of just over 60%. Therefore, it is essential that we seek to better prepare students and/or find ways to keep them engaged and motivated in order to promote the learning of often complex and abstract content found in lower-division chemistry courses.

There are also reports indicating a disconnection between the number of males and females succeeding in the science field and/or entering into science professions. A recent survey of 3,800 graduate students discovered that there are 48% more males receiving PhDs in the science fields compared to females (Fox & Stephan, 2001). A 2007-2008 study by the U.S. Department of Education found that 56.5% of male students receiving doctoral degrees were also receiving a degree in a science compared to 43.5% of women (U.S. Department of Education, 2010). Another study went so far as to suggest that one reason there is a lack of women in the science fields is that their confidence in their science ability is lacking compared to that of their male counterparts (Seymour & Hewitt, 1994).

Prior studies evaluating how to succeed in science classrooms have focused on three variables: Chemistry readiness, logic skills and spatial awareness. One such study focused on developing the California Chemistry Diagnostic Exam (a general chemistry placement exam) and found a positive correlation between the pre-exam measuring prior knowledge and the final grade in the course \( r = 0.42, N = 4,023 \), proposing that prior knowledge accounts for approximately 18% of the final grade (Russel, 1994). Correlations between logical thinking and science, technology, engineering and mathematics (STEM) students’ success are widely reported in research studies.
Chemistry readiness is defined by the Education Policy Improvement Center (EPIC) in 2008 as the “level of preparation a student needs in order to enroll and succeed without remediation in a chemistry classroom” (Educational Policy Improvement Center, 2008, p. 3). The problem in the U.S. is that 20-80% of students, depending on institution type, are required to enroll in remedial courses and 30% fail to go beyond the first year of chemistry. Another study at the University of Notre Dame found that approximately 60% of students drop out of chemistry after their second year (Educational Policy Improvement Center, 2008). Rowe (1983) described chemistry as a “killer course” that students simply are not prepared to take. These data beg the question: If students do not receive the instruction they need in high school to succeed as freshmen in introductory chemistry courses, is their science future irreversibly doomed?

Fortunately, we live in a world that has infinite resources by which to learn. Students of today have been trained to learn in snippets by television and other audio-visual media. When using today’s reality and readily available tools to our advantage, can STEM learning be improved and will these uncovered abilities influence the perseverance of the freshmen STEM learners? I believe one possible solution is to train
STEM students via the use of cybertechnology tools that they are familiar with but have not yet used to their fullest benefit. Implementing active-learning methods and incorporating learned logic and spatial skills into cyber-learned materials gives students a relevant way to build upon the already formed foundation. In this new age of intermittent learning and information glut, educators can use cybertechnology to their advantage as long as they develop the tools leading directly to the desired outcomes and continually reward students as they improve through immediate recognition.

Malone (1981) studied the effects of using computer games for instruction. She found that motivation is created in three ways: challenge, fantasy and curiosity. Challenge depends on the uncertainty of the activity; fantasy depends on the skill level for the instruction; and curiosity is aroused when the learner believes their knowledge is incomplete without finishing the activity. Malone found that cyber-learning activities provide students with challenge, concrete feedback and a clear gauge for success to build motivation and learning (Malone, 1981). Many other studies have found that computer games can be motivating for students (Jaeggi, Buschkeuhl, Jonides, Perrig, 2008; Reiber, 1991; Rosas et al., 2003; Scanlon, Drescher & Sarkar, 2006; Stewart, 1997). Motivation is vital to learning because a student will not learn if he or she is not motivated (Shell, Brooks, Trainin, Wilson, Kauffman, & Herr, 2010). In addition, several studies focused beyond motivation and measured the use of cybertechnology in the classroom to enhance learning (Feng, 2007; Kumta, Tsang, Hung & Cheng, 2003; Tracy, 1987). One study found that by using technology developed by the researchers in a geography classroom, 74% of the experimental group (multimedia group) received
a letter grade of B or higher in the classroom compared to 27% in the control group (Frear & Hirschbuhl, 1999).

In this study it is hoped that incorporating cybertechnology as a way to intrinsically motivate the students to learn will improve students' logic and spatial skills and therefore promote success in the science classroom. Implementing active-learning methods and incorporating logic and three-dimensional (3-D) skills into cyber-learned materials gives students a relevant way to build upon the already formed foundation. Gaming industries such as Nintendo® are describing the benefits of developing brain enhancement games that could possibly be used in the classroom (Ashcraft, 2006). New research is being conducted to understand the impact and how cybergames such as, Brain Age™, might be used to engage and enhance student learning. In general, the use of educational cybergames has allowed students to enhance their science knowledge to think like scientists while improving students’ cognition and self-esteem (Soderberg & Price, 2003).

The educational cybertechnology tool used in this study is Lumosity™. The Lumosity™ labs have developed highly motivating, fun games in their training courses that aid students in logic and spatial reasoning. These games help students combine cognitive processes such as attention, memory-processing speed, and pattern recognition to draw conclusions and make decisions. The design of the Lumosity™ labs was based on research showing that continuous practice on a learning concept can actually change the shape and size of your brain, resulting in higher cognitive abilities on that concept (Drananski et al., 2004; Maguire et al., 2000). Characteristics that
make the Lumosity™ training programs effective are targeting, adaptivity, novelty, engagement, and completeness (Hardy, 2010).

Current ongoing research on Lumosity™ has found exciting new brain training possibilities. The Lumosity™ labs conducted their own study testing the cognitive ability in healthy adults (N = 25). The mean age was 54 and the participants were divided into control and experimental groups. The experimental groups played Lumosity™ games every day for five weeks and were measured on post-standardized assessments of cognitive abilities. Working memory was measured pre- and post-intervention using a reverse span board exam, an exam that measures memory by placing blocks in a certain sequence where the student has to replicate the pattern while the sequence becomes larger and more complex. The experimental group significantly improved (p < .01) while the control group had no significant improvement. Visual attention (ability to process many streams of visual information) and executive function (ability to control aspects of cognition) using the Trailmaking Part B test were also measured between groups with the experimental group being found to improve significantly (p < .01) (Scanlon et al., 2006). Other studies have shown similar results from cognitive and memory improvements using the Lumosity™ labs (Kesler, 2008; Scanlon et al., 2006).

To conclude, science education is important for the US to progress and compete internationally. Unfortunately, the U.S. has recently fallen behind in science and technology compared to the rest of the world (U.S. Department of Education Institute of Education Sciences, 2010). The U.S. has additionally lagged in attracting future students into the science careers and therefore is not meeting the demands to fill
competitive science occupations. It is important to encourage students to improve their science skills in hopes that more men and women will be attracted to enter into productive science fields. In order to improve students' science skills, cybertechnology may be the solution to promote the improvement of logic and spatial skills deemed important to succeed.

Research Questions

The purposes of this study are to investigate the importance of logic and spatial skills needed to succeed in the lower-division chemistry courses and whether cyber-learning games can be used to improve students' academic skills dependent on these abilities. In other words, whether or not practiced logic and spatial skills can be transferred to positively affect academic performance. In particular, this study focuses on the idea of using educational cybergames as a way to motivate students to improve their logic and spatial skills needed to become successful in lower-division chemistry courses. This study is important to unveil the dynamic relationship between logic and spatial abilities and students' success in the entry-level general chemistry I (gen chem I) and organic chemistry I (o-chem I) courses.

It is important to understand the role of cybertechnology as a training tool in the classroom. In this study the training tools available on the Lumosity™ commercial Website have been utilized in a typical classroom setting at no charge to the researcher or the students who helped to complete the study. Previous studies regarding cyber-learning may have over generalized the results. This research generates data from a
controlled study at a large north central Texas public university, targeting students enrolled in gen chem I and o-chem I courses.

The research questions for this dissertation are:

1. What do student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group?

   $H^o_{1.1}$: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial as measured by scores on the General-Organic-Biochemistry (GOB) 2007 exam and the final course grades compared to the control (non-gaming) group in organic chemistry I on average and over the 10-week intervention period.

   $H^o_{1.2}$: There is no significant difference between students participating in the cybergaming intervention group of combination logic-spatial as measured by scores on the California Chemistry Diagnostic Test 1997 (CA Dx) and the final course grades compared to the control (non-gaming) group in general chemistry I on average and over the 10-week intervention period.

2. When students participate in cybergame training over the span of 10 weeks, how is student performance on logic ability as measured by the Group Assessment of Logic Thinking (GALT) affected?
$H_{0,2.1}$: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial and the control (non-gaming) group in logic ability as measured by the GALT exam on average and over the 10-week intervention in organic chemistry I.

$H_{0,2.2}$: There is no significant difference between students participating in the cybergaming intervention group of combination of logic-spatial and the control (non-gaming) group in logic ability as measured by the GALT exam on average and over the 10-week intervention in general chemistry I.

3. When students participate in cybergame training over the span of 10 weeks, how is student performance on spatial ability as measured by the Purdue Visualization of Rotations (ROT) test affected?

$H_{0,3.1}$: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial and the control (non-gaming) group in spatial skills as measured by the ROT test on average and over the 10-week intervention in organic chemistry I.

$H_{0,3.2}$: There is no significant difference between students participating in the cybergaming intervention of combination of logic-spatial and the control (non-gaming) group in spatial skills as measured by the ROT test on average and over the 10-week intervention in general chemistry I.
4. What are the effects when participating in cybergame training over the span of 10 weeks between genders as measured by the outcomes on the content diagnostic exams (GOB and CA Dx), GALT and ROT, and final course grade?

H⁰₄.₁: There is no significant difference between genders in organic chemistry I as measured by the scores on the GOB, GALT and ROT and final course averages and grades.

H⁰₄.₂: There is no significant difference between genders in general chemistry I as measured by the scores on the CA Dx, GALT and ROT, and final course averages and grades.

5. What are the experiences and attitudes of general chemistry I and organic chemistry I students using the logic and spatial cybergame training intervention for a span of 10 weeks as measured on a Likert-scale and by responses to an open-ended questionnaire?

Overview of Methodology

The research methodology used in this study is considered mixed methods, which combines both quantitative and qualitative data in different phases of the research process. The study acknowledges that both methods have limits, but the triangulation of the methods can eliminate most of the biases that can occur (Creswell, 2003). A mixed methods approach is soundly grounded in the pragmatic knowledge claim. In this claim the problem is the most important concern and many different approaches, quantitative and qualitative, are utilized to determine the best solution to
the problem. In this technique the researcher is free to choose any technique to accomplish the goal of solving the problem (Creswell, 2003).

In this study I chose to take a post-positivist researcher role. The post-positivism doctrine claims that social reality is independent of those who observe it, and that observations, if unbiased, compose scientific knowledge. The majority of the data are quantitative, numerical evaluations that allow for an unbiased approach in analyzing the data and attaining more generalizable results. In addition, qualitative data from closed- and open-ended surveys allows students to give their personal opinion on the study without interference providing a deeper knowledge of the progress of the study (Creswell, 2003).

Limitations of the Study

The intent of this study arises as this research seeks to better understand how to best prepare the minds of entry-level chemistry students using the technology many are familiar with. Contributing new data on the impacts of online gaming protocols and on chemistry students’ logical thinking, working memory capacity, and success in gen chem I and o-chem I are explored. In order to generalize the results, it is important to accurately characterize the students participating. Failure to accurately describe the sample population will result in external validity problems for the study (Creswell, 2003). A rich definition of the sample must include size, demographics, institution type, and location (Creswell, 2003). A limitation of this study is restricting the scope of the study to a large Texas public university that provided samples of opportunity. The generalizing power of the study is therefore limited to the sample studied: Any study
that incorporates a different sample description can result in different effects. In order to increase the internal validity, students chosen for the cybergaming intervention were systematically and randomly assigned to each treatment group. The purposeful sampling procedure used in this research, although based on results from a pilot study conducted the previous semester, still limits the generalizability due to the fact that only one section of each course was studied.

In addition, there is a limitation of the instruments used to measure students’ learning abilities. Logic and spatial abilities can be difficult to precisely measure, and more importantly, the exams can measure different concepts than intended. Therefore, clearly explaining each tool used and being consistent with descriptions of proposed uses from literature will help to improve external and internal validities. The test score consistency for the selected instruments has been historically high (α , but not 100% reliable. Each student has a unique mind and therefore a different ability to perceive the exams. It is important to realize that the statistics on each tool only give the average performance of the sample; for example, just because the sample improved does not mean each individual improved. These limitations are true for this study, too. The intention is to be aware of the study’s limitations so the reader will find the research was complete without unexplained experimental bias.

Definition of Terms

*Cybergaming*: Games that are developed to use networked computer and communication device technologies.
Cyber-learning: The use of networked computer and communication device technologies to support learning.

Cybertechnology: Networked computer and communication device technologies.

General chemistry I: First semester college chemistry covering broad topics such as:
 - chemistry nomenclature, stoichiometry, bonding and the laws governing the states of matter.

Logic ability: The ability to reason and think abstractly according to Piaget’s developmental theory.

Logical thinking: To think abstractly and reason ideas according to the Piagetian model.
 - (A superior logical thinker in this study is defined as a student who has developed into a formal operational thinker as established by a Piagetian model.)

Lower-division/Lower-level chemistry: Chemistry courses taken during first two years at the college level (general chemistry and organic chemistry are the typical courses).

Lumosity™ Labs: Commercial Website that provided the cyber-learning tools for the participants at no financial charge.

Organic chemistry I: First semester organic chemistry covering topics such as nomenclature, R,S configurations, Lewis dot structures, and organic reactions.

Science expert: A person possessing special skill or knowledge in the science field, and usually having attained an advanced degree in a specific field.

Spatial ability: The ability to generate, retain, and transform visual images.
**Spatial training:** Training that is specifically focused on improving a person's spatial skills.

**Training tools:** Tools used to train a person in a specific cognitive area.

**Summary**

The study evaluated the use of cybergaming training tools to exercise the brains of lower-level chemistry students in order to improve their logic and spatial skills in hopes that a 10-week intervention will improve the experimental groups' course success rates in organic chemistry I and general chemistry I. The remaining chapters can be summarized as follows: Chapter II includes a summary of the supporting literature; Chapter III describes the research design and methodology; Chapter IV presents a summary of the results; and Chapter V discusses the implications of using cybergaming as an appropriate training tool to improve student outcomes in organic chemistry I and general chemistry I at a large university in north central Texas with a population exceeding 36,000 students.
CHAPTER II

LITERATURE REVIEW

There is a large body of literature found on logical thinking, spatial ability and cybertechnology training tools. Information on these topics was found through searches in Education Research Information Center (ERIC), Academic Search Premiere, Wiley Periodicals and other online databases at the University of North Texas and Internet sources using Google Scholar. In addition, readings from educational psychology and chemical education were searched for relevant supporting information. This chapter examines an overview of student achievement in the science classroom and the theoretical perspective supporting this foundational knowledge. Special attention is paid to research on students' logic and spatial abilities and the gender differences therein along with a discussion of the pilot study.

Overview of Student Success in the Science Classroom

Today's classes are diverse as noted by the range in varying levels of academic skills, prior knowledge, teaching experiences and expectations (Zeegers & Martin, 2001). For this reason it has become more difficult to actively engage students in learning, resulting in more students failing to complete the science classes in which they are enrolled. A study ($N = 156$) found the failure rate at the university level in basic sciences to be 12% (Illing, 1998). In another study focusing on the reasons for the dropout rate in science courses, the authors determined that difficulties in understanding material, class overload, poor teaching and loss of interest were rated among the top factors contributing to high attrition rates among science and
engineering undergraduate majors (Seymour & Hewitt, 1994). Evidently, the students in this study were struggling to succeed in many science classrooms allowing the authors to suggest that practicing skills needed to succeed as a science expert might increase these students' ability to perform if their confidence in their own ability improved.

Many studies have also found major differences in success rates between genders in the science classroom and even into work fields. On The National Assessment Exam in science and mathematics, males continue to perform better than females (Antasi et al., 1984; Grant & Eiden, 1986; National Science Foundation, 2006). Statistics from the National Center for Education Statics found that men outperformed women ($p < .00002$) on the Life Science portion of the Texas Assessment of Knowledge and Skills (TAKS) exams (National Science Foundation, 2006). In another study that compared the science ability between genders, it was found that males received a higher final grade in entry-level chemistry compared to females ($t = 6.39, p = .01$) (Boli, Allen & Payne, 1985). All of these studies suggest a prominent gap between genders in science achievement. As suggested in Chapter I, this gap appears to be from indicators of females exhibiting lower cognitive abilities on the given assessments used and a lack of confidence that they have in their science aptitudes.

Prior studies evaluating how to succeed in the science classroom have focused on two cognitive abilities: logical thinking and spatial awareness. Correlations between logical thinking, spatial intelligence and STEM (science, technology, engineering and/or mathematics) students’ success are widely reported in research studies (Baenninger & Newcombe, 1989; Bodner & Guay, 1997; Bunce & Hutchinson, 1993; Hahn & Polik,
2004; Linn & Hyde, 1989; Shea et al., 2001). Foci of the research were concentrate on the differences between genders in these cognitive abilities and investigate if practice will help eliminate the gap between these cognitive abilities therefore allowing females a better chance to succeed in the lower-division chemistry classrooms.

There is evidence supporting that part of the brain's executive function consists of multiple discrete components, like those associated with verbal and visuospatial abilities (Miller & Cummings, 1999). In 1993 Gardner proposed the theory of multiple intelligences (MI). Gardner asserted that every individual possesses MI in varying degrees. Of the primary MIs (linguistic, musical, logical mathematical, spatial, body-kinesthetic, intrapersonal and interpersonal), STEM instruction usually targets the logical-mathematical intelligence and abilities (Gardner, 1993). Successful students in many science classes have been defined as those that have higher analytical ability usually translated as the students having greater mathematical skills. However, STEM students' success may reside deeper than just basic mathematics skill building alone; STEM students' success and the rate of spatial processing may also be related. "Mental rotation takes place in the right cerebral hemisphere, in the area where perception occurs" (Johnson, 1990, p. 803). Constructivist theory predicts that students learn better when they build their knowledge through understanding rather than memorization of unrelated facts, so how can we train the underprepared mind to think like a successful STEM graduate student and/or scientist? A science expert is expected to have both increased logical thinking skills to solve complex algorithmic and conceptual problems and a distinguished spatial intelligence level to visualize complex
structures in three-dimensional (3-D) space. This begs the question — will the combination of both logical thinking and spatial intelligence increase students’ success in the lower-level chemistry classroom?

Overview of Logic Ability

Logic Ability as Defined in Literature

Intelligence according to the Mainstream Science of Intelligence Report (1994) is a “very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience” (Gottferdson, 1997, p. 4). To measure intelligence, IQ tests have been nationally recognized educational tools that measure a person’s reasoning and logic skills (Miyake et al., 2001). A student’s logic ability is defined by Gardner as someone having a superior ability in reasoning and number recognition; this intellect embraces the traditional concept of “intelligence” and is the type measured on many standardized tests (Gardner, 1993). Students with superior logic skills have the ability to handle long chains of reasoning. They have superior reasoning skills, abstract pattern recognition, scientific thinking and the ability to perform complex algorithmic problems (Gardner, 1993). These students tend to become mathematicians, scientists, doctors and engineers. The left hemisphere of the brain is responsible for analytical, sequential, deductive skills (Springer & Deutsch, 1998).

According to Piaget logical thinking intelligence is developed in three stages that are progressive so must be accomplished one after the other. In each stage of development the typical child views reality appropriate for advancement of that age
period base on mental capacity. For each stage succession the child must maintain the prior level of mental abilities to reconstruct concepts. Intellectual development is constantly expanding and children must make connections between previous ideas and with new higher order concepts. For this reason a student/child can always revert to a lower stage of cognitive ability to learn a novel concept but a student with lower cognitive ability cannot jump to higher order thinking without being provided the necessary links to construct the new knowledge. The Group Assessment of Logical Thinking (GALT) is a good measure of a person’s developmental stage of logical thinking. The cognitive developmental stages of logical thinking based on Piaget’s model of cognitive ability levels are the following (Huitt & Hummel, 2003):

1. Pre-operational stage: (GALT: Not applicable). In this cognitive stage thinking is done in a non-logical manner. Egocentric thinking (meaning one cannot perceive the world from others' viewpoints) predominates and eventually begins to weaken. Children cannot conserve or use logical thinking; they use casual reasoning with unwarranted coincidence (e.g., “It’s raining because I am sad”). They can only group ideas or objects by single features; for instance, all the red objects despite shape.

2. Concrete operational stage: (GALT: Concrete). In this stage thinking becomes more logical and systematic where manipulation of symbols related to concrete objects and aids occurs. Children begin to think logically but are very concrete in their thinking. Operational thinking develops and egocentric thought diminishes. Subjects can classify objects according to several features and can order them in
a series of a single dimension. Children can understand the concepts of mass, length and conservation of numbers. There is also a transitional stage measured by the GALT when students begin to develop partial formal operational logical thinking.

3. Formal operational stage: (GALT: Abstract). In this stage, thinking is fully logical and is demonstrated through use of symbols related to abstract concepts, both abilities very important to success in the study of chemistry. Children can test hypotheses abstractly and become more concerned with the future and ideological problems. Children can classify objects abstractly according to several features and can order them on many dimensions. They begin to order and increase the size of their schemata (interconnections are formed; information is organized).

According to Piaget development of propositional logic is essential for a child to progress from one cognitive logical development stage into another (Bitner-Corvin, 1987). Propositional logic is the branch of logic that studies approaches to join or modify statements to form more complicated statements as well as logical relationships (Klement, 2004). In propositional logic the individual statements are indivisible units of more complex connections of logical relationships. To relate this to Piaget’s developmental theory, students will begin with individual ideas and slowly develop these ideas that will begin to be connected to each other in order to establish more complex thinking that helps them develop into formal operational thinkers. The idea of propositional logic is related to the idea of schema in educational research.
Barlett (1932) was the first to propose the idea of schema; this phenomenon being a framework developed by a person’s brain to understand and remember information. A schema provides meaning to experiences and allows the person to make connections of new knowledge to the old. A schema can be thought of as a unit of knowledge each related to different aspects of the world. The schema is stored, categorized prior knowledge (Kearsley, 2010). When a person learns a new concept, he/she will make a connection to a schema that is most similar to this new concept and then build upon it to expand their knowledge (i.e., develop into a formal operational thinker) which sometimes leads to misconceptions and certainly lends explanation to why students can be presented with the same information and understand it differently.

The five modes of reason and logic found in formal operational thinkers are: Proportional reason, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. In order for a student to progress into a full formal operational thinker he/she has to develop all formal operational reasoning skills (Lawson & Nordland, 1976; Lawson, 1982). Formal operational reasoning begins with hypothetical thinking and progresses with verified empirical evidence (i.e., scientific thinking) (Lewis & Lewis, 2007). Adey and Shayer (1990) further grouped these reasoning modes into three categories. The first category is classification of variables that includes controlling and excluding variables, multiple classification schemata and descriptions of all combinatorial possibilities. The second category is the relationship between variables that includes ratios, proportions, inverse relationships, correlations and probabilities. The last group is a formal model that includes describing an abstract
representation of the relationship of variables and logical reasoning (Adey & Shayer, 1990). A student that is a formal operational thinker can view a scientific problem, classify each variable and make a detailed description, and then construct relationships between the variables finally drawing conclusions about the problem and future problems that can occur.

One study found that only approximately 35% of high school graduates in industrialized countries develop into abstract thinkers that, according to Piaget, should be fully developed by age 15 (Renner et al., 1976). Another study at the University of Oklahoma found that 50% of incoming freshmen were considered concrete thinkers and only 25% developed into formal operational thinkers by the end of the study (Mckinnon & Renner, 1971).

Williams et al. (1979) studied 435 science majors, 426 non-majors and 27 third-year physical chemistry students using the Piaget’s Interview Task a 20-item exam (similar to the GALT used for this study) and analyzed each cognitive mode for formal operational thinking. When analyzing proportional reasoning, the researchers found that only 56% of science majors and 38% non-science majors developed these reasoning skills. Test items were designed to test the concepts of conservation of mass and density in chemistry. An additional item analyzed was conditional reasoning where the questions focused on chemistry concepts such as combustion and metabolism. The statistics reported were approximately the same for all items. In addition, controlling variables were tested and most students despite rank and major missed these problems. Common mistakes students would make were controlling all variables or only
controlling one while neglecting the other variables that could have an effect on the experiment. Finally, combinatorial and probabilistic reasoning were measured, and it was determined that most students struggled the most with these topics and were highly discouraged. From the results of the study it appears that most of the students had not developed to the level of being formal operational thinkers that is needed to truly succeed in the science field (Williams et al., 1979).

Abstract logical thinking is essential for an abundant number of scientific concepts, laws, principles and algorithmic relationships (energy, kinetics, gas laws, force, etc.) (Bitner-Corvin, 1987). Though the success in STEM instruction is not limited to only a student's logic ability, it usually targets the students' logical-mathematical intelligence (Gardner, 1993). Successful students in many science classes have been defined as those that have higher analytical ability usually translated as students having greater mathematical skills. In this study a superior logical thinker is defined as a student who has developed into a formal operational thinker as established by this Piagetian model.

**Academic Success and Logic Ability**

Several studies have found formal logical reasoning skills are directly correlated to chemistry (Bird, 2010; Bunce & Hutchinson, 1993; Hahn & Polik, 2004; Slattery, 2009). A recent study (Bird, 2010) analyzed the relationship between final grade in a general chemistry classroom and Piagetian operational levels. To measure students’ operational level the GALT exam was used, and the results indicated a significant difference when GALT scores were compared to students' final grades ($\chi^2 = 52.89, p <$
Formal operational students averaged a letter grade of A in the classroom, students at the transitional stage averaged a B and students who scored low on the GALT (concrete) averaged a C in the class (Bird, 2010). Scores on the GALT exam were also compared to the student’s grade on an American Chemical Society (ACS) general chemistry exam. Significant results were found ($p < .001$) comparing operational levels and success on the ACS exam favoring formal operational thinkers (Bird, 2010). This strongly suggests that formal operational thinking is essential to highly successful students (those who received an A) in the chemistry classroom and potentially to those entering into the science-schooled workforce.

A similar result found by Bitner-Corvin (1991) suggested that the five formal operational reasoning modes (proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning and combinatorial reasoning) as measured on a GALT exam were found to be significant predictors for success (defined by final grade) in science and mathematics classrooms. The five formal operational reasoning modes explained 29% of the variance in the mathematics final grade and 62% of the variance in the science final grade.

Other studies have focused on the relationship between formal logical thinking and conceptual understanding of chemistry topics. Herron (1975) found that logical thinking could be directly linked to specific chemistry concepts that are needed to be successful in the classroom. A brief summary of some chemistry concepts that students who have not reached the formal operational thinking cannot do included: Measuring quantities that are not directly observed (i.e. density), making indirect observations (i.e.
atoms combine in definite proportions), reading of energy and cooling diagrams, and calculating non-ideal gas laws, empirical formulas, ratio proportions, law of conservation of mass, collision theory, etc. Another study focusing on chemical calculations and concepts and their relationship to logic ability, found senior chemistry students \((N = 119)\) who used multiple linear regression to calculate acid-base equilibrium not only needed good reasoning ability but also their cognitive style was important to correctly evaluate the problems; 28% of the variance in the total score was explained due to these factors (Demerouti, 2004). A study conducted by Abraham, Williamson, and Westbrook (1994) sampled 100 students from high school physical science, high school chemistry and college general chemistry to examine outcomes for understanding various chemistry topics: Chemical change, dissolution of solids, conservation of atoms, periodicity and phase change. The students’ grade level and logical reasoning ability were measured for possible sources of variation of understanding. Differences in understanding due to grade level were found to be significant for the concepts of chemical change, dissolving solids, conservation of atoms and periodicity. Analysis of results found that very few college chemistry students could correctly understand the concepts of chemical change, periodicity or phase change. Also, logical reasoning ability was found to be a significant factor for understanding the more abstract concepts such as conservation of atoms and periodicity. Boujaoude, Salloum, and Abd-El-Khalick (2004) found comparable results when investigating the relationship between the same cognitive factors and the chemistry topics: Chemical change, chemical equations, gas laws, limiting reagents and oxidation-reduction equations. Formal operational
developmental level had the greatest predictive power in determining students’ success in correctly solving these types of chemistry problems.

Nicoll and Francisco (2001) found a significant correlation between logical thinking ability and success in physical chemistry. A study of a sample of 77 students at a Purdue University provided evidence on how various cognitive abilities and students' perceptions affected their performance in a physical chemistry course. To measure students’ perceptions of their own ability, a Student Perceptions Inventory was given the first day of class. On the second day of class the mathematics diagnostic exam was given to measure students' mathematics ability. Finally, on the third day of class students were given the conceptual diagnostic exam that assessed a combination of the Figural Intersection Test (FIT) and the GALT. The FIT examines a student’s ability to process information while the GALT examines a student’s logical thinking ability. Each of these three exams was further analyzed to understand the correlation between final grade and ability being measured. There was not a significant correlation between student perception of themselves and the FIT portion of the conceptual diagnostic exam. However, significant correlations between final grade and mathematics ability and GALT scores were evident ($p < .0001$). These results suggest that performance in this physical chemistry class was a function of students’ logical thinking skills (Nicoll & Francisco, 2001).

Niaz and Robinson (1992) examined the effect of students’ performance on manipulating the logical structure of stoichiometry problems. The logical structure is the number of operative schemata entering the problem. A schema, according to Piaget, is
an organized structure of information while the operation is the number of ways we manipulate the schema (recall prior knowledge). Results showed that Piaget’s cognitive developmental stages are the best predictors of determining if a student can manipulate complex chemical problems, and that the number of operative schemata involved in a chemistry problem is the main factor determining the difficulty of the problem.

Bunce and Hutchinson (1993) investigated the use of the GALT, which measures logical thinking ability according to the Piaget model, as a good predictor to determine college success in a chemistry classroom. Three populations were used: (1) science and engineering majors, (2) non-science majors, and (3) nursing majors. The students’ final grade, GALT and Scholastic Aptitude Test (SAT) scores were all analyzed to determine if the GALT was as good as or maybe better predictor of success. After analysis it was concluded that the GALT was a better predictor of success than the SAT mathematics section for the non-science and nursing majors. On the other hand, the SAT mathematics score was a slightly better predictor of success for science majors. Since the GALT is easier to obtain and does not cost to administer, it can be used in science classrooms to identify those students who might struggle in the class.

Upon analysis of each of these studies, it seems apparent that students who have achieved higher-level logical reasoning abilities are more successful in the chemistry classroom. The development into Piaget’s formal operational level of reasoning is essential for a student to understand many of the concepts introduced in
chemistry. Investigation of practicing logical thinking skills to achieve a formal operational level needed to succeed in the chemistry classroom is important.

*Practice and Logic Ability*

Various studies have also focused on increasing students' logical thinking ability by noting their practice patterns (Hurst & Milkent, 1996; Kumta et al., 2003; Yaman, 2005). Yaman (2005) found that incorporating problem-based curriculum into the classroom significantly \((p < .05)\) increased a student’s logical thinking as measured on pre/post GALT examination. A similar study found that when fourth-year medical students practiced their logical thinking skills using a computer-based tutorial program, they significantly improved their logic skills (Kumta et al., 2003).

The Stress on Analytical Reasoning (SOAR) Project was developed for a Piagetian summer program in all foundational science fields (physics, chemistry, mathematics and biology) based on the Karplus design, a three-part learning program to aid students in attaining formal operational thinking skills. In the first stage, the explorative stage, the student interacts with materials with minimal guidance similar to an inquiry-learning lab. In the second stage, invention, the student analyzes the data they gathered in the initial stage and are then encouraged to form hypotheses. Finally, in the application stage the student explores ideas for future experimentation and analysis (Karplus, 1974). Professors were trained according to the model and the students performed labs based on all the logical modes required for formal operational thinking. For instance, in chemistry week 1 student focused on controlling variables and performed an iodine clock reaction to determine rate. Week 2 focused on proportional reasoning and a lab
analyzing the relationship of the amount of reactant and product produced when burning magnesium. Week 3 focused on combinatorial reasoning and a lab was performed where students had to identify chemicals with missing labels. Probability was the focus of the following week in lab where the students had to sample to estimate the number of beads in a jar. Finally, in week 5 recognizing correlation was the focus and the students did a lab to determine the relationship between concentration and reaction time needed. The classroom test for formal reasoning developed by Lawson (1978) was used as a pre/post exam to determine if there was improvement in formal operational thinking. After analysis it was concluded that the students did significantly improve their scores on the exam ($p < .001$) (Carmichael et al., 1980).

All of these studies suggest that through practice and experience students are able to increase their logical thinking skills. Piaget theorized that through life experiences children develop into higher-level formal operational thinking; therefore practicing logical thinking should improve these skills. Piaget’s theory of cognitive development suggests that new information is gained gradually and slowly as people acquire new information, construct and use it. He argued that human reasoning is adaptive and constantly developing (Piaget, 1983). If intelligence is active and constructive as Piaget suggested, then practice and experience will improve a persons’ logical thinking skills. These studies and the Piaget’s model suggest that various practicing techniques (paper and pencil, curriculum, multimedia) can enhance students' logical thinking skills.
When analyzing the difference between gender and logic ability, male students have consistently tested higher on several logic exams (Bird, 2010; Farrell & Farmer, 1985; Meehan, 1984). This could be a factor that influences female confidence in their science ability as well as their decision to enter a science career. In general, it is found that males outperform females on basic formal reasoning tasks. Bird (2010) using 486 freshmen taking general chemistry found significant gender differences favoring males ($t = 5.09, p < .001$) was observed. Another significant effect was found when concentrating on operational level ($\chi^2 = 20.16, p < .001$) favoring males at the formal operational level.

Farrell and Farmer (1985) studied 902 college-bound students and investigated gender difference in logic ability. The subjects were administered a tall-short task test that measures proportional reasoning and found a significant result in favor of the male subjects. A meta-analysis of 53 studies conducted by Meehan (1984) found that males outperformed females in propositional logic, controlling variables, and proportionality. Meehan discovered a 1-5% difference in variance due to gender differences in formal operational thinking. Lawson (1975) used two Piagetian tests measuring formal operational thinking and the Longeot pencil and paper test to measure formal reasoning of high school biology students ($N = 62$). For all measures the males' mean was higher than females'. Another historic meta-analysis by Stumpf (1995) found females have a superior ability in verbal, memory, perceptual speed and fluency and males have an advantage in number sense, closure, spatial orientation and reasoning, further
suggesting male students have higher developed formal operational reasoning skills on average.

Feingold (1992) reported several instances in which males showed a larger variance than females on cognitive test scores. Feingold’s results concluded that males test consistently higher than females in quantitative reasoning, spatial visualization, spelling and general knowledge (Feingold, 1992). Similarly, Stumpf and Jackson (1994) investigated gender differences in reasoning skills over a nine-year period. The sample consisted of medical school applicants in West Germany ($n_{\text{male}} = 96,968; n_{\text{female}} = 90,142$). Through correlational analysis it was concluded that males perform significantly better in reasoning skills than females. Research on mathematical reasoning abilities were studied in a meta-analysis by Hyde, Fennema and Lamon (1990) and found that during ages 5 through 14, female students showed a higher computational ability but at ages 15 and older male students had a significantly higher mathematics solving ability ($d = 0.41$).

Although many studies have found differences in logical reasoning skills between female and male students not all studies agree. Some studies implied it might be a problem with sampling error and other studies indicated that the general population shows little difference in reasoning skills. A meta-analysis focusing on gender differences and cognitive ability, reported that the sample differences in the studies could be greater than in the general population and that the results are being over generalized (Hyde et al., 1990). In the analysis of 100 different studies, it was found that averaging all the effect sizes the $d$ was -.05 actually favoring females (though not
statistically significant) overall. The study further investigated effect of gender and age on cognitive ability, and the authors concluded that a greater effect size was found as the students aged favoring males (\(d = .32\)) (Hyde et al., 1990). Another study by Jensen and Johnson (1994) found negligible differences between males and females in IQ and general intelligence. When measuring formal operational thinking using the GALT exam, it was found that male students did not dominate in all reasoning skills measured on the exam. Significant values for the male students were found for conservation mode, conservation of volume and probabilistic reasoning while females were found to be statistically better in combinatorial logic (Bitner-Corvin, 1987).

Though there has been some debate about intelligence and logical reasoning and gender differences overall, the consensus seems to agree that at younger ages (below 15) females tend to either favor or show positive differences in cognitive abilities compared to males but as they begin to mature, men tend to gain superior formal logical reasoning skills. There has been further debate on the reasoning that some argue social gender roles play a part in subjects' cognitive ability (e.g., gender preferred toys, self-confidence, etc.). If a portion of the reason women are not entering the science field is because they lack the logical thinking skills, then it will be interesting to see if training targeting these skills can improve female logic and spatial abilities and therefore encourage more women to major in a science.

**Overview of Spatial Ability**

*Spatial Ability as Defined in Literature*

Gardner defined a students’ spatial ability as the potential to recognize and use
patterns of wide space and more confined areas. According to both Smith (1964) and a meta-analysis by Linn and Peterson (1986) there are three types of spatial ability: Spatial orientation, mental rotation and spatial visualization. Spatial orientation is the ability to recognize how large scenes such as a landscape or countryside appear after a change in viewpoint while avoiding distractions. Mental rotation is the ability to visualize objects in two dimensions (2-D) or three dimensions (3-D) and mentally rotate them. Finally, spatial visualization is the ability to solve multistep problems that are spatially oriented (Linn & Petersen, 1986; Smith, 1964). Psychologists have evidence that strong visuospatial skills and working memory may be at least as good as verbal skills and working memory as indicators of general intelligence (Miyake et al., 2001).

Spatial ability refers to representing, transforming and recalling symbolic 3-D information. There are three categories recognized in literature of spatial ability (Linn & Petersen, 1985). The first is spatial perception (orientation above): This measures a student’s ability to determine spatial relationships with respect to their own body while ignoring any distractions. An example of this type of test is the rod and frame test that instructs a person to visualize a rod vertically while viewing the frame oriented at 220° (Wikin, Dyke, & Faterson, 1962). Corballis and Roldan (1975) witnessed the cognitive rationale most participants used to answer questions on spatial perceptions. These researchers found that most participants process spatial perceptive questions by visually rotating either the paper or tilting their head. Also, in order to overcome distractions (dis-embedding) while performing these tasks, the participants either ignored them or corrected for them (Corballis & Roldan, 1975).
The second type of spatial ability is mental rotation, which is a measure of how accurately and rapidly a student can mentally rotate 2-D and 3-D objects. Educational tools used to measure this ability are the Shepard-Metzler Mental Rotation Test (MRT) (Shepard & Metzler, 1971) and the Purdue Visualization of Rotations (ROT) test (Bodner & Guay, 1997). Shepard and Cooper (1982) examined the cognitive rationale involved in a mental rotation activity. They hypothesized that during a mental rotation the participants' (with true spatial ability) internal cognitive processes aligned with the external rotation of the object (i.e., a Gestalt process governs the rotation). The Gestalt process refers to the ability to mentally rotate a whole figure instead forming just a collection of simple lines (Ellis, 1999). These students hold the whole 3-D figure in their mind and rotate it instead of using partial clues on the object. Participants who lacked in spatial ability were found, in the amount of time given to process, to be unable to complete the mental rotation; these participants tended to use analytical processes in rotating the object (Shepard & Cooper, 1982). Therefore it is important for mental rotation tests to have a minimal amount of time so that Gestalt reasoning is required to gain the greatest score and analytical processing is minimized.

The final component to spatial ability is spatial visualization that refers to the ability to synthesize complicated, multistep spatial information. This ability can involve both spatial perception and mental rotations. Spatial visualization tasks are measured by the Paper Folding Exam, Block Design Exam and the Guildford-Zimmerman Spatial Visualization (Linn & Petersen, 1985). The cognitive processes involved in spatial visualization are multiple analytical processes. A successful performance involves
flexibility of mental strategy where memory is involved to advance to the next visualization step. Mental rotation steps involve Gestalt reasoning and the perception steps involve kinesthetic operations (Linn & Petersen, 1985). Many different analytical and mental strategies are involved to successfully spatially visualize a multistep problem.

When analyzing age and spatial ability, a study investigated the age when the average student developed their spatial ability. Age is important to study because educators need to know when it is appropriate to introduce spatial material to the classroom of students. Many teachers represent molecules in 2-D and expect students to be able to visualize them in 3-D, and the younger students might not yet have skills developed to view them spatially (Barke, 1993). Barke, based on these findings, wanted to determine the minimum age the average student begins to develop their spatial skills. The sample consisted of 7-9th grade students \( (N = 50) \). In the first phase of the study, logic and spatial exams were administered to students in order to determine the correlation. In the second phase, the researchers had students play with chemistry models for several hours and then evaluated the change over time of the administered pre/post spatial exams. The study concluded that, “Spatial ability with respect to structural chemistry has not developed sufficiently until eighth grade at the age of 14. Before this time, spatial relations cannot be recognized by the majority of students” (Barke, 1993, p. 969).

*Academic Success and Spatial Ability*

In the chemistry field, students are expected to visualize and manipulate 3-D
molecules for crystallography, group theory, R,S configurations, synthesis, etc. according to Habraken (2004). Thinking in chemistry has transformed from only logical algorithmic skills to also including visual-spatial skills (Habraken, 2004). The importance of spatial intelligence in chemistry has been widely documented (Bodner & Guay, 1997; Linn & Hyde, 1989; Shea et al., 2001; Tversky, 2004; Wu & Shah, 2004). To investigate science through the ideas of molecules, atoms and relationships amongst them a variety of representations, such as models, chemical structures, formulae, equations and symbols are needed (Hoffmann & Laszlo, 1991). A typical organic synthesis problem is multistep and highly spatially oriented. Chemical representations of molecules are presented in 2-D but symbolize a 3-D spatially oriented object; these symbols are the spatial language of chemists (Habraken, 2004). Therefore upon visual analysis it seems that spatial ability is very important to succeed in chemistry.

In chemistry textbooks spatial visualizations are used to communicate concepts to the students (Noh & Scharmann, 1997). Noh and Scharmann reported that students at the college and secondary levels were having difficulties translating molecular objects into symbolic representations. For instance, to identify R,S configurations a student is required to translate a 2-D representation of the molecule into a 3-D representation, mentally rotate the molecule and compare the structures. In addition students usually have difficulty perceiving molecules on a microscopic scale since textbooks convey them macroscopically. Students did not realize that Cl₂ was a multitude of chlorine molecule in the reaction not just one molecule (Krajcik, 1989). Students also have difficulties visualizing 3-D representations of chemical formulae and electron configurations.
Chemistry is a very visual science that tends to be represented two-dimensionally and flat, and it takes a spatially gifted mind to fully understand and appreciate the science. Students need spatial visualization training and practice in order to fully comprehend that most chemistry textbooks used within the classroom only illustrate part of the picture.

**Algorithmic and Spatial Abilities**

Mathematics is also heavily involved in many chemistry disciplines and the idea that mathematics is a visual-spatial subject is reported throughout literature, dating back to a 1954 Einstein paper (Lean & Clements, 1981). Meehan (1984) found that spatial ability might even be linked to success in Piaget’s proportional reasoning. Piaget even suggested there is a relationship between spatial reasoning and the formal reasoning on the projection of shadows’ test (Piaget & Inhelder, 1967). Therefore, to succeed as a scientist there is an intertwined relationship between mathematics, logical reasoning and spatial abilities.

Bodner is a chemical education researcher dedicated to studying the effects of spatial ability and chemistry academic success. The following are summaries of many of his important findings. A study by Bodner, McMillen & Greenbow (1983) investigated the relationships between spatial ability, verbal and numerical skills to students’ performance on a first-year college chemistry course ($N = 700$). The study used verbal and mathematics scores from the SAT and the Purdue Visualization of Rotations Test (ROT), Find-A-Shape-Puzzle, embedded figure test and successive figures test to measure spatial ability. To measure achievement in the classroom, sub-scores were
calculated using the course exams. The results indicated colinearity between mathematics scores and the scores on the spatial exams. Males did significantly better on the mathematics scores, ROT, FASP and the chemistry sub-scores. These results suggest that spatial ability plays a significant role in chemistry achievement and women need more training in spatial ability to help them improve chemistry scores (Bodner, McMillen & Greenbow, 1983). Another study by Pribyl and Bodner (1987) reported that correlations were found in an organic chemistry course where students were able to successfully manipulate 2-D representations of molecules for exam sub-scores. The study concluded that students with superior spatial ability are better at “understanding the problem.” Also, the study discovered that students with higher visuospatial abilities tended to draw more preliminary figures to aid them in problem solving of non-apparent spatial problems that were solved correctly compared to students with lower spatially ability. Bodner concluded that the figures drawn help to convey information to the more spatially oriented mind aids them in spatially organizing and representing the concepts in the problem (Pribyl & Bodner, 1987). Another study by Carter, LaRussa and Bodner (1987) compared general chemistry success and spatial ability. A correlation between spatial ability and performance in a general chemistry course was found for highly spatial tasks such as ion solid structures ($r = 0.29$) and stoichiometry questions ($r = 0.32$). Again, correlations were found between problems that use more problem-solving skills rather than rote memory or simple algorithmic problems. Finally, Bodner and Guay (1997) reported that scores on spatial tests contribute a small, but significant measure of successful performance in chemistry. These researchers found that spatial
ability was highly correlated with the ability of students to dis-embed and restructure relevant information from verbally complex problems that are an integral part of problem solving in lower levels of chemistry. The Bodner and Guay (1997) study found that students with high spatial scores do significantly better on questions that require problem-solving skills, such as completing a reaction or outlining a multi-step synthesis, and questions that required students to mentally manipulate 2-D representations of a molecule. Spatial ability was not significant, however, for questions that could be answered by rote memory or by the application of simple algorithms.

In contrast other studies have found no correlation between spatial ability and success in a science classroom. Baker and Talley (1972) found no correlation between visualization skills and chemistry achievement. Also, high school students’ ability to translate chemistry representations did not correlate to spatial ability but did correlate to reasoning and prior knowledge (Keig & Rubba, 1993). There are several reasons why these studies might not have a significant correlation of spatial ability and chemistry success. First, in the Keigh and Rubba study, during the interviews the students suggested their low scores on the Ball and Stick model exam were due to lack of content knowledge and not their spatial ability. Second, each study listed had a small sample group: Keigh and Rubba used 42 college students and Baker and Talley used 52 college students (Baker & Talley, 1972). The effect of spatial ability and chemistry success has been small but significant indicating that a larger sample size would be needed to possibly produce a significant result (Wu & Shah, 2004).
Gender Differences and Spatial Ability

When comparing gender differences, studies indicate that men tend to outperform women in spatial ability when measured using the ROT Test (Bodner & Guay, 1997; Brownlow, McPheron & Acks, 2003). One study even implied this could be a factor discouraging women to enter the science field (Brownlow et al., 2003). The Brownlow et al. study focused on determining the difference of spatial ability in gender versus extent of science taken. The participants (N = 129) were from a liberal arts college who either had no chemistry, beginning chemistry (no organic) or advanced chemistry. A student’s spatial ability was measured using the ROT and questionnaires were given to determine a student’s difficulty taking the test, and another questionnaire was given to get personal information such as years of science taken, GPA, and hours/week playing video games. Also students' grades were obtained by the professors for those in general chemistry to be analyzed using ANOVAs to determine the results.

The conclusions drawn were that on average men did better than women on the spatial exams but only when limited number of science courses had been taken. The more science courses taken or when no science course was taken there was no statistical difference between genders. It was also found that as women take more science courses the difference between spatial ability of men and women begins to decrease so women should not be discouraged based on entering exposure to science study. “Training in rotation may thus help women believe that they can succeed and master necessary concepts, thus increase both liking of the physical sciences and a desire to pursue chemistry” (Brownlow et al., 2003, p. 375).
A study by Coleman and Gotch (1998) using the subset of the 12-question Inventory of Piaget’s Developmental Tasks to measure spatial ability compared the results between genders. The sample consisted of general chemistry for science majors \((N = 755)\) from the early 1980-1990s. The study found a statistical gender difference favoring male students in spatial ability. The gap was found to be larger during the beginning of the study and gradually began to become smaller; the reason given was because the male students showed a declining cognitive ability while the female students remained the same. The study concluded that the male students in particular were less prepared in formal thought when entering freshman chemistry in the 1980s than from the 1990s (Coleman & Gotch, 1998).

In a meta-analysis to determine gender difference in spatial ability, a significant result on average favoring male students \((d = .26)\) was found. When separating results by age, a mean difference amongst adolescents (younger than 18) favored male students \((d = 0.37)\) and for older students \((d = 0.64)\). The mental rotations exam that gave the greatest gender difference was the MRT that showed a substantially large effect size \((d = 0.94)\). The study concluded that mental rotation was the spatial ability factor that separated the gender gap the most (Stumpf, 1995).

There have been many studies focusing on mental rotation specifically finding that men rotate images quicker (Kail & Pellegrino, 1979) and more accurately. Success in chemistry, particularly organic chemistry, has been linked to superior mental rotational skills (Coleman & Gotch, 1998; Walter, Roberts & Brownlow, 2000). A study by Brownlow and Miderski (2001) found that the difference in mental rotation between
male and female students might contribute to the lack of women studying science. The study focused on students with no science background who were enrolled in a psychology class ($N = 22$) and compared them to students who have taken science courses (enrolled in organic chemistry, $N = 22$). Each student completed a 12-item Vanderberg and Kuse MRT. There was no statistical difference between gender when enrolled in organic chemistry suggesting that taking chemistry courses improved female confidence and ability in mental rotations as compared to students with no science background.

Investigating the reason the gender gap in spatial ability has occurred is important. A literature review article by Tracy (1987) traced the relationship between children playing with toys and their spatial, science and mathematics abilities. The sample consisted of children ranging in age of 3-13. After analysis it was first determined that gender plays a role in toy playing selection. Boys tend to play a wider variety of toys compared to girls. In addition, boys tend to play with more spatially oriented toys and girls tend to play with more verbally oriented toys. When analyzing studies comparing a child’s spatial ability to gender, it was found that males have a higher spatial ability on average that could be due to childhood toy selection. In connecting this idea to science success, many studies have concluded that spatial ability positively correlates with science and mathematics success; therefore, since males tend to play with a wider variety of spatial toys, they have greater spatial, mathematics and science abilities compared to females (Tracy, 1987).
Another study concluded that male students take more science classes (chemistry, mathematics, engineering) in their leisure time than females leading to a greater spatial ability (Stericker & LeVesconte, 1982). Other studies have focused on the discouragement female students receive from teachers and peers about their spatial abilities, which tends to lower their confidence (Arlington, Leaf & Morachan, 1992; Baenniger & Newcombe, 1989). Some studies have even suggested that genetics and hormones play a role in sex differences when comparing spatial abilities (Peterson, 1980; Wittig, 1979). Though there has been dispute about when the spatial gap begins to emerge or even the extent of the gap, most researchers agree that there is a difference between male and female students’ spatial ability. Through practice it might be possible to eliminate this gap so females have an equal chance in ability to succeed in the chemistry classroom.

*Practice and Spatial Ability*

The right hemisphere of the brain is responsible for visual, perceptive, synthesizing, and spatially oriented tasks (Springer & Deutsch, 1998). Therefore training of the right hemisphere of the brain should increase spatial awareness in students. Many studies have focused on the effect of practicing spatial ability (Baenninger & Newcombe, 1989; Bodner & Guay, 1997; Malinowski, 2007; Malone, 1981; Shea et al., 2001; Tuckey & Selvaratnam, 1993). A study using 11- to 20-year-old participants (N = 3,360) studied the effects of training and improving response time to mental rotations. The participants were training using letters in different orientations and were asked to mentally rotate them to a specific orientation. Over the trial the
participants significantly improved their response time of the mental rotations (Kail & Park, 1990). Another study used a video game for 4-weeks for exercising spatial ability skills. The results indicated that participants' spatial skills were significantly increased according to pre/post exam statistics on the MRT (Feng, 2007). Lohman and Nichols (1990) focused on spatial intelligence to determine if practice can enhance a person’s spatial ability. In the first experiment, participants were given practice with 1,200 different spatial problems over three training sessions. Comparing pre/post exam scores on four different spatial exams found was an average gain in spatial ability of over 1-standard deviation. In the second experiment, the researchers wanted to determine if gains in the first study were due to just taking the same spatial exam twice. The same pre/post exams were given with the same delay period, and it was found that after a correction the gain in Study 1 was mainly due to familiarity of the spatial test. However, though it was found that the females still significantly improved on the spatial exam even after correcting for test familiarity. Therefore, those students who have needed to most improve in spatial ability can gain it through practice (Lohman & Nichols, 1990).

Linn and Hyde (1989) suggested that if enough training and practice are given to female students in spatial ability, then the gender gap begins to diminish.

Many studies investigating the effects of practicing spatial ability have observed effects in science achievement. Studies have found that using molecular models in the classroom have improved both chemistry and spatial skills measured on recognized exams (Lazarowitz, Hertz-Lazarowitz, 1994; Talley, 1973). One such study focused on spatial training and the effects that could be seen in an organic classroom at a small
liberal arts school \((N = 67)\). Through observation, results were noted that students were able to improve their skills in using an organic model kit and apply that learning to the classroom (Small & Morton, 1983).

One study found that molecular models that help improve spatial understanding could have greater effect on students when the learning tool is actually animated and dynamic (Ferk, Margareta & Andrej, 2003; Kaufmann-Goetz & Kaufmann, 1976; Tuckey & Selvaratnam, 1993). The study found this observation to be due to the fact that the learner has the ability to control the animation and manipulate it to help develop their spatial skills (Wiley, 1990). One study sampled 97 tenth-grade students taking high school chemistry to determine the effects of using computerized 3-D models to teach students spatial ability related to chemistry (e.g., molecule rotations). The students were split so half of the sample was a control group and only received traditional lectures in chemistry. The software tool used to train students in chemical spatial ability was Desktop Molecular Modeler that allows students to build 3-D molecules and rotate them while getting feedback from the program explaining energy minimization. The tools used to measure chemistry aptitude and spatial ability were the Structure and Bonding Achievement Test and Eckstrom Spatial Ability Test, respectively. Results showed significant gains in chemistry and spatial ability of the experimental group compared to the control \((p < .001)\). These results indicated that incorporating 3-D computer programs that students can manipulate have an impact on improving chemistry and spatial reasoning (Barnea & Dori, 1999).
Pilot Study: Importance of Spatial and Logic Abilities in the Chemistry Classroom

To evaluate the importance of logic and spatial abilities an initial descriptive and predictive study was performed using a population similar to the present study. In the pilot study 132 of 251 students taking an entry-level, first semester general chemistry (gen chem I) course at the University of North Texas (UNT) were targeted after correcting for students with incomplete datasets. The anticipated gender, racial/ethnic composition, age range, and health status of the study population are reflective of the current population of UNT students enrolled in lower division chemistry courses:
Average age range from 18-22; 45% female, 55% male; 50% White, 25% Black, 15% Hispanic, 8% Asian and 2% other. Each academic instrument chosen to measure the selected variables was given as pre/post exams. Each exam was analyzed using multiple linear regressions to understand the relationship of chemistry readiness, logic ability and spatial skill and the chosen instruments' ability to predict chemistry success. Using both standardized beta weights and structure coefficients in a multiple linear regression model, it can be determined which variable is the most important in predicting success in the chemistry classroom. The research questions analyzed are the following:

1. What is the predictive power of chemistry readiness, logic ability and spatial skill for first-year chemistry success?

2. Is there a statistical mean difference between chemistry readiness, logic ability, spatial skill and general chemistry success compared by gender?
3. Is there a statistical difference between pre/post tests for logic ability, spatial skill and chemistry knowledge gained?

The instrument chosen to measure chemistry readiness and the amount of chemistry knowledge gained was the California Chemistry Diagnostic Exam (CA Dx). The CA Dx exam is a chemistry placement test used to determine how ready high school students are for first semester general chemistry. This 44-item chemistry placement exam published by the American Chemical Society (ACS) covers topics such as compounds and elements, states of matter, reactions of matter, structures of matter, periodic properties, solutions, qualitative kinetics, thermodynamics, lab skills, and mathematics (Division of Chemical Education Exam Institute: American Chemical Society, 2010). The instrument chosen to measure spatial skills was the Purdue Visualizations of Rotations (ROT) test. The ROT test is a 20-item assessment that is given in a 10-minute time period. Logic ability was measured using the Group Assessment of Logical Thinking (GALT). The GALT is a 12-item, 20-minute assessment of logical thinking based on the Piaget model.

All variables were examined for missing data prior to conducting the analyses, and any subjects with missing data were eliminated from further investigation. Descriptive statistics were examined for all three variables: Prior knowledge, logic ability and spatial skills. Skewness was found to be fairly close to zero; prior knowledge was found to have a slight positive skew while both logic and spatial ability have a slight negative skew (see Table 1). Kurtosis was also found to be close to zero for all
variables. The results from both the skewness and kurtosis statistics indicate a fairly normal distribution of these data.

Table 1

Descriptive Statistics for Pilot Study Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Instruments</th>
<th>$\bar{x}$</th>
<th>SD</th>
<th>Skew</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge</td>
<td>Pre CA Dx Exam</td>
<td>16.80</td>
<td>4.98</td>
<td>0.76</td>
<td>0.92</td>
</tr>
<tr>
<td>Logic Ability</td>
<td>Pre GALT</td>
<td>7.86</td>
<td>2.28</td>
<td>-0.48</td>
<td>-0.36</td>
</tr>
<tr>
<td>Spatial Skills</td>
<td>Pre ROT test</td>
<td>12.21</td>
<td>4.17</td>
<td>-0.27</td>
<td>-0.62</td>
</tr>
</tbody>
</table>

Pilot Study: Research Question 1

The data were screened for the presence of outliers by calculating the standardized residual scores. The data appeared to fit within the normal probability for each occurrence. These data were also examined for any violations for the multiple linear regression assumptions. Correlation coefficients were examined between variables and none of the correlations were found to be greater than 0.60 suggesting they are not closely related and therefore measuring distinctly different attributes of the beginning students' profile.

A multiple linear regression was conducted using SPSS version 16.0 for Windows to determine the importance of each variable (i.e., spatial and logic abilities) in predicting chemistry success as defined by their score on the post CA Dx exams and to determine the variance explained by each variable. Prior knowledge (as determined by the pre CA Dx) had the highest correlation with the post CA Dx exam so it was entered first into the regression. The variable produced an $R^2$ of .295 ($F = 54.48$, $p < .001$). Second, logic and spatial ability variables were added into the regression and produced
a new $R^2$ of .436 ($F = 32.95, p < .001$) resulting in an additional 14% variance explained (see Table 2).

Table 2

_Pilot Study Regression Summary of Prior Knowledge, Logic Ability and Spatial Skills:

Variables Effecting Chemistry Success_

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>$R^2$</th>
<th>$\Delta R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regression</td>
<td>1104.5</td>
<td>1</td>
<td>1104.514</td>
<td>54.476</td>
<td>.001</td>
<td>.295</td>
<td>.000</td>
</tr>
<tr>
<td>Residual</td>
<td>2635.9</td>
<td>130</td>
<td>20.276</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3740.8</td>
<td>131</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regression II</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regression</td>
<td>1630.1</td>
<td>3</td>
<td>543.372</td>
<td>32.959</td>
<td>.001</td>
<td>.436</td>
<td>.140</td>
</tr>
<tr>
<td>Residual</td>
<td>2110.2</td>
<td>128</td>
<td>16.486</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3740.3</td>
<td>131</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Because the final regression model produced a significant and large effect, the standardized beta weights and the structure coefficients were further analyzed for each variable. Each variable was found to be significant within the regression model. A students’ prior knowledge was the best predictor of chemistry success and explained nearly 68% of all the variance ($\beta = .425$, $r_s^2 = .677$). A student’s logical reasoning ability was the next best predictor of chemistry success and was able to still explain 53% of the variance ($\beta = .261$, $r_s^2 = .528$). Finally, spatial skill is still a good predictor of success because it can explain 39% if the variance ($\beta = .194$, $r_s^2 = .390$) (see Table 3).
Table 3

*Summary of Beta Weight and Structure Coefficients for Pilot Study*

<table>
<thead>
<tr>
<th>Predictor (Assessment)</th>
<th>$B$</th>
<th>$\beta$</th>
<th>$r_s$</th>
<th>$r_s^2$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge (CA Dx Exam)</td>
<td>.456</td>
<td>.425</td>
<td>.823</td>
<td>.677</td>
<td>.001</td>
</tr>
<tr>
<td>Logic Ability (GALT)</td>
<td>.612</td>
<td>.261</td>
<td>.295</td>
<td>.528</td>
<td>.001</td>
</tr>
<tr>
<td>Spatial Skills (ROT test)</td>
<td>.248</td>
<td>.194</td>
<td>.217</td>
<td>.390</td>
<td>.012</td>
</tr>
</tbody>
</table>

Analyzing the standardized beta weights and structure coefficients together gives a complete interpretation of these data. The structure coefficients can be used to determine the predictive power of each predictor variable and the beta weights can indicate the importance of the predictor variable for the specific equation (Henson, 2002). Using these data the predictive power and importance of the variables assume the following order: Prior knowledge, logic ability and finally spatial skills. Each variable was found to be significant ($p < .05$) and are important in predicting success in the chemistry classroom.

*Pilot Study: Research Question 2*

The data were screened for the presence of outliers by calculating the standardized residual scores. All the data appeared to fit within the normal probability for each occurrence. These data were also examined for any violations for the $t$-tests assumptions. A $t$-test was conducted using SPSS version 16.0 for Windows to determine if there was a statistical mean difference between each variable (chemistry readiness,
logic ability and spatial skills) and gender (see Table 4). It was determined that there was no statistical difference of prior knowledge between genders ($t = 1.32, p < .189$).

When comparing logic ability between genders there was a statistical difference between genders ($t = 3.54, p < .001$). Finally, when comparing spatial skills between genders there was a statistical significant result found ($t = 5.11, p < .001$). When the results of the post CA Dx exam are included to determine if there is a difference between genders on chemistry success, it is found that a statistical significant result occurred ($t = 2.18, p < .030$). These results are consistent with several other research studies conducted on gender where males outperform females (Antasi et al., 1984; Bird, 2010; Bodner, McMillen & Greenbow, 1983; Grant & Eiden, 1986; Meehan, 1984; Tracy, 1987).

Table 4

_Pilot Study Summary of t-Tests Results between Gender and Prior Knowledge, Logic Skills and Spatial Ability_

<table>
<thead>
<tr>
<th>Variable (Assessment)</th>
<th>$\bar{X}$</th>
<th>$SD$</th>
<th>$N$</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge (Pre CA Dx Exam)</td>
<td>Male: 17.32</td>
<td>5.22</td>
<td>71</td>
<td>1.32</td>
<td>.189</td>
</tr>
<tr>
<td></td>
<td>Female: 16.18</td>
<td>4.64</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Skills (GALT)</td>
<td>Male: 8.48</td>
<td>2.18</td>
<td>71</td>
<td>3.54</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Female: 7.13</td>
<td>2.18</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Ability (ROT Test)</td>
<td>Male: 13.79</td>
<td>3.99</td>
<td>71</td>
<td>5.11</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Female: 10.37</td>
<td>3.61</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry Success (Post CA Dx Exam)</td>
<td>Male: 30.49</td>
<td>5.49</td>
<td>71</td>
<td>2.18</td>
<td>.030</td>
</tr>
<tr>
<td></td>
<td>Female: 28.49</td>
<td>4.98</td>
<td>61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pilot Study: Research Question 3

The answer to the last research question determined if taking a general chemistry course can increase students' logic and spatial skills. It is important to investigate if these skills can be learned and therefore improved. These data were screened for the presence of outliers by calculating the standardized residual scores. All the data appeared to fit within the normal probability for each occurrence. These data were also examined for any violations for the \( t \)-tests assumptions. A \( t \)-test was conducted using SPSS version 16.0 for Windows to determine if there was a statistical mean difference between pre/post exams for each variable (logic ability and spatial skills). As reported in Table 5, the improvement of logic ability by taking a general chemistry course was analyzed using pre/post GALT scores and a statistical significant result was found (\( t = 5.44, p < .001 \)). Improvement in students' spatial skills were analyzed using the difference between the pre/post ROT test, upon analysis a statistical significant results was found (\( t = 8.45, p < .001 \)).

Table 5

Pilot Study Summary of \( t \)-Tests Results between Difference in Pre/Post Exam Scores

Measuring Logic Ability and Spatial Skills

<table>
<thead>
<tr>
<th>Variable (Assessment)</th>
<th>Pre:</th>
<th>SD</th>
<th>( r^2 )</th>
<th>( t )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic Ability (GALT)</td>
<td>7.87</td>
<td>2.26</td>
<td>.466</td>
<td>5.44</td>
<td>.001</td>
</tr>
<tr>
<td>Post: 8.70</td>
<td>2.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Skills (ROT test)</td>
<td>12.21</td>
<td>4.17</td>
<td>.477</td>
<td>8.45</td>
<td>.001</td>
</tr>
<tr>
<td>Pre: 14.63</td>
<td>3.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Discussion of Pilot Study

The interpretation of the multiple linear regressions from research question 1 implies that students' prior knowledge is the most important factor to predict success in a college general chemistry course. This is consistent with the unified learning model (ULM) of Shell et al. (2010). This suggests how important it is for high school teachers to successfully teach chemistry material to students. A student's logic and spatial skills were also shown to be very important to succeed in the chemistry classroom. A scientist needs logic skills to solve complex problems and spatial skills to manipulate 3-D molecules so this was not a surprising result.

After analysis of chemistry readiness, logic ability and spatial skills compared to gender, it was concluded that each gender had statistically equivalent amount of chemistry prior knowledge entering the chemistry classroom. Interestingly, male students performed better on the post CA Dx exam than females suggesting there is more than a student’s prior knowledge that effects how they will perform in the course. After examining the difference in scores on the logic and spatial exams, it was concluded that the male students had superior logic and spatial awareness compared to the females. This suggested that the greater logic and spatial awareness found in male students aided them in succeeding in the gen chem I course further supporting the importance of logic ability and spatial skills.

Finally, the difference between pre/post exams measuring logic and spatial skills were investigated to understand if a student could improve his/her logic and spatial abilities therefore suggesting these skills can be learned. The results illustrated that
both logic and spatial skills were improved on average for each student in the classroom by taking a gen chem I course. This result is promising because it implies that students can improve their logic and spatial skills and therefore improve their success in a college chemistry classroom. In this dissertation study it will be investigated if practicing logic and spatial skills using cybertechnology will improve students' success rate in the gen chem I course at greater rate than is typical of a traditionally taught gen chem I lecture class.

Effective Use of Cybertechnology in the Classroom

Digital gaming is a multibillion-dollar empire in the United States as indicated by sales of 221 million games worth $6.9 billion in 2002 alone (Entertainment Software Association, 2010). The youth in the U.S. (under 18) account for 38% of the current video game players (Entertainment Software Association, 2010). Digital games are widely popular and enjoyed by the general public, and for these reasons educators are interested in using them in the classroom to help motivate students and hopefully allow students to enjoy learning. Digital games have been found effective tools in educational learning (Cordova & Lepper, 1996; Ricci & Cannon-Bowers, 1996). There have been many studies also suggesting that educational cybergames are highly motivating for students (Malone, 1981; Rosas et al., 2003). Given these benefits the use of digital games in the classroom to improve learning and motivation is where the future of academe is headed, but increasing a student's ability to attend to a problem for an extended period of time continues to be an exacerbating variable.
According to Mayer’s cognitive theory of multimedia learning, students learn most effectively with visual and audio stimulation via technology animation (Mayer, 1999). This is a branch of the constructivist theory developed by Bruner, who developed a learning theory based upon the idea of students as active learners. Students learn by drawing connections to their prior knowledge (Bruner, 1960). Students need to actively participate in the learning processes by selecting the information they feel is the most important, then reflect on the concept and connect it to prior knowledge and finally construct their own understanding of the concept (Kearsley, 2010). The constructivism philosophy is based on the idea that our own experiences and prior knowledge construct our perception of the world. Constructivism views every student as unique and having their own social background and prior knowledge; therefore, students will construct their own meaning of knowledge differently (Bruner, 1960). The prominent theme in the constructivism theory is that the student is an active learner. Students are responsible for their own learning outcome, not the teacher. Incorporating Mayer’s technology theory with constructivist theory, research suggests that students will actively be engaged to learn when using cybertechnology games due to visual and audio stimulation that may prove to be motivators for exploring information at a greater depth.

Implementing active-learning methods and incorporating learned logic and spatial skills into cyber-learned materials give students relevant ways to build upon the already formed foundation. In this new age of intermittent learning, this technology can be used to our advantage as long as the tools are developed that lead directly to the
desired outcomes and continually reward students as they improve through immediate recognition. Malone found that cyber-learning activities provide students with challenge, concrete feedback and a clear gauge for success to build motivation and learning (Malone, 1981). Using cybertechnology in the classroom has shown to intrinsically motivate students, meaning they are engaged because they choose to be (Malone, 1981). When a student is intrinsically motivated, they tend to spend more time learning and enjoy what they have learned (Malone, 1981). When students are playing games they usually described as “fun,” they tended to spend more time playing them hence increasing intrinsic motivation (Rosas et al., 2003).

An important extension of intrinsic motivation is continued motivation (Maehr, 1976). Continued motivation can be defined as continued engagement on an idea or concept that was originally confronted or learned in a instructional context (Maehr, 1976). For example, if a student learns the concept of electrochemistry in the classroom then proceeds to read more information on the topic on his/her own time even going to the extent of building his/her own battery, then he/she is motivated beyond the classroom setting. Continued motivation in science can lead to a better performance in the science classroom that ultimately can lead students to choose to work in the science field.

Many other studies have found that computer games can be motivating for students (Reiber, 1991; Rosas et al., 2003; Russel, 1994; Stewart, 1997). Motivation is vital to learning because a student will not learn if he or she is not motivated (Shell et al., 2010). In addition, several studies focused beyond motivation and measured the
use of cybertechnology in the classroom to enhance learning (Feng et al., 2007; Kumta et al., 2003; Oliver & Okey, 1986; Tracy, 1987). One study found when using technology developed by the researchers in a geography classroom that 74% of the experimental group (multimedia group) received a B or higher in the classroom compared to only 27% in the control group (Frear & Hirschbuhl, 1999). Studies previously mentioned also noted that when technology was incorporated into the science classroom, increased students' skills led to higher grades in the class (Frear & Hirschbuhl, 1999; Kaufmann-Goetz & Kaufmann, 1976; Krajcik, 1989; Kumta et al., 2003). The inference made by a review article about incorporating technology into the science classroom concluded that there are many powerful chemical computer programs designed for research and education, and only by incorporating this technology into today's classroom will students' learning of chemical concepts be revitalized (Habraken, 2004).

In this study, cybertechnology was incorporated as a way to intrinsically motivate the students to learn, and it was anticipated that this practice would improve students' logic and spatial skills and therefore promote success in the chemistry classroom. Implementing active-learning methods and incorporating logic and 3-D skills into cyber-learned materials give students a relevant way to build upon the already formed foundation. Dr. Ryuta Kawashima, the developer of Nintendo’s Brain Age™, a multimedia game used to enhance cognitive ability, stated about his game “We expect improvements of memory functions, extroversion, and positiveness. It is important to note here that we think DS [dual screen] games are not only for brain training, but also
for a tool for communication” (Ashcraft, 2006). This is an illustration of how large gaming industries such as Nintendo® are seeing the benefits of developing brain enhancement games that could possibly be used in the classroom. New research is being conducted to understand how the impact of games such as Brain Age™ might be used to engage and enhance student learning (Ashcraft, 2006). In general, the use of educational cybergames has allowed students to enhance their scientific knowledge and think like a scientist while improving students' cognition and self-esteem (Soderberg & Price, 2003).

The educational cybertechnology tool used in this study is Lumosity™: a website dedicated to using cutting edge science to develop tools to exercise the brain and enhance learning (Hardy, 2010). The Lumosity™ labs have developed highly motivating, fun games in their training courses that aid students in logical and spatial reasoning. These games help students combine cognitive processes such as attention, memory processing speed and pattern recognition to draw conclusions and make decisions. The design of the Lumosity™ labs was based on research showing that continuous practice on a learning concept can actually change the shape and size of your brain resulting in higher cognitive abilities on that concept (Drananski et al., 2004; Maguire et al., 2000). Characteristics that make the Lumosity™ training programs effective are targeting, adaptivity, novelty, engagement, and completeness (Hardy, 2010). Targeting the most critical aspects of brain functions leads to maximum benefit of learning. Adapting to individual needs is key to enhancing learning and motivation; each game level is set to a person’s strength and weakness in order not to discourage learning. Novelty of the
cyber-learning games is important in order to effectively exercise the brain; tasks that are too repetitive become mundane and second nature therefore resulting in no new learning. Engagement and rewards are important to encourage students to learn. When the brain is engaged and motivated, it is more open to learning. Finally, the Lumosity™ labs are designed to give the brain a complete workout by promoting learning in memory, logic, and spatial and visual abilities (Hardy, 2010).

The Lumosity™ labs are divided into different cognitive learning courses and each course used in this study on the Lumosity™ Website is developed into sessions; each session contains approximately five short games. Each session only takes about 25 minutes to complete, which allows the player to attain a small goal everyday giving the player a sense of personal achievement. After each game encouragement is always given to student on how well they are doing (Figures 1 and 2). This gives students motivation because it is positive reinforcement that encourages students to do better next time. Also, students are able to graphically see the progress of their development allowing setting achievement goals for themselves further encouraging them to be motivated. All of these combined allow the Lumosity™ courses to enhance a person’s attention and focus skills, so when they are motivated to learn and the student can focus his/her attention on the most important material.

Typical Information Obtained from Lumosity™ Labs

Figures 2 and 3 provide details of summary information available from the Lumosity™ Website that is provided to each participant upon request.
**Figure 1.** Typical "weekly average" print out from Lumosity™ labs regarding a student's brain profile information (BPI) over a 10-week experiment.

**Figure 2.** Example of a brain profile provided by Lumosity™ Labs. (Overall bar indicates that the subject's BPI is 42% better than the mean of other similar participants in that category based on demographic information like gender and age.)

Current ongoing research on Lumosity™ has found exciting new brain training possibilities. An exciting study by Jaeggi, Buschkeuhl, Jonides, Perrig (2008) found that using the Lumosity™ course "Dual N-Back" significantly improved participant’s
performance on a tool measuring fluid intelligence and supported that this intelligence is not fixed. The study included healthy adults with a mean age of 25.6 divided into a control and experimental groups ($N = 70$). Participants trained either 8, 12, 17 or 19 days for 25 minutes depending on experimental group. Every experimental group improved significantly in fluid intelligence compared to the control. In addition, the more days the experimental group trained the more improvement was seen in fluid intelligence (Jaeggi et al., 2008). Other studies have shown similar results of cognitive and memory improvement using the Lumosity™ labs (Kesler, 2008; Scanlon et al., 2006). Lumosity™ is a great educational tool I am excited to utilize within my own study. The effect of how using Lumosity™ Labs to enhance logic and spatial skills in specific subject content (like chemistry) using college-going students in an academic setting has yet to be studied.

Theoretical Perspective of Learning

This research study incorporates several well-established learning theories that are supportive of students learning logical and highly spatial science content. The ULM is a theory that encompasses many learning theories connecting them into a simple model. The ULM focuses on the basic components of learning that are common amongst all learning theories. It is a simple model that can be used to explain all observed learning phenomena. The main components of this model are: Working memory, knowledge, and motivation (Shell et al., 2010). The central component of the ULM is the working memory. The working memory is the location where new knowledge is temporarily stored and processed. Knowledge is defined as everything we
know stored in long-term memory or our prior knowledge. This prior knowledge includes everything from facts, skills, behaviors and thinking processes. Knowledge plays two roles in the ULM: First knowledge is the goal of learning and learning occurs when new knowledge is stored. New knowledge is stored as a result of the working memory processing. The second role of knowledge is being recalled by the working memory to influence learning. Most of our learning is based on building on our prior knowledge because it is easier to build on something we already know creating a schema as described by Piaget (Piaget, 1983). Therefore, working memory creates new knowledge but in order for this to occur memory must first recall one’s prior knowledge to build upon connections. The final component of the ULM is motivation. Motivation is the catalyst to learning (Shell et al., 2010). If a student is not motivated to learn a new concept, the new knowledge will not even be temporarily stored into the working memory. Motivation directs the working memory to learn a new task. There are three basic principles to the ULM in order for a student to learn (Shell et al., 2010):

1. Learning is a result of working memory processing.
2. Working memory capacity is based on prior knowledge.
3. Working memory processing is initiated by motivation.

The Mason research group has modified the ULM of Shell et al. (2010) based on the fact that both training and experience allow learning to occur (Figure 3). We moved “motivation” into “regulation” rather than leaving it in “working memory,” since students use all regulatory functions, not just motivation, to allocate working memory space for learning a new task. Also, a new category of “attention span” has been added.
to “regulation.” The overlap between the “cognition” box and “working memory”
denotes the influence that previous “knowledge” and “regulation” have on the function
of “working memory,” and the overlap of “working memory” and “learning” represents
the connections used in the learning process. The arrows from “learning” to
“knowledge” and “regulation” indicate the incorporation of learned knowledge and
processes into future cognitive processing.

Figure 3. Modified ULM (Shell et al. 2010) by Powell, member of Mason's research
group (unpublished).

According to the ULM, for learning to occur a student must first be motivated to
temporarily store information into the working memory. The working memory processes
this new information by recalling prior knowledge and making new connections. After
new connections to prior knowledge occur, new knowledge is formed creating learning.
Biologically, learning occurs in the cortex of a person’s brain and occurs when the ability of a neuron to fire neurotransmitters is changed or strengthened (Shell et al., 2010). Every time a neuron fires it becomes easier for it to fire again. When a new concept is being learned the working memory recalls prior knowledge from the long-term memory storage and the working memory works to strengthen this connection; therefore, learning does not occur without the working memory. Attention to a concept requires a lot of effort and this is necessary to store the concept in the working memory to become new knowledge (see Figure 4). The ULM biological foundation requires the following (Shell et al., 2010, p. 3):

1. Learning requires attention: For learning to even begin to occur attention to the concept is required.
2. Learning requires repetition: To fully learn a concept the neuron connections need to be strengthened and this only occurs through repetitious learning of the concept.
3. Learning occurs when connections are made through prior knowledge: When new knowledge is connected to prior knowledge (schema) then that concept is strengthened and therefore the neuron firing ability is strengthened.
4. Some learning takes more effort: To deliberately learn a concept, attention is required that takes a lot of effort and dedication.
5. Learning is learning: All neurons are strengthened in the same way so all students learn the same way. The difference is how the student is motivated and the strategies that are employed under the control of the learner.
Motivation

The first stage of the learning processes is motivation. Motivation is psychological and consists of things that impel us to maintain the effort to learn (Shell et al., 2010). Motivation takes effort and concentration; a student needs to focus their attention for an amount of time necessary to new concepts in order to store them in the working memory (Shell et al., 2010). Motivation influences how much working memory capacity is being used (i.e., in order to fill the working memory a person must be motivated to do so). Another component of regulation is attention span. If a student is distracted or bored their attention span is never focused long enough for the experience to become a learned concept. For these reasons it is important to motivate students and to increase their attention span. In learning new concepts a student has to be paying attention and be motivated to even bring this potential new knowledge from the working memory to be processed. A component of attention is focus, which entails paying attention to only the most important information while ignoring the rest (dis-embedding). A focused student is able to avoid distractions and only pay attention to the new concept. Therefore a student in addition to being motivated to learn a new concept must be paying attention and focused. If a student is motivated to learn they will be more inclined to pay attention and stay focused in the classroom.

The question then is “how do we motivate students?” According to the ULM one important theory of motivation to consider is Maslow’s (1954) motivation and personality theory that explains motivation based on a hierarchy of needs. He proposed that people are motivated when their basic needs are met (Maslow, 1954). There are
several general needs everyone has: physiological, survival, safety, love and esteem. In this theory the lower-level needs need to be met before a person can be motivated to meet the others. For instance, a student cannot attempt to learn if they are hungry or tired because physiological needs (sleep, hunger, air, water) should be met first.

According to this theory for students to effectively learn, they need all types of needs met to be motivated to learn (Maslow, 1954):

1. Physiological: breaks, eat meals, snacks, water
2. Safety: Provide a safe learning environment, freedom of harsh criticism
3. Social: Provide a feeling of acceptance and belonging in the classroom, group projects
4. Esteem: Recognize student achievement, set student goals, let student monitor their learning goals
5. Self-actualization: Offer challenging assignments, student appreciation

An important concept of motivation according to the ULM is goal setting. All intentional learning is based on setting and achieving goals. Once a student has a cognitive goal, he/she will exert effort and employ working memory to achieve this goal (Shell et al., 2010). Goals allow students to feel as though they have purpose in learning. Also, as a student begins to meet his/her learning goals, they begin to feel more confident in themselves and in their academic ability. This idea is prominent in Bruner’s cognitive theory that motivation is due to the confidence a student feels about his/her own cognitive ability. Instructors need to initially help the students set small academic goals for themselves that can be easily attained. This will begin to build
students' confidence. One of the reasons that Lumosity™ labs were chosen for this study is because these commercial games have programmed small attainment goals into their system that are triggered in response to individual performance. Over time more challenging goals can be set to give students a healthy motivation to learn. These goals are best achieved when their progress is monitored over time (Kearsley, 2010). Therefore, students are the most motivated when they have their hierarchy of needs met during the learning processes and are working to achieve academic goals.

The learning tool used in this study, Lumosity™, aids students' motivation in two ways. First, the games are developed to help students learn to pay attention and focus on the most important concepts. Attention and focus as mentioned above are important aspects of learning. If students can improve their attention span, they will be able to learn new concepts with ease. New research using the Lumosity™ training tools has shown that attention can be improved (Hardy, 2010). Further, this improved attention ability positively impacts your memory, learning and performance on tests. Games such a Lost in Migration and Playing Koi found on the Lumosity™ Website were developed to improve a person's ability to avoid distraction (dis-embedding ability) and stay focused in order to increase their productivity of mastering the game. These are important concepts to develop to succeed in a classroom setting. In my specific study, I am using the Lumosity™ labs to improve students’ logic and spatial skills to succeed in the chemistry classroom. If the students can learn to pay attention and focus on these concepts while taking exams and learning in the classroom, they should increase their success in the class. Anticipated is that students will be able to transfer their increased
focus and their newly learned logic and spatial skills to affect their success on learning chemistry concepts in a classroom setting.

Working Memory

As stated above the working memory temporarily stores information and creates new knowledge and connections by recalling the prior knowledge. Working memory refers to the limited capacity system that provides both information storage and processing function (Shell et al., 2010). The working memory is necessary for complex cognitive tasks such as learning, reasoning, and comprehending complex problems. This model of working memory was established and developed by Baddeley and Sala (Baddeley & Sala, 1996). The concept of working memory has been supported by neuroscience. One study employed positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) and found that quantitative differences in basic working memory components could account for differences in brain activity and cognitive ability (Cabeza & Nyberg, 2000; Smith & Jonides, 1998).

George Miller established the idea of limited working memory in his information processing theory. This theory states that our working memory has limited storage and its capacity is about 7±2 concepts at one time (Miller G. A., 1956). Working memory seems to be a combination of space (number of elements a person can processes at a time) and speed (how fast these elements can be processed), and relies on how many elements a person can focus on at a time (Shell et al., 2010). This suggests when someone says a student has a limited cognitive ability they are really implying the student has a limited working memory capacity. This is also prevalent in Piaget’s
cognitive learning theory; he suggests that as a person develops cognitively, he/she increases their schemata that connect new knowledge to prior knowledge thereby increasing a student's working memory capacity. Students who have large schemata have developed into formal operational thinkers (Huitt & Hummel, 2003; Piaget, 1983). The more limited the working memory capacity (smaller or no schema) becomes the less a person processes at a time and less learning that occurs.

After the maximum numbers of elements are stored in the working memory, one has to attend to gain new knowledge. When new knowledge is gained a connection to prior knowledge is established. Working memory interacts with long-term memory to establish a pattern matching of knowledge. When a novel concept (element) is temporarily stored to be processed, the working memory retrieves anything connected to the concept from the long-term memory. This new concept is then processed and connected to long-term memory increasing a students’ knowledge leading to new learning (Shell et al., 2010). For this reason, learning is a result of the working memory processing information.

This idea of working memory is similar to Sweller’s cognitive load theory. In the cognitive load theory the working memory is limited to a certain load capacity. The three loads associated with working capacity (Sweller, 1988) are:

1. Intrinsic load: The new information or concept the student is attempting to learn
2. Extrinsic load: Any distractions that occur in the classroom
    a. Talking
    b. Unorganized PowerPoint
c. Images that are not explained well

3. Germane load: This is the “space” needed in the working memory to process the new information (intrinsic load) and make connection to prior knowledge. According to this theory, in order to maximize learning intrinsic and germane loads need to be amplified while limiting the extrinsic load. To increase the amount of knowledge in the working memory a student can “chunk” or create schema of information together as stated by Miller and Piaget. The idea of chunking information and making connections to prior knowledge (schema) highlights the dynamic role of the working memory (Sweller, 1988). The working memory not only temporarily stores the new concept and processes it but it recalls the prior knowledge with similar ideas and cognitive patterns permitting the new information to be stored in long-term memory (knowledge) and therefore allowing the student to learn.

To summarize, the working memory is limited to a certain number of elements or chunks (7±2 bits of information) that at a time can be processed. The new elements learned need to be connected to prior knowledge in order to create new knowledge. A chunk is a connected group of knowledge such as letters in a word or grouping of numbers. Chunks can expand our working memory capacity. Instead of learning seven different numbers a person can learn to group the numbers as seen in phone numbers. For this reason, working memory capacity is not fixed and can be greatly influenced by chunking or schemata as acknowledged by Miller and Piaget. At an expert level, a person is able to easily and efficiently chunk large amounts of knowledge together greatly expanding the working memory as related to a specific field.
In this study students are playing online brain training games that were developed to help increase the working memory capacity by influencing students' ability to chunk knowledge. If a student can learn to efficiently chunk items together this will increase his/her working memory capacity consequently increasing the chance that more new knowledge will be processed and learned.

In this study, the Lumosity™ courses are designed to improve the size of the chunks of information that a person can store. The games developed by Lumosity™ aid students in remembering locations, names, sense of direction in order that the user can recall and make connections to prior knowledge more accurately. Each course chosen to improve the participants' logic or spatial skills incorporates the idea of memory and intelligence so participants can develop into experts with greater chunking capacity. Games such a Familiar Faces challenge students to recall names, faces, and orders to improve their chunking ability in order to maximize working memory capacity. Other games were developed to aid students in recognizing patterns in order to maximize the size of chunks of information. The game Memory Matrix challenges students to remember patterns of squares as they grow larger and more complex. This game helps to improve the persons' sense of their 3-D environments, location of objects, and visual patterns. Some games are also developed to fit the cognitive load model of working memory and incorporate the idea of attention and avoiding distractions in order to minimize the extrinsic cognitive load of the student. An example of this type of game is Playing Koi: This game encourages the user to focus on spatial surroundings while avoiding distractions. The user needs to feed every fish in the koi pond only once; to
succeed the user must pay attention to the fish he/she fed while they are constantly moving at the same time feeding the other fish. The Lumosity™ labs are developed to expand the working memory so students can process information faster and strengthen their connections to their prior knowledge. Processing speed and working memory are also correlated. Processing speed allows a person to think quicker and be more alert and clearer. Games such as “Speed Match” help students to improve their mental processing speed allowing them to improve their working memory processing speed.

Knowledge

Knowledge is “everything we know or can do that is stored in the neurons in our long-term memory” (Shell, et al., 2010, p. 33). According to a biological prospective, knowledge is anything stored in the long-term memory by making permanent changes to the neuron activity. This stored knowledge can be a smell, image, idea or concept that is stored in an organized chunk or even a schema in the long-term memory (Shell et al., 2010). A concept that takes effort to learn (semantic knowledge) for instance, like chemical stoichiometry, takes repetition to be stored in the long-term memory. This concept implies for a student to fully learn a concept they must practice many times and continue to practice. If a student learns a concept and then does not practice for a long period of time, the neurons connected to this concept will become weak and the student will eventually lose this ability in his/her knowledge bank.

A chunk of information stored in a person’s long-term memory is the connections to a single idea when a person interconnects chunks of information to gain new knowledge called a schema. The idea of a chunk of information being stored is found in
Miller’s information processing theory (Miller, 1956) – even though the use of the term, chunking, did not appear until 1973 – while the idea of organized, interconnected chunks into a schema is based on Piaget’s cognitive learning theory (Piaget, 1983). The interconnections of chunks into schemata are what an instructor is attempting to do when teaching students new concepts. An instructor needs to direct students into making connections to their prior knowledge to build on the new concept and encourage learning.

Working memory and knowledge are dynamically connected. The working memory is the area of the brain responsible for temporary storage of thoughts and processing these thoughts by connecting them to a person’s prior knowledge. The working memory capacity is limited but can be expanded by organizing new knowledge into single chunks of information and also interconnecting these chunks into a schema. A single chunk or a network of chunks (schemata) only take up one “space” in the working memory; therefore expanding on chunks and schemata increase a person’s working memory capacity (Shell et al., 2010). This difference in working memory capacity is the difference seen in a novice versus an expert in a particular field of study. Knowledge is important in this working memory process because it supplies the prior chunks and schemata developed by the person to the working memory in order to make connections to the new knowledge. Making connections is important in learning because it strengthens the neurons' firing ability of the concept therefore making it easier to retrieve the next time.
The concept of making connections to prior knowledge is used in this study. Lumosity™ logic and spatial courses are employed to train the students. These games are very repetitious therefore are continually strengthening the connections of new knowledge to a student's prior knowledge. The games operate to improve a learner's working memory that recalls a person's prior knowledge and processes the new information. In our case learning logic and spatial skills make connections and reorganize new knowledge that is then organized with prior knowledge into schemata. In this way the working memory is responsible for organizing and processing schemata. Training to improve the working memory will be beneficial to develop and strengthen a person's schemata. Therefore, not only are students playing games that directly improve logic (arithmetic type games) and spatial abilities but there are also games that incorporate concepts such as attention, chunking and processing to improve working memory that improve the amount of knowledge gained.

The current study investigates the effects of practicing basic logic and spatial skills that can be applied to everyday life and hopefully the chemistry classroom using the Lumosity™ labs as a cyber-learning tool. The Lumosity™ labs follow the ideals of the unified learning theory to aid students in learning basic logic and spatial skills. The games are intrinsically motivating allowing students to become excited to learn. Also, such games as “Playing Koi,” are training students to avoid distractions and pay attention that can ultimately be applied to the lecture setting. The games are designed to improve working memory by incorporating ideas such as chunking in the game Memory Matrix and increasing mental processing speed in games such as Speed Match.
The games are very repetitious, which allow strengthening of neurons and increased learning and knowledge. Incorporating the ideas of motivation, avoiding distractions, chunking, processing speed and repetition into each course makes Lumosity™ an ideal tool to use in this study. The courses chosen for the students training in logic ability are Problem Solving Boost that targets mathematical and reasoning skills and Speed Boost that targets mental processing speed. The courses used to train spatial ability are Memory Boost, which targets memory and spatial reasoning, and Attention Boost, which targets avoiding distractions peripheral and spatial vision (Hardy, 2010). The group training in the combination of spatial and logic ability are used in the course Basic Training, which targets spatial ability, reasoning, processing speed and avoiding distractions. It is my hope that training in logic and spatial abilities or a combination of both using the concepts of the ULM will improve students' success in the chemistry classroom.
CHAPTER III

METHODOLOGY

This chapter explains the methodology that was used in the study of training entry-level organic I and general chemistry I students in the development of basic logic and spatial skills using Lumosity™ brain-training games to determine the effects on various student assessment measures selected for this research. In this study the philosophical stance of the researcher is one of pragmatism using a mixed methods approach to analyze the data gathered from two different sample populations of convenience: Students studying either general chemistry I (gen chem I) or organic chemistry I (o-chem I). This chapter examines the general methods of the design rationale, describes the demographics of the population studied, and discusses the experiments performed and the assessment procedures followed.

General Methods

Purpose and Research Questions

The purposes of this study were to investigate the importance of logic and spatial skills needed to succeed in the o-chem I and gen chem I classrooms, whether playing cyber-learning games can be used to improve students’ logic and spatial abilities that are also used in chemistry courses, and if practice using this intervention is transferable to improve students' chemistry performance. In particular, this study focused on the use of educational cybergames as a way to motivate students to improve their logic and spatial skills needed to become successful scientists. This study is important to unveil the dynamic relationship between logic and spatial abilities and
academic success in entry-level chemistry courses. The outcomes of this study will allow researchers to understand the importance of logic and spatial abilities in entering the science field, and determine if training in these skills can improve students’ scores in the classroom. Also, it is important to understand the role of cybertechnology as a training tool in the classroom, specifically the training tool Lumosity™. Finally, previous studies in cybertechnology may have over generalized results to all student populations. This study allowed specific data collected at a central Texas public university to be evaluated under a controlled experimental protocol.

The research questions evaluated for this dissertation are:

5. What do student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group?

   H°_{1.1}: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial as measured by scores on the General-Organic-Biochemistry (GOB) 2007 exam and the final course grades compared to the control (non-gaming) group in organic chemistry I on average and over the 10-week intervention period.

   H°_{1.2}: There is no significant difference between students participating in the cybergaming intervention group of combination logic-spatial as measured by scores on the California Chemistry Diagnostic Test 1997 (CA
Dx) and the final course grades compared to the control (non-gaming) group in general chemistry I on average and over the 10-week intervention period.

6. When students participate in cybergame training over the span of 10 weeks, how is student performance on logic ability as measured by the Group Assessment of Logic Thinking (GALT) affected?

$H^{o}_{2.1}$: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial and the control (non-gaming) group in logic ability as measured by the GALT exam on average and over the 10-week intervention in organic chemistry I.

$H^{o}_{2.2}$: There is no significant difference between students participating in the cybergaming intervention group of combination of logic-spatial and the control (non-gaming) group in logic ability as measured by the GALT exam on average and over the 10-week intervention in general chemistry I.

7. When students participate in cybergame training over the span of 10 weeks, how is student performance on spatial ability as measured by the Purdue Visualization of Rotations (ROT) test affected?

$H^{o}_{3.1}$: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial and the control (non-gaming) group in spatial skills as
measured by the ROT test on average and over the 10-week intervention in organic chemistry I.

H₀³,₂: There is no significant difference between students participating in the cybergaming intervention of combination of logic-spatial and the control (non-gaming) group in spatial skills as measured by the ROT test on average and over the 10-week intervention in general chemistry I.

8. What are the effects when participating in cybergame training over the span of 10 weeks between genders as measured by the outcomes on the content diagnostic exams (GOB and CA Dx), GALT and ROT, and final course grade?

H₀⁴,₁: There is no significant difference between genders in organic chemistry I as measured by the scores on the GOB, GALT and ROT and final course averages and grades.

H₀⁴,₂: There is no significant difference between genders in general chemistry I as measured by the scores on the CA Dx, GALT and ROT, and final course averages and grades.

5. What are the experiences and attitudes of general chemistry I and organic chemistry I students using the logic and spatial cybergame training intervention for a span of 10 weeks as measured on a Likert-scale and by responses to an open-ended questionnaire?

Rationale

Logic and spatial cybertraining can be used to attempt to improve students' success in the entry-level chemistry courses. The first research question addressed this
idea; it asked how the cybertraining affects chemistry classroom success as measured on standardized exams and final course grades. The second and third questions addressed the ability of logic and spatial training with cybergaming to improve logic ability and spatial skills as measured on standardized exams. The fourth question explored the effect of combined training on student classroom success in chemistry as it is related to gender differences. These questions combined led us to understand the meaningfulness of basic (non-subject) cybertraining and how it can affect students in lower-level chemistry courses. The final question addressed what the students’ experiences were concerning the Lumosity™ labs and their effect on their chemistry studies. It was important to acquire qualitative data regarding the experiences and attitudes of students to elicit their motivation to continue to play the games after this study concludes.

Research Design

The research methodology used in this study was a pretest/posttest control group/experimental group mixed-methods design, which combined both quantitative and qualitative data in sequential phases of the research process. The design involved systematic random assignment of students enrolled in organic chemistry I (spring 2010) or general chemistry I (fall 2010) to control and experimental groups. Both groups were administered pretests and posttests but only the experimental group received any treatment (cybergaming intervention). The limitations acknowledged support that both qualitative and quantitative methods have limits, but the triangulation of the methods can eliminate most of the biases that can occur (Creswell, 2003). The majority of the
data were quantitative, numerical evaluations that allowed for an unbiased approach in analyzing the data in a mixed method, repeated measures design. This allowed for more generalizable results. The quantitative data focused on pre/post exams given in the classroom to numerically determine the improvement of outcome scores due to treatment. In addition, qualitative closed- and open-ended surveys allowed students to give their own personal opinion on the study without influence that provides a deeper knowledge of the progress of the study (Creswell, 2003). The questions included topics on their personal experiences while participating in the study. The study was conducted in two different classes each supporting different aspects of the study. The first division of the study was used to determine what type of training: Spatial, logical or a combination would better prepare students to succeed in the o-chem I classroom. The final portion of the study was used to investigate the affect on intensifying the spatial and logic training in a gen chem I classroom based on statistical information gained from the study performed in the o-chem I class.

As argued in Chapter II, spatial and logical skills are essential to succeed in chemistry courses. It is pertinent that student are given the proper training in these skills to aid them in future science courses and career choices. The tool used to train students to improve their spatial skills and logic ability in the lower-level gen chem and o-chem courses was the cybergames developed by Lumosity™ Labs. Lumosity™ is a brain-training program that is deeply rooted in the unified learning model (ULM) developed by Shell et al. (2010). This teaching model combines ideas from all learning and teaching theories to better understand how students learn. There are three
principles to the ULM: Working memory, knowledge and regulation. The essence of the model is the working memory, the section of the brain for temporary storage of memories, thoughts and ideas as well as the information-processing center. This part of the brain is where new ideas and concepts are learned and connected to previously acquired knowledge (Shell et al., 2010). Lumosity™ courses are designed specifically to improve a student's working memory. A study in 2006 was conducted using the Lumosity™ labs and their effect on the working memory. The participants in the treatment group improved their working memory significantly ($p < .01$) while the control group did not. The study furthered examined the improvement of spatial skills and executive function, which measures the ability to process multiple forms of information simultaneously. The treatment group improved significantly compared to the control group (Hardy, 2010). Believed is that training the working memory to increase processing speed and cognition will lead students to improve their logic and spatial skills.

Another important aspect of the ULM is regulation. Motivation is central to how regulation affects the ability to direct the working memory to learn a new task. The student has to be encouraged to want to learn a new concept while avoiding distractions (Shell et al., 2010). Lumosity™ has developed games that are motivating and fun for students. The Website offers encouraging supporting information to students on their progress (see Figures 2 and 3, Chapter II). A brain performance index (BPI) is given to students, and over time they are able to watch this number increase with training. Also, graphical information is given on the student’s improvement of
scores. All of this information is fun and encouraging to students so they will be motivated to improve their logic and spatial skills.

The final component to the ULM is knowledge (i.e., everything a student knows and is stored in long-term memory.) The working memory unites information from temporary storage (a new concept) to the knowledge previously learned building on the understanding of the concept (Shell et al., 2010). This is achieved through repetition to strengthen the idea. The Lumosity™ labs expose students to games and concepts many times to ensure the idea is deeply embedded into long-term memory. Practicing according to the ULM is one of the best ways to get new information stored in long-term memory, but can knowledge from cybergaming practice significantly impact chemistry classroom learning?

Demographics

Participants

In this study the sample targeted \(N = 187\) STEM (science, technology, engineering and mathematics) students taking organic chemistry I and general chemistry I courses at the University of North Texas (UNT) in the spring and fall 2010 semesters. The participants chosen for this research were a sample of convenience from professors' classes who were willing to allow their class to participate. UNT is the fourth largest public research university in the state of Texas with over 36,000 students enrolled in various undergraduate and graduate programs. The school currently offers 97 bachelor degrees, 101 master degrees and 48 doctoral degrees. Participants in the organic chemistry course \(N = 99: n_{\text{control}} = 8; n_{\text{logic}} = 29; n_{\text{spatial}} = 30; n_{\text{combination}} = 32\)
had an age range, gender, racial/ethnic composition and classification reflective of the current population of UNT students enrolled in lower division chemistry courses: Age range was from 18-22; 41.4% female, 58.6% male; 50% White, 25% Black, 15% Hispanic, 8% Asian and 2% other; 2% freshmen, 32.3% sophomores, 43.8% juniors, 17.2% seniors and 5.1% post-baccalaureate. No subpopulations were specifically included or excluded and 100% of the population was eligible to participate. In the gen chem I classroom ($N = 88$: $n_{\text{experimental}} = 27$; $n_{\text{control}} = 61$). The sample age range, gender, major and classification are reflective of current population of UNT students enrolled in lower division chemistry courses: age range was from 18-26 (80% under 21); gender: 50.5% male, 49.5% female; intended major: 51.4% biology, 10.8% chemistry, 5.4% physics, 8.1% pre-medical, 24.3% other; and classification: 60% freshmen, 21.1% sophomore, 11.7% junior, 4.2% senior, 3.2% post-baccalaureate. In addition, from self-reported data, 43.2% had completed college algebra, 16.2% had completed college statistics, 40.5% had completed college pre-calculus; 94.6% were right-handed and 5.4% were left-handed; 45.9% did not play video games, 18.9% played for 1 hour a week, 5.4% played 2 hours a week, and 13.5 played 3+ hours a week.

The UNT organic class is designed for science or pre-professional health majors who have completed general chemistry II with a grade of C or better. The organic chemistry section chosen was taught in a traditional lecture style format. The students enrolled in the course were asked to sign an approved IRB informed consent form to participate in the study (see Appendix A). Of the 250 enrolled in both classes only 187
participated (99 from the o-chem I class and 88 from the gen chem I class) due to dropouts, failure to sign the IRB agreement to participate form, being under 18 years of age that excluded participation, and failure to complete the cybergaming intervention, which made the usable population only 74.8% of the potential participants.

Since both experimental classes only provided samples of convenience to the study, in order to improve the experimental strength students were systematically randomized and assigned to treatment and control groups during the first day of class. In order to ensure a high number of volunteers in o-chem I, 20 points (2%) total extra credit for the semester was rewarded to those who finish 95% of the required time. In gen chem I student participants received 45 points (1.8%) of extra credit, but the inflations to final averages were deleted before the data for this study were evaluated. Data collected from the students focused on gender and on pre/post-test scores on the GALT, ROT, and CA Dx (used in gen chem I) or GOB (used in o-chem I) exams.

Teaching Team

The instructor of the organic chemistry course had 5 years experience teaching organic chemistry in a traditional lecture format. He is also the laboratory director and has post-doctoral experience in computational chemistry and synthetic organic chemistry research. The general chemistry professor has over 30 years of teaching experience in general chemistry using a traditional lecture format. She is also involved in many chemical education endeavors both inside and outside the classroom. Neither professor involved in the lecture portion of this study interfered with the intervention protocol, since it was a totally voluntary endeavor on the students' part. The only
student contact in regards to the investigation from either class was with the primary investigator of this study.

**Environment**

The organic and general chemistry classes were taught in large classrooms with less than 150 fixed seats. Each class met Tuesday and Thursday mornings for 90 minutes over 15 weeks throughout the semester. There was also an additional recitation section for the lecture every week for one hour. A typical class period consisted of lectures, questions and answers sessions and worked example problems. In o-chem I there were three exams and final exam that composed the final course grade. In gen chem I there were four exams and a final exam along with required online homework that composed the final course grade. Periodic quizzes occurred in each class that contributed to the final course grades.

**Approval Process**

The first steps for conducting this research were to obtain approval of the research site, the professors, the participants and the University of North Texas' IRB. Approval of the site and classroom consents were obtained from the participating professors by verbal agreement. An application for approval for the study of human subjects was submitted to the IRB (see Appendix A). The first study's approval was granted through September 2, 2010. An extended approval was obtained to complete the study in the fall 2010 and was extended until February 2, 2011 (see Appendix A).
*Lumosity™ Labs*

The Lumosity™ labs have developed games that are motivating to play. As mentioned before digital games are found to be intrinsically motivating (Malone, 1981) by involving students to become excited to learn. These games are fun and enjoyable making them easier to engage in for longer periods of time. The courses used in this study on the Lumosity™ Website were arranged into sessions, each session containing about five short games. One session only takes about 25 minutes to complete allowing the player to attain a small goal everyday and giving the player a sense of personal achievement. A calendar of scheduled goals was developed for the class to increase compliance with the demand of the program (see Appendix B). After each game encouragement from automatic feedback is always given to students on how well they are doing. This gives students motivation because it is positive reinforcement encouraging students to do better next time. From graphical analyses produced by the Lumosity™ labs, students are able to see the progress of their development allowing the setting of achievement goals for themselves to further encourage them to be motivated. All of these combined allow the Lumosity™ labs to enhance students' attention and focus their skills so when they are motivated to learn the student can focus their attention on the most important material.

*Dependent Variables*

Research Question 1

The dependent variable for the first question was student success in the chemistry classroom. Student success was evaluated by achievement scores on the
GOB exam and final course averages in o-chem I and CA Dx and final course averages and grades in gen chem I.

Research Question 2

The dependent variable was logic improvement as measured by pre/post scores on the GALT.

Research Question 3

The dependent variable was spatial skills improvement. Spatial skills were measured using pre/post scores on the ROT test.

Research Question 4

The dependent variables were scores on logic, spatial and chemistry-content knowledge assessments. The progress for both males and females in logic was measured by the GALT, the progress for spatial skills was measured using the ROT test and finally chemistry success was measured using final course grade and GOB exam results (o-chem I) and CA Dx and final grade (gen chem I).

Research Question 5

The dependent variable was students’ experiences using the Lumosity™ Labs and how they improved their classroom performance. Scores on the researcher-developed survey were evaluated using a Likert-type scale and open-ended questions to determine students’ thoughts regarding their experiences.

Independent Variables

The independent variables for both studies were the time-spent cybertraining and gender. The three experimental groups are spatial, logic and combined training (o-
chem I) and intensive combination training (gen chem I); each group the students played games developed by Lumosity™ in an attempt to improve their logic and spatial skills over a period of ten weeks.

Experiment 1

Research Procedure

The purpose of experiment 1 was to investigate which Lumosity™ learning course best-motivated and aided students in succeeding in the organic chemistry classroom chosen for this study. Lumosity™ courses that specifically trained students in spatial, logical and a combination of these skills were chosen. The research tools used to measure improvement upon treatment follow.

Materials and Experimental Tools

Data collected focused on STEM students' success as well as gender scores on pre/post tests: Purdue Visualizations of Rotations (ROT) test, Group Assessment of Logical Thinking (GALT) and General-Organic-Biochemistry (GOB) 2007 Exam; and final course grades.

1. "Spatial visualization tests are more complex than perceptual speed tests and thus draw on the mental ‘executive’ more fully, revealing the close ties between the two" (Bodner & Guay, 1997). Spatial intelligence involves exams that incorporate apprehending and mentally manipulating in a complex sequence (Wu & Shah, 2004). A test that is widely used in educational practices to measure such ability is the ROT (Bodner & Guay, 1997; Lean & Clements, 1981; Shea Lubinski & Benbow, 2001). Within this spatial evaluation instrument, students
observe two example 3-D images that illustrate how the other is rotated, and then a third image is shown that the student now has to rotate like example rotation. Spatial intelligence (as measured by this test) is important for STEM students' understanding of complex organic structures.

ROT test scores have been found to be highly valid and reliable. The ROT was highly correlated with the Shepard–Metzler measuring spatial ability scores \( r = .61, p < .001 \). The measure of reliability, the Kuder–Richardson 20 \( (K-R 20 = .80) \) and/or split-half \( (SH = .82) \) reliability coefficients, suggests that the ROT test is internally consistent. These data were obtained in studies of more than 4,800 students at Purdue University enrolled in general or organic chemistry courses. The ROT exam is a 20-item test that is given in a 10-minute time period partly eliminating that analytical skill will play a large part in the assessment.

2. The GALT has been used as a predictor of academic success in college chemistry since it was published in 1982. The abbreviated 12-item, 20-minute form of the GALT continues to identify students from as young as 7th grade to those enrolled in college course as to their Piagetian cognitive ability level (Roadrangka, Yeany and Padilla, 1982). Scores on the GALT are used to establish a student’s ability to think abstractly (or a Piagetian formal operational level). The scores used to identify different operational levels are concrete operational (0-5), transitional (6-7) and formal operational (8-12) (Roadrangka, Yeany and Padilla., 1982). Types of logical reasoning questions found on the GALT include: Proportional reasoning, probabilistic reasoning, controlling variables, correlation reasoning
and combinatorial reasoning that directly align with the Piagetian formal operational modes. Each of these types of reasoning skills is essential for science and mathematics achievement (Bird, 2010). Students at the college level should be formal operational or at the abstract cognitive level; if not, they will struggle to succeed in college. The GALT scores have shown to be both valid and reliable. In a validation study conducted by Roadrangka, Yeany and Padilla (1982), they found the criterion correlation coefficient compared to the Piagetian Interview Tasks to be .85. The coefficient alpha for the GALT was .89 and the mean item discrimination was measured at .44. The mean inter-correlation coefficients averaged .49 (Roadrangka, Yeany, & Padilla, 1982).

3. The GOB exam is a chemistry placement test used to determine how ready students are for the multiple disciplines in chemistry. The GOB exam is a 180-item multiple-choice test covering areas of general chemistry, organic chemistry and biochemistry. Each part consists of 60 questions with two subparts of 40 items and 20 items; for instance, Organic Chemistry Part A has 40 items and Organic Chemistry Part B has 20 items (Division of Chemical Education Exam Institute: American Chemical Society, 2010). In this study only Organic Chemistry Part A (40 items) was used to quantify the chemistry ability of organic students. The normalized average for the complete organic subtest (60 questions) has a national mean of 29.52 (8.33) (Division of Chemical Education Exam Institute: American Chemical Society, 2010).
Using a single exam to help understand student success in chemistry content will help make the results more generalizable. The exam questions are normalized and have readily available national statistics to use for comparison. There is less ambiguity for a single exam than if only a final classroom grade is considered, since there are many uncontrolled variables indicative of the typical class grade. In addition to scores on the GOB, final grades in the organic chemistry classroom were analyzed to quantify chemistry ability and success of students. The final grade in the class is affected by many uncontrolled factors such as: Student attendance in class, health, instructor teaching method, grading policy and institution type; as a result, generalizability of the study would be much lower if only course grades were used to assess student success in this study. Therefore, the GOB exam is also used as a predictor of success to provide a more replicable option to use than a single course average.

Procedures

Students were systematically randomly assigned by choosing every fourth student on the roster to belong to the treatment and control groups during the first week of class. After the students were assigned to groups, pretests of the GOB-organic section, GALT and the ROT were given during the first week of class. Handouts were given during the first week of class to aid students in registration and scheduling issues (see Appendix B). The pretests were given to ensure statistically equivalent groups and to assess the student’s initial content knowledge in chemistry, logic and spatial abilities. The pretests were examined using independent $t$-tests and to determine that no
The experimental group was statically different ($p > .05$) establishing homogeneity of the groups.

**Spatial Experimental Group:** Students were required to attend their regular chemistry classroom lectures. In addition, these students enrolled in two courses on the Lumosity™ Website: “Memory Boost” and “Attention Boost”. Each course is 20 sessions long (about 25-minutes/session). In weeks 1-5 students played four sessions a week from the “Memory Boost” course. In weeks 6-10 students played four sessions a week from the “Attention Boost” course. These weekly sessions were conducted on the student’s own time in a naturalistic setting and they were required to submit weekly screen shots as proof of completion of each session. Confirmation codes were distributed to the experimental group that could only be used once to create a Lumosity™ profile to ensure the control group cannot play on the selected Lumosity™ courses.

**Logic Experimental Group:** The students were required to attend their regular chemistry classroom lectures. In addition, these students were enrolled in two courses on the Lumosity™ Website: “Problem Solving” and “Speed Boost”. Each course is 20 sessions long (about 25-minutes/session). In weeks 1-5 students played four sessions a week from the “Problem Solving” course. In weeks 6-10 students played four sessions a week from the “Speed Boost” course. These weekly sessions were conducted on the student’s own time in a naturalistic setting and they were required to submit weekly screen shots as proof of completion of each session. Confirmation codes were distributed to the experimental group that could only be used once to create a
Lumosity™ profile to ensure the control group cannot play on the selected Lumosity™ courses.

Combination Experimental Group: The students were required to attend their regular chemistry classroom lectures. In addition, these students were enrolled in one course on the Lumosity™ Website: “Basic Training I”. This course is 40 sessions long (about 25-minutes/session). Each week for 10 weeks these students played the selected cybergames for four sessions per week. These weekly sessions were conducted on the student’s own time and they were required to submit weekly screen shots as proof of completion of each session. Confirmation codes were distributed to the experimental group that could only be used once to create a Lumosity™ profile to ensure the control group cannot play on the selected Lumosity™ courses.

Control group: The students attended the regularly scheduled chemistry lectures. These students did not enroll in or play any of the Lumosity™ course games.

After 10 weeks (completion of experimental treatment) post exams of the GOB, GALT and ROT assessments were given to analyze the scores over time comparing the experimental and control groups.

Lumosity™ courses and additional games are listed below.

Attention Boost: This course was designed to strengthen attention and spatial abilities.

The games included improve spatial awareness, focus and avoiding distractions.

Memory Boost: This course was designed to strengthen spatial ability and working memory. The games included help improve name recall, spatial awareness and working memory.
Problem Solving Boost: This course was designed to improve a student’s mathematics and quantitative reasoning skills. These games target arithmetic and problem solving skills that can be used in the chemistry field.

Speed Boost: This course was designed to increase a student’s cognitive thinking speed. The games included help improve mental processing speed.

Basic Training Boost: This scientifically designed fundamental course provides a balanced workout of cognitive and spatial awareness skills. The games included help improve memory, attention, focus, processing speed, flexibility and spatial awareness.

Reliability

The Chronbach’s alpha for each exam used was calculated for our specific sample to determine the reliability. The GALT scores' alpha coefficient was .834, the ROT scores' alpha coefficient was .812 and the GOB scores' alpha coefficient was .398. The scores for the GALT and ROT instruments produced a high alpha coefficient, so the scores seem to be consistent and reliable. The scores for the GOB exam produced a low alpha coefficient and therefore were not very reliable, so no further analysis was used. The fact that prior knowledge was not a reliable predictor of success in o-chem I was not consistent with the result from the pilot study in general chemistry. This might be due to the fact that only subset A of the complete GOB exam was utilized due to the time constraints of this particular class. Therefore, to determine chemistry success only the final course grade was ultimately used.

The survey developed for the study consisted of 11-items measuring students’
thoughts about the study and the use of the Lumosity™ games. The scores from the survey are consistent: The reliability coefficient alpha was calculated to be .826 (see Table 6). The reliability scores of the survey results show high consistency therefore no question was deleted. Consequently, this survey was used for experiments 1 and 2.

Table 6

Coefficient Alpha for Total Exam and Corrected Alpha by Item Analysis of the Interview Survey Questions

<table>
<thead>
<tr>
<th>Item</th>
<th>Corrected α</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>.793</td>
</tr>
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<td>.861</td>
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<tr>
<td>Total Alpha</td>
<td>.826</td>
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</tbody>
</table>

Analyses

Analyses of each research question are provided below for the quantitative and qualitative data collections. Descriptive statistics for all dependent variables including, means, medians, modes, skewness, kurtosis and standard deviations were calculated.
In addition, since test score reliability can be vastly different on each administration of a given test, it is important to calculate the reliability for each study (Henson, 2001). This allows a researcher to understand the internal consistency of their results; therefore, test score reliability, Cronbach’s alpha, was calculated for each assessment: ROT, GALT and GOB. Finally, ANOVA assumptions were analyzed to ensure the data analyzed followed rules assumed by the General Linear Model.

Quantitative Data

1. What do student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group?

   To examine if students participating in the experimental treatment groups statistically improved in organic chemistry compared to the control group over time a mixed repeated measures factorial ANOVA was used, using the pre/post exams on the GOB. To determine which group (if any) performed statistically different than the other experimental groups, a post hoc Cohen’s $d$ was calculated to determine the magnitude of mean differences. This comparison allowed the determination of the best Lumosity™ course to focus on for the second experiment.

2. When students participate in cybergame training over the span of 10 weeks, how is student performance on logic ability as measured by the Group Assessment of Logic Thinking (GALT) affected?
To determine if the treatment groups improved logic ability compared to the control group a mixed method repeated measures factorial ANOVA was used to test for statistical difference in pre/post GALT scores. A post hoc Cohen $d$ was calculated to determine the magnitude of the mean differences between groups.

3. When students participate in cybergame training over the span of 10 weeks, how is student performance on spatial ability as measured by the Purdue Visualization of Rotations (ROT) test affected?

To determine if the treatment improved participants' spatial ability compared to the control group a mixed repeated measures factorial ANOVA was used to test for statistical difference in pre/post ROT scores. A post hoc Cohen $d$ was calculated to determine the magnitude of the mean differences between groups.

4. What are the effects when participating in cybergame training over the span of 10 weeks *between* genders as measured by the outcomes on the content diagnostic exams (GOB and CA Dx), GALT and ROT, and final course grade?

Repeated Measures ANOVA was used incorporating gender as a factor to determine if there is a statistical difference between genders in the study.

Qualitative Data

5. What are the experiences and attitudes of general chemistry I and organic chemistry I students using the logic and spatial cybergame training intervention for a span of 10 weeks as measured on a Likert-scale and by responses to an open-ended questionnaire?
A Likert-type survey was used to understand the student experience while participating in the Lumosity™ games they played. The questions were calculated on a 5-point scale. Each question was averaged to determine students' experiences and attitudes (see Appendix C).

Included in the survey were three open-ended questions that asked students how they felt the Lumosity™ study impacted their chemistry course success. The students were encouraged to write any response and were not limited in any way. Analyzing all the responses by experimental group generated themes common to the phenomena being studied. The techniques used to determine the open-coded themes were based on analysis of words used (word repetitions and key-terms) and careful reading of the paragraph responses of students and comparing and contrasting ideas in each experimental group (D'Andrade, 1995). To determine word repetition, a simple analysis of the text was used by noting words and synonyms the students used consistently. The responses for each student in the experimental groups were then further compared and contrasted to evolve the common themes.

Experiment 2

Research Procedure

The purpose of this experiment was to determine the effects of using an intensive combination-training course to assist students to succeed in the general chemistry I course. It was decided that a combination of logic and spatial training would benefit the students the most in the gen chem I classroom because historically both are important for chemistry success and the results from the first experiment supported this
impression. Below are the research tools used to measure improvement upon treatment.

**Materials and Experimental Tools**

Data collected focused on students' success as well as gender scores on pre/post tests: Purdue Visualizations of Rotations (ROT) test, Group Assessment of Logical Thinking (GALT), California Chemistry Diagnostic Exam (CA Dx), and final course grades.

1. ROT (Purdue Visualization Rotational Test). Bodner and Guay (1997) reported that scores on spatial tests contribute a small, but significant, measure of successful performance in chemistry. The ROT exam is a 20-item multiple choice test that is given in a 10-minute time period measuring a student's ability to mentally rotate objects. The validity of the test scores of the ROT was highly correlated in measuring spatial ability with the Shepard–Metzler tests ($r = .61, p < .001$). The test score reliability was calculated using the Kuder–Richardson 20 (KR-20 = .80) and/or split-half (SH = .82) reliability coefficients, which suggested that the ROT test is internally consistent. These data were reported in studies of more than 4,800 students at Purdue University enrolled in chemistry by Bodner and Guay (1997).

2. Group Assessment of Logical Thinking (GALT): The GALT has been used as a predictor of academic success in college chemistry since it was developed in 1982 (Bunce & Hutchinson, 1993). The abbreviated 12-item, 20-minute form of the GALT identifies students' Piagetian cognitive learning ability as young as 7th
grade to those enrolled in college courses. Scores on the GALT are used to establish a student’s ability to think abstractly (or attain a Piagetian formal operational level). The scores used to identify different operational levels are concrete operational (0-5), transitional (6-7) and formal operational (8-12) (Roadrangka, Yeany, & Padilla, 1982). Students at the college level should be at the formal operational abstract cognitive level; if not, they will struggle to succeed in college courses. The GALT scores have shown to be both valid and reliable. In a validation study conducted by Roadrangka, Yeany and Padilla (1982), they found the criterion correlation coefficient compared to the Piagetian Interview Tasks to be .85. The coefficient alpha for the GALT scores was .89 and the mean item discrimination was measured at .44. The mean inter-correlation coefficients averaged .49.

3. California Chemistry Diagnostic Exam (CA Dx): The 1997 CA Dx exam is a nationally normalized chemistry placement test used to determine a general chemistry students’ prior knowledge in what should be from high school chemistry. This 44-item chemistry placement exam is published by the American Chemical Society and covers topics such as compounds and elements, states of matter, reactions of matter, structures of matter, periodic properties, solutions, qualitative kinetics, thermodynamics, lab skills, and mathematics. The national average on the exam is 20.45 (SD = 7.56) and a KR-21 reliability score = .83 (Division of Chemical Education Exam Institute: American Chemical Society, 2010).
Procedures

The students were systematically randomly assigned by choosing every fourth student on the roster to treatment and control groups during the first week of class. After the students were assigned to groups, pretests of the CA Dx, GALT and the ROT were given during the first week of class. Handouts were given during the first week of class to aid students in registration and scheduling issues (see Appendix B). The pretests were given to ensure statistically equivalent groups and to test the students' initial knowledge in chemistry, logic and spatial abilities. The pretests were examined using independent t-tests and no experimental group was found to be statically different ($p > .05$) establishing homogeneity of the groups.

Combination Experimental Group: The students were required to attend their regular chemistry classroom lectures. In addition, these students were enrolled in one course on the Lumosity™ Website: “Basic Training I”. This course is 40 sessions long (about 25-minutes/session). Each week for 10 weeks the students chosen for the experimental group played four sessions a week. In addition, two extra Lumosity™ games were assigned each week for students to play one level. The games chosen were: “Rotation Matrix”, “Space Junk”, “Brain Shift” and “Route to Sprout”. These games focused on logic and spatial training. These weekly sessions were conducted on the student’s own time and they were required to submit weekly screen shots as proof of completion of each session. Confirmation codes were distributed to the experimental group that could only be used once to create a Lumosity™ profile to ensure the control group cannot play on the selected Lumosity™ courses.
Control group: The students attended the regularly scheduled chemistry lectures. These students did not enroll or play any of the selected Lumosity™ courses.

After 10 weeks (completion of experimental treatment) post exams of the CA Dx, GALT and the ROT instruments were given to analyze the scores progression over time for the experimental and control groups.

Lumosity™ courses and additional games follow:

Basic Training Boost: This scientifically designed fundamental course provides a balanced workout of cognitive and spatial awareness skills. The games included help improve memory, attention, focus, processing speed, flexibility and spatial awareness.

Rotation Matrix: A game developed to enhance a student’s visual/spatial recall. A $5 \times 5$ square matrix is shown and students have to remember the pattern displayed while the matrix rotates upon an axis.

Space Junk: A game developed to enhance a student’s visual/spatial field. In this game a number of objects will appear on the screen for about 2 seconds. The student has to hold the image of the objects in their mind and determine how many were shown.

Brain Shift: A game developed to enhance cognitive control and logical thinking. A student is given a set of rules that have to be remembered; these rules then have to be applied to the game.
Route to Sprout: A game developed to enhance planning and logical thinking skills. The student has to plan and direct their way through a maze in the least number of steps.

Reliability

The Chronbach’s alpha for each exam used was calculated for our specific sample to determine the reliability. The GALT scores alpha coefficient was .821, the ROT scores alpha coefficient was .828 and the CA Dx scores alpha coefficient was .822. The scores for the GALT, ROT and CA Dx exam produced a high alpha coefficient so the scores seem to be consistent and reliable.

Analyses

Analyses of each research questions are provided below for quantitative and qualitative data collections. In addition, since test score reliability can be vastly different on each administration of a given test, it is important to calculate the reliability for each study (Henson, 2006). This allows a researcher to understand the internal consistency of their results. Therefore, test score reliability, Cronbach’s alpha, was calculated for each assessment: ROT, GALT and CA Dx. Finally, ANOVA assumptions are analyzed to ensure the data analyzed followed rules assumed by the General Linear Model.

Quantitative Data

1. What do student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group?
To examine if students participating in the experimental treatment group statistically improved in chemistry content scores compared to the control group over time a mixed repeated measures factorial ANOVA was used, using the pre/post exams on the CA Dx. To determine the statistical difference between the experiment and control groups, a post hoc Cohen’s $d$ was calculated to determine the magnitude of the mean difference.

2. When students participate in cybergame training over the span of 10 weeks, how is student performance on logic ability as measured by the Group Assessment of Logic Thinking (GALT) affected?

   To determine if the treatment group improved statistically on logic ability compared to the control group a mixed method repeated measures factorial ANOVA was used comparing pre/post GALT scores. A post hoc Cohen’s $d$ was calculated to determine the magnitude of the mean difference between groups.

3. When students participate in cybergame training over the span of 10 weeks, how is student performance on spatial skills as measured by the Purdue Visualization of Rotations (ROT) test affected?

   To determine if the treatment improved participants' spatial skills compared to the control group a mixed repeated measures factorial ANOVA was used to determine statistical difference of pre/post ROT scores. A post hoc Cohen $d$ was calculated to determine the magnitude of the mean differences between groups.
4. What are the effects when participating in cybergame training over the span of 10 weeks between genders as measured by the outcomes on the content diagnostic exams (GOB and CA Dx), GALT and ROT, and final course grade?

Repeated Measures ANOVAs were used incorporating gender as a factor to determine if there is a statistical difference between genders in the study.

Qualitative Data

5. What are the experiences and attitudes of general chemistry I students using the logic and spatial cybergame training intervention for a span of 10 weeks as measured on a Likert-scale and on an open-ended questionnaire?

A Likert-type survey was used to understand the students' experiences while participating in the Lumosity™ games they played. The questions were calculated on a 5-point scale. Each question was averaged to determine students' experiences and attitudes (see Appendix C).

Included in the survey were four open-ended questions that asked students how they felt the Lumosity™ study impacted their chemistry course success. The students were encouraged to write any response and were not limited in any way. Analyzing all the responses by experimental group generated themes common to the phenomena being studied. The techniques used to determine the open-coded themes were based on analysis of words used (word repetitions and key-terms) and careful reading of the paragraph responses of students comparing and contrasting ideas in each experimental group. To determine word repetition, a simple analysis of the text was used by noting
words and synonyms the students used consistently (D'Andrade, 1995). The responses for each student in the experimental groups were then further compared and contrasted to evolve the common themes.

Summary

This study was designed to determine what affect playing weekly logic and spatial cybergames using the Lumosity™ Labs for approximately 1.5 hours a week have on students in an entry-level chemistry classroom. Experiment 1 was used to determine which Lumosity™ Labs aided students the most in improving their organic chemistry skills. The second study was used to determine the effects of intensifying the cybergame workload and how it improved general chemistry course success.

The dependent variables for this study are improvement in logic, spatial and chemistry success. Each of these variables was measured using national recognized exams. The independent variables are cybergame playing over time and gender. The study used repeated measures ANOVA analysis to see the effects of improving the dependent variables through cybertraining over time. The results also compared gender interactions in each ANOVA. A final open and closed-ended survey was given to determine the personal thoughts of the students. It was important to know how the students enjoyed the study and if they saw any personal improvements in their own studies.
CHAPTER IV

RESULTS AND DISCUSSION

This chapter includes the results obtained from experiments 1 and 2 in this dissertation study that trains introductory organic and general chemistry students in basic logic and spatial skills using Lumosity™ brain-training games to determine the transferable effects within the chemistry classroom. The remainder of this chapter examines the study's limitations, statistical analysis and discussion for each research question in experiments 1 and 2, and a summary of the results.

Limitations

The study's greatest weakness is the external validity. External validity is the ability to apply the study to other populations. This study is specific to a traditional lecture style approach to teaching. In addition, the sample was taken from a tier 2, north central Texas public university (World Report and U.S. News, 2011). A higher or lower tiered, privately funded or well endowed university or a study from a different region of the state of Texas or the U.S. could present varied results.

There are also threats to internal validity that need to be addressed: Construct validity, testing instrument validity and statistical validity. Validity measures if the concept or idea of a study is actually being measured. This study measured chemistry course success and the study attempted to accomplish this by using final course grades and normalized exam scores. The final course grade is based on several grades (tests, quizzes, homework, etc.) that can be affected by history of the students and therefore can be a threat to validity. In addition the experiments were performed in naturalistic
settings instead of a tightly controlled environment, this setting could alter the results because there is less control. Also, the General-Organic-Biochemistry (GOB) exam in experiment 1 produced a low reliability coefficient. This low reliability effects internal validity so it was not included in the study analysis for experiment 1. Statistical validity is addressed by selecting appropriate statistical test for the study with conservative assumptions.

Statistical Justifications

The data for both experiments and each research question were screened for the presence of outliers by calculating standardized residual scores. No scores were considered outliers (residual scores ±2.5) therefore; all scores were included for analysis. The data were analyzed using SPSS version 17.0 to perform the repeated measures ANOVA. The repeated measures ANOVAs were justified because each variable explored differences both between groups over time; time served as the within variable. Statistical assumptions for the ANOVA were tested: Normality, linearity and univariate outliers (Maxwell & Delaney, 2004). There were no other violations of assumptions. All computations were analyzed using an alpha value of .05 level risk for type I error.

Data Selections

All variables were examined for missing data prior to conducting any analysis; missing data were deleted so only scores were used if pre- and post-exam scores for each assessment were reported. Consequently, the number of students is different for each analysis. Therefore, each exam analysis will have a different number of degrees of freedom. The first experiment (N = 99) had a 66.0% completion rate and the second
experiment ($N = 88$) had a completion rate of 60.3%. Participants included in the organic chemistry I (o-chem I) course by experimental group ($N = 99$: $n_{\text{control}} = 8$, $n_{\text{logic}} = 29$, $n_{\text{spatial}} = 30$, $n_{\text{combination}} = 32$) and in the general chemistry I (gen chem I) experiment ($N = 88$: $n_{\text{experimental}} = 27$, $n_{\text{control}} = 61$).

Experiment 1

First Research Question

What do student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group?

Data Analysis

The investigative purpose was to determine the effect (if any) of participating in cybergame training over time to increase chemistry course success. The within variable was time and the between variables were gender and training groups. The four training groups were logic, spatial and combination logic-spatial and control; each group focused on training specifically in logic ability, spatial skills or a combination of both. The methods used to determine chemistry success were pre/post GOB organic section exam scores and final course grades. The pre-GOB exam was given on the first day of class and the post-GOB was given the week before in class' final exam.

Descriptive data for all variables were determined and can be found in Table 7, ($N = 99$: $n_{\text{control}} = 8$, $n_{\text{logic}} = 29$, $n_{\text{spatial}} = 30$, $n_{\text{combination}} = 32$). Skewness was found to be near an absolute value of 1 for all variables. Kurtosis was found to below 2.0 for all
variables. The results from both the skewness and kurtosis statistics suggest a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997).

Table 7

**Descriptive Statistics for Chemistry Success Variables on the GOB in the O-Chem I Class**

<table>
<thead>
<tr>
<th>Variable by research group</th>
<th>Description</th>
<th>Mean (SD)</th>
<th>Kurtosis</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-GOB</td>
<td></td>
<td>Max Score = 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Ability</td>
<td>Chemistry</td>
<td>14.482 (4.837)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Skills</td>
<td>prior</td>
<td>14.933 (3.352)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>knowledge</td>
<td>14.406 (3.251)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>15.750 (3.195)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>14.909 (3.777)</td>
<td>-0.022</td>
<td>0.329</td>
</tr>
<tr>
<td>Post-GOB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Ability</td>
<td>Chemistry</td>
<td>16.069 (4.567)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Skills</td>
<td>success</td>
<td>15.667 (4.482)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td></td>
<td>16.156 (4.296)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>16.153 (3.739)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>15.838 (4.355)</td>
<td>0.224</td>
<td>0.526</td>
</tr>
<tr>
<td>Course grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Ability</td>
<td>Chemistry</td>
<td>81.781 (14.022)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Skills</td>
<td>Chemistry</td>
<td>81.345 (13.863)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>Success</td>
<td>80.133 (14.266)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>78.375 (14.644)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>80.879 (14.022)</td>
<td>-0.476</td>
<td>0.526</td>
</tr>
</tbody>
</table>

The null hypothesis of importance being tested for the first questions of experiment 1 is:

\[ H^0_{1.1} : \text{There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial as measured by scores on the General-Organic-Biochemistry} \]
(GOB) 2007 exam and the final course grades compared to the control (non-gaming) group in organic chemistry I on average and over the 10-week intervention period.

Table 8 gives the test results for this null hypothesis for the GOB scores. There were no statistically significant results. The difference between the GOB score over the 10 week intervention comparing experimental groups was not statistically significant, $F = 0.837 (3, 95); \eta^2 = .026; p = .477$. The average differences between the experimental groups was also not statistically significant, $F = .267 (3, 95); \eta^2 = .008; p = .849$. Therefore I failed to reject the null hypothesis and there is no statistical difference in GOB scores between experimental groups over the 10-week intervention or between experimental groups on average. In addition, the effect size is small for both statistical analyses so the there is little practical significance.

Table 8

*Repeated Measure ANOVA Results for GOB Scores in the O-Chem I Class*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Error</td>
<td>129.889</td>
<td>3</td>
<td>43.296</td>
<td>0.267</td>
<td>.849</td>
<td>.008</td>
</tr>
<tr>
<td>Time</td>
<td>101.261</td>
<td>1</td>
<td>101.261</td>
<td>2.048</td>
<td>.156</td>
<td>.021</td>
</tr>
<tr>
<td>Time*Group Error</td>
<td>124.153</td>
<td>3</td>
<td>41.384</td>
<td>0.837</td>
<td>.477</td>
<td>.026</td>
</tr>
<tr>
<td>Total</td>
<td>20461.236</td>
<td>197</td>
<td>49.433</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The line graph below (Figure 4) illustrates the pre- and post-scores for the GOB exam scores; the difference in height between the pre/post scores is the gain score
over time. The vertical axis is the score on the GOB exam and the horizontal axis divides the pre- and post-scores. Though neither gain score is significant by group overall, the group with the highest gain score average was the combination (+2.0) and the group with the lowest gain score was the control (+0.4).

Table 9 presents the results of the hypothesis employing the final course grade in the class as the predictor for success using a one-way ANOVA with four groups, \( N = 99; n_{\text{control}} = 8, n_{\text{logic}} = 29, n_{\text{spatial}} = 30, n_{\text{combination}} = 32 \). The null hypothesis of importance is the last part of \( H_{1.1}^0 \): There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial as measured by the final course grades compared to the control (non-gaming) group in organic chemistry I. The differences between the experimental groups was \( F = 0.164 (3, 95); \eta^2 = .005; p = .920 \). Therefore I failed to reject the null hypothesis and there are no statistical differences between experimental groups and

![GOB Gain Scores](image)

*Figure 4. GOB pre/post scores compared by experimental group.*

Table 9 presents the results of the hypothesis employing the final course grade in the class as the predictor for success using a one-way ANOVA with four groups, \( N = 99; n_{\text{control}} = 8, n_{\text{logic}} = 29, n_{\text{spatial}} = 30, n_{\text{combination}} = 32 \). The null hypothesis of importance is the last part of \( H_{1.1}^0 \): There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial as measured by the final course grades compared to the control (non-gaming) group in organic chemistry I. The differences between the experimental groups was \( F = 0.164 (3, 95); \eta^2 = .005; p = .920 \). Therefore I failed to reject the null hypothesis and there are no statistical differences between experimental groups and
final course grade in the organic chemistry classroom. The effect size for this result is small, so group membership explains little of the variance in the final course grade.

Table 9

ANOVA Results for Final Course Grade in the O-Chem I Class

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>ρ</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>99.183</td>
<td>3</td>
<td>33.061</td>
<td>0.164</td>
<td>.920</td>
<td>.005</td>
</tr>
<tr>
<td>Error</td>
<td>19169.362</td>
<td>95</td>
<td>201.783</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19268.545</td>
<td>98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 shows the averages of the final course grades for the participants in the organic control group compared to experimental groups in a histogram representation. The vertical axis represents the final average course grade and the horizontal axis separates each average by group. Though the results were not statistically significant, the histogram below indicates the highest final course average was achieved in logic experimental group (\( \bar{X} = 81.781 \)) and the lowest final average was in the control group (\( \bar{X} = 78.375 \)). All of the experimental groups had a higher course average compared to the control group.

Figure 5. Final course grade compared by experimental group.
Discussion

There were no statistically significant results when comparing control and experimental groups over time on the GOB exam score. The reliability coefficient ($\alpha = .398$) was very low for the GOB test scores. This implies the measurement was not reliable and so therefore there is less confidence can be placed in the analysis (Henson, 2002). The results from the repeated measures ANOVA imply there is no difference between the experimental groups using scores on GOB exam over time therefore the null hypothesis failed to be rejected. Since there is less confidence due to low reliability and a low effect size, I chose not to further analyze the results.

Chemistry success as defined by final course grade in the class comparing experimental groups over time was not statistically significant. The control group was found to have the lowest final average ($\bar{X} = 78.375$) and the logic group had the highest final average ($\bar{X} = 81.781$). Despite the difference in final averages the result is not statistically significant therefore I failed to reject the null hypothesis. The lack of group differences could be attributed to the fact that it is difficult to create practical changes in the thinking patterns and mental processing of an organic I student in a matter of 10 weeks. The study suggests that one semester of Lumosity™ training does not transfer into the organic chemistry classroom as a viable intervention. This is further supported when analyzing the effect size that was very small.

Second Research Question

When students participate in cybergame training over the span of 10 weeks, how is student performance on logic ability as measured by the Group Assessment of Logic
Thinking (GALT) affected?

**Data Analysis**

The investigative purpose was to determine the effect (if any) of participating in cybergame training on logic ability. The *within* variable was time and the *between* variables were gender and training group. The four training groups were logic, spatial and combination logic-spatial and control; each group focused on training in logic ability, spatial awareness or a combination of both. The methods used to determine logic ability improvement were pre/post GALTs. The pre-GALT was given on the first day of class and the post-GALT was given the week before in class finals to the o-chem I class.

Descriptive data for all variables were determined and can be found in Table 10, \((N = 99: n_{control} = 8, n_{logic} = 29, n_{spatial} = 30, n_{combination} = 32)\).

**Table 10**

*Descriptive Statistics for Logical Thinking Variables on the GALT in the O-Chem I Class*

<table>
<thead>
<tr>
<th>Variable by Group</th>
<th>Description</th>
<th>(\bar{X} (SD)) Max Score = 12</th>
<th>Kurtosis</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-GALT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Ability</td>
<td>Logical thinking</td>
<td>8.931 (2.251)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Skills</td>
<td>prior knowledge</td>
<td>8.000 (2.319)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>knowledge</td>
<td>8.375 (2.485)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>7.875 (2.385)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>8.384 (2.385)</td>
<td>0.880</td>
<td>-1.081</td>
</tr>
<tr>
<td><strong>Post-GALT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic Ability</td>
<td>Logical thinking</td>
<td>9.000 (2.329)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Skills</td>
<td>thinking success</td>
<td>8.467 (1.871)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>success</td>
<td>9.000 (2.185)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>7.250 (3.535)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>8.697 (2.288)</td>
<td>-.234</td>
<td>-0.646</td>
</tr>
</tbody>
</table>
Skewness was found to be near an absolute value of 1 for all variables. Kurtosis was found to below 2.0 for all variables. The results from both the skewness and kurtosis statistics suggested a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997).

The null hypothesis being tested for the second question of experiment 1 is:

\[ H_{2.1}^0: \text{There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial and the control (non-gaming) group in logic ability as measured by the GALT exam on average and over the 10-week intervention in organic chemistry I.} \]

Table 11 gives the statistical test results for the null hypothesis for the GALT scores for experiment 1.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Error</td>
<td>60267.491</td>
<td>95</td>
<td>634.395</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Error</td>
<td>44.460</td>
<td>1</td>
<td>44.460</td>
<td>0.372</td>
<td>.543</td>
<td>.004</td>
</tr>
<tr>
<td>Time*Group Error</td>
<td>11343.880</td>
<td>95</td>
<td>119.409</td>
<td>1.220</td>
<td>.307</td>
<td>.037</td>
</tr>
<tr>
<td>Total</td>
<td>74372.463</td>
<td>197</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There were no statistically significant results. The difference between the GALT scores over the 10-week time period comparing experimental groups was not statistically significant, $F = 1.220 (3, 95); \eta^2 = .037; p = .307$. The differences between the
experimental groups was also not statistically significant, $F = 1.198 (3, 95); \eta^2 = .036; p = .315$. Therefore I failed to reject the null hypothesis and there are no statistical differences in GALT scores between experimental groups over time or on average. Additionally, the effect sizes for both results comparing experimental groups are small ($\eta^2 < 4\%$) further implying there is no statistical significance to the results.

Figure 6 displays a line graph illustrating the gain scores on the GALT exam by group. The vertical axis is the score on the GALT and pre/post exams are arranged on the horizontal axis. The bars in the graph represent pre- and post-scores; the differences in height gives the gain scored over time. Though not statistically significant, the group that had the highest gain score was the combination group ($\Delta = 0.625$). The group with the lowest gain score was the control group ($\Delta = -0.625$). This shows that in this sample the control group scored less on the GALT at the end of the semester than at the beginning and all of the treatment groups increased in logic ability.

![GALT Gain Scores](image)

*Figure 6. GALT pre/post scores compared by experimental group.*
Discussion

There were no statistically significant results when comparing experimental group over time and experimental group on average using the scores on the GALT exam. Therefore it cannot be definitively stated that the treatment groups increased logic ability compared to the control group over time. If comparing gained scores over time the control group had the lowest gain score, it was actually a negative gain score signifying the samples logic skills decreased over time with no treatment. The experimental group with the highest logic ability gain score on the GALT was the combination group. This is not a startling result because Piaget theorized in his studies that a person needs both maturity in logical thinking ability and spatial skills to develop into a formal operational thinker (Piaget, 1983). Despite the difference in gain scores the results on the repeated measures ANOVA were not significant and I failed to reject the null hypothesis. Though statistically significant results are important, effect sizes are equally important. The effect size of a statistical calculation represents the variance explained of the dependent variable (i.e., GALT gain score) or practical significance (Henson, 2006). The experimental group differences failed to explain most of the variance in the GALT gain score therefore resulting in a low effect size.

Third Research Question

When students participate in cyberteam training over the span of 10 weeks, how is student performance on spatial ability as measured by the Purdue Visualization of Rotations (ROT) test affected?
Data Analysis

The investigative purpose was to determine the effect on spatial ability (if any) of participating in cybergame training over time. The within variable was time and the between variables were gender and training group. The four training groups were logic, spatial and combination logic-spatial and control; each group focused on training in specifically logic ability, spatial awareness or a combination of both. The assessments used to determine spatial ability improvement were pre/post ROT tests. The pre-ROT test was given on the first day of class and the post-ROT was given the week before class finals.

Descriptive data for all variables were determined and can be found in Table 12, \((N = 99: n_{\text{control}} = 8, n_{\text{logic}} = 29, n_{\text{spatial}} = 30, n_{\text{combination}} = 32)\).

Table 12

**Descriptive Statistics for Spatial Thinking Variables on the ROT Test in O-Chem I Class**

<table>
<thead>
<tr>
<th>Variable by Group</th>
<th>Description</th>
<th>(X(\text{SD})) (\text{Max Score} = 20)</th>
<th>Kurtosis</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-ROT</td>
<td><strong>Logic Ability</strong></td>
<td>Spatial</td>
<td>12.724 (4.471)</td>
<td>-0.153</td>
</tr>
<tr>
<td></td>
<td><strong>Spatial Skills</strong></td>
<td>thinking prior knowledge</td>
<td>12.000 (4.094)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Combination</strong></td>
<td>Control</td>
<td>12.031 (4.115)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>12.152 (4.156)</td>
<td>-0.153</td>
</tr>
<tr>
<td>Post-ROT</td>
<td><strong>Logic Ability</strong></td>
<td>Spatial</td>
<td>13.138 (4.206)</td>
<td>-0.698</td>
</tr>
<tr>
<td></td>
<td><strong>Spatial Skills</strong></td>
<td>thinking success</td>
<td>13.333 (3.977)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Combination</strong></td>
<td>Control</td>
<td>11.688 (5.189)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>12.505 (4.541)</td>
<td>-0.698</td>
</tr>
</tbody>
</table>

Skewness was found to be near an absolute value of 1 for all variables. Kurtosis was
found to be below 2.0 for all variables. The results from both the skewness and kurtosis statistics suggest a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997).

The null hypothesis being tested for the third questions is:

Hº3.1: There is no significant difference between students participating in the cybergaming intervention groups of logic, spatial and combination of logic-spatial and the control (non-gaming) group in spatial skills as measured by the ROT test on average and over the 10-week intervention in organic chemistry I.

Table 13 gives the statistical test results for this hypothesis for ROT scores. There was a statistically significant result when comparing scores over the 10-week intervention between experimental groups. The difference between the ROT scores over time when comparing experimental groups over time was statistically significant, \( F = 2.982 \) \((3, 95)\); \( \eta^2 = .086 \); \( p = .035 \). The average difference between the groups was not statistically significant, \( F = 0.912 \) \((3, 95)\); \( \eta^2 = .006 \); \( p = .912 \). Therefore the null hypothesis is rejected, and there is a statistical difference in ROT scores between experimental groups over the 10-week intervention time period. I failed to reject the null hypothesis comparing between groups on average and there is no difference between experimental groups on average. Although there is a statistically significant result, the effect size is only moderate (8.6%) and therefore a modest amount of the variance is explained by group differences on the ROT gained scores implying some practical significance (Henson, 2006; Huck, 2008).
Table 13

Repeated Measures ANOVA Results for ROT Test Scores in the O-Chem I

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>236.346</td>
<td>3</td>
<td>78.782</td>
<td>0.177</td>
<td>.912</td>
<td>.006</td>
</tr>
<tr>
<td>Error</td>
<td>42292.694</td>
<td>95</td>
<td>445.186</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>886.129</td>
<td>1</td>
<td>886.129</td>
<td>1.856</td>
<td>.176</td>
<td>.019</td>
</tr>
<tr>
<td>Time*Group</td>
<td>4270.955</td>
<td>3</td>
<td>1423.652</td>
<td>2.982</td>
<td>.035</td>
<td>.086</td>
</tr>
<tr>
<td>Error</td>
<td>45354.045</td>
<td>95</td>
<td>477.411</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>93040.169</td>
<td>197</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The line graph shown in Figure 7 illustrates the average gain scores on the ROT test by group. The vertical axis is the score on the ROT test and pre/post testing times arrange the horizontal axis. The bars in the graph represent pre/post scores; the differences in height give the averaged gain score over time. The group that had the statistically highest gain score was the spatial group (Δ = 1.33). The group with the lowest gain score was the control group (Δ = -0.75). This shows that in this sample, the control and the combination groups scored lower on the ROT test measuring spatial skills and the spatial and logic groups significantly increased test scores over time.

![ROT Gain Scores](image)

*Figure 7. ROT pre/post scores compared by experimental group.*
Discussion

There was a statistically significant result when comparing groups over time on the ROT test. The spatial group had the highest averaged gain score. The spatial group had an average increase in score of 1.33 over time compared to -0.75 over time of the control group. Spatial ability has been found to be important for chemistry success so it is exciting to find a way to improve spatial ability over time (Bodner & Guay, 1997). Although Lumosity™ was not found to statistically affect final grade in the classroom it is at least a small indication that it can enhance spatial ability. The estimated effect size ($\eta^2 = .086$) is considered moderate so the result explains a fair amount of the variance between groups on the ROT gained scores indicating the practical significance of the results is average and could possibly be used in a real situation.

Fourth Research Question

What are the effects when participating in cybergame training over the span of 10 weeks between genders as measured by the outcomes on the content diagnostic exams (GOB and CA Dx), GALT and ROT, and final course grade?

Data Analysis

Skewness was previously determined and found to be near an absolute value of 1 for all variables. Kurtosis was found to be below 2.0 for all variables. The results from both the skewness and kurtosis statistics suggested a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997). The control had a low number of participants actually complete the expected experimental
criteria; therefore, the gender*group interaction cannot be analyzed due to a small number of participants in the control group \((N = 8)\).

Final Course Grade

The descriptive data for gender and final course grade are listed below in Table 14, \((N = 99; \text{male} = 41; \text{female} = 58)\). Male and female students had approximately the same mean for the final course grade.

Table 14

*Descriptive Statistics for Final Course Grade Comparing Genders in O-Chem I Class*

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>(\bar{X}% (SD)) (\text{Max} = 100%)</th>
<th>(SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final course grade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>81.756 (14.259)</td>
<td>2.737</td>
</tr>
<tr>
<td>Female</td>
<td>80.259 (13.943)</td>
<td>2.186</td>
</tr>
<tr>
<td>Overall</td>
<td>80.878 (14.022)</td>
<td>1.752</td>
</tr>
</tbody>
</table>

The null hypothesis being tested for the fourth questions is:

\(H_{0,4.1}: \text{There is no significant difference between genders in organic chemistry I as measured by the scores on the GOB, GALT and ROT and final course averages and grades.}\)

There were no statistically significant results (Table 15). The *between* gender differences was not statistically significant, \(F = 0.272 (3, 97); \eta^2 = .003; p = .603\). Therefore I failed to reject the null hypothesis and there is no statistical difference in final course grade analyzing *between* genders. The effect size is small further implying that there are no significance comparing gender differences on final course grade in the classroom.
Table 15

ANOVA Results Comparing Gender Differences for Final Grade in O-Chem I

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>ρ</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>53.864</td>
<td>1</td>
<td>53.864</td>
<td>0.272</td>
<td>.603</td>
<td>.003</td>
</tr>
<tr>
<td>Error</td>
<td>19214.682</td>
<td>97</td>
<td>198.090</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19268.545</td>
<td>98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GALT

The descriptive data for gender and final course grade are listed below in Table 16. The null hypothesis being tested for the fourth questions is:

\[ H^o_{4.1}: \text{There is no significant difference between genders in organic} \]

chemistry I as measured by the scores on the GOB, GALT and ROT and final course averages and grades.

There were no statistically significant results on the GALT between the experimental groups.

Table 16

Descriptive Statistics for GALT Scores Comparing Genders in O-Chem I

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>Pre-GALT</th>
<th></th>
<th>Post-GALT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \bar{x} ) (SD)</td>
<td></td>
<td>( \bar{x} ) (SD)</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>8.390 (2.691)</td>
<td></td>
<td>9.098 (2.426)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>8.390 (2.691)</td>
<td></td>
<td>9.098 (2.426)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>8.379 (2.167)</td>
<td></td>
<td>8.413 (2.161)</td>
<td></td>
</tr>
</tbody>
</table>

There were no statistically significant results, Table 17. The difference on the GALT exam over the 10-week time intervention comparing between gender was not statistically significant, \( F = 3.212 (3, 97); \eta^2 = .032; p = .076. \) When comparing results
for the average gender differences the results were not significant $F = 0.628 (3, 97); \eta^2 = .006; p = .430$. Therefore I rejected the null hypothesis and there is no statistical difference on the GALT exam analyzing between gender over the 10-week time period or on average. Additionally, the effect sizes for both calculations were low comparing gender differences on the GALT gained scores.

Table 17

*Repeated Measures ANOVA Results Comparing Gender Differences on the GALT Scores*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>5.796</td>
<td>1</td>
<td>5.796</td>
<td>0.628</td>
<td>.430</td>
<td>.006</td>
</tr>
<tr>
<td>Error</td>
<td>894.881</td>
<td>97</td>
<td>9.226</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>6.609</td>
<td>1</td>
<td>6.609</td>
<td>3.904</td>
<td>.051</td>
<td>.039</td>
</tr>
<tr>
<td>Time*Gender</td>
<td>5.437</td>
<td>1</td>
<td>5.437</td>
<td>3.212</td>
<td>.076</td>
<td>.032</td>
</tr>
<tr>
<td>Error</td>
<td>164.209</td>
<td>97</td>
<td>1.693</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1076.932</td>
<td>197</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ROT

The descriptive data for gender and final course grade are listed below in Table 18. The null hypothesis being tested for the fourth questions is:

$H^0_{4,1}$: There is no significant difference between genders in organic chemistry I as measured by the scores on the GOB, GALT and ROT and final course averages and grades.
Table 18

Descriptive Statistics for ROT Scores Comparing Genders in O-Chem I

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>Pre-ROT (χ (SD))</th>
<th>Post-ROT (χ (SD))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max Score = 20</td>
<td>Max Score = 20</td>
</tr>
<tr>
<td>Overall Male</td>
<td>13.219 (4.568)</td>
<td>13.000 (4.959)</td>
</tr>
<tr>
<td>Female</td>
<td>11.397 (3.884)</td>
<td>12.155 (4.229)</td>
</tr>
</tbody>
</table>

There were no statistically significant results (Table 19). The between gender differences over time was also not statistically significant, $F = 1.526 (3, 97); \eta^2 = .016; \ p = .218$. The inferential results between genders was not significant, $F = 2.278 (3, 97); \eta^2 = .028; \ p > .098$. Therefore I failed to reject the null hypothesis and there are no statistical differences on the ROT test scores analyzing between gender over time or on average.

Table 19

Repeated Measures ANOVA Results Comparing Gender Differences on the ROT Scores in O-Chem I Class

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial (\eta^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender Error</td>
<td>85.477</td>
<td>1</td>
<td>85.477</td>
<td>2.789</td>
<td>.098</td>
<td>.028</td>
</tr>
<tr>
<td>Time Error</td>
<td>30.646</td>
<td>97</td>
<td>30.646</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time*Gender Error</td>
<td>3.491</td>
<td>1</td>
<td>3.491</td>
<td>0.466</td>
<td>.496</td>
<td>.005</td>
</tr>
<tr>
<td>Total Error</td>
<td>725.823</td>
<td>97</td>
<td>7.483</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>856.928</td>
<td>197</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussion

When comparing the results on the final course grade in the classroom, though
not statistically significant, the male students had a higher course average in the class compared to female students. The effect size of this result is very low; therefore, gender differences on final course grade may have little practical significance.

When comparing the results on the GALT there were no statistically significant results. Though not statistically significant the male students had the greatest gain in GALT score (+0.71) compared to the female students (+0.11). This non-stastically significant results could be due to the fact that o-chem I is not as mathematically intensive as compared to other chemistry fields; therefore, students are not getting as much logical thinking exposure. On average the male and female students did not have statistical difference in their logic ability. Again, the practical significance is low when analyzing the effect sizes so there might not be any practical significance to the results when comparing gender by GALT gain scores.

When comparing gender differences by group on the ROT test there were no statistically significant results. Though not significant the female students on average received a higher gain score (+0.759) compared to the male students (-0.200). This might imply that female students could have the greater benefit from spatial training. Male and female students on average had equivalent spatial ability skills. Again, the results of study did not result in high effect sizes (the highest 2.8%), so the results may not have any practical significance.

Fifth Research Question

What are the experiences and attitudes of general chemistry I and organic chemistry I students using the logic and spatial cybergame training intervention for a
span of 10 weeks as measured on a Likert-scale and by responses to an open-ended questionnaire?

Data Analysis

To determine the experience and attitudes of the students using the Lumosity™ training tool, a survey was distributed containing closed and open-ended questions. The close-ended questions (see Appendix C) were analyzed using a Likert-type scale. The averages of each question can be found in Table 20, \((N = 68)\). The responses were based on a 5-point scale: 5: strongly agree; 4: agree; 3: neutral; 2: disagree; 1: strongly disagree.

Table 20

<table>
<thead>
<tr>
<th>Questions</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you feel that the Lumosity™ courses improved your everyday reasoning skills?</td>
<td>3.68</td>
</tr>
<tr>
<td>2. Did you enjoy playing each game?</td>
<td>3.54</td>
</tr>
<tr>
<td>3. Did you feel the games became repetitive?</td>
<td>4.13</td>
</tr>
<tr>
<td>4. Would you continue playing these courses beyond this study?</td>
<td>3.54</td>
</tr>
<tr>
<td>5. Did you find these games motivating?</td>
<td>3.30</td>
</tr>
<tr>
<td>6. Do you feel like your spatial skills improved?</td>
<td>3.70</td>
</tr>
<tr>
<td>7. Do you feel like your logic ability improved?</td>
<td>3.76</td>
</tr>
<tr>
<td>8. Did these Lumosity™ games aid in improving in your chemistry classroom grade?</td>
<td>3.20</td>
</tr>
<tr>
<td>9. Did you improve your memorization skills playing the games?</td>
<td>3.57</td>
</tr>
<tr>
<td>10. Were you able to better visualize chemistry molecules after playing these games?</td>
<td>3.65</td>
</tr>
<tr>
<td>11. Did you feel your chemistry test response time improved?</td>
<td>3.70</td>
</tr>
</tbody>
</table>

After analyzing the data it was evident that most averages for each question were about 3.5, somewhat agree. The statement the students felt most strongly about
asked if the games were repetitive ($\bar{x} = 4.13$). The question the students had the most neutral opinion asked if Lumosity™ training improved their chemistry skills in the classroom ($\bar{x} = 3.20$). On average the students did not have any negative complaints about the Lumosity™ study; there were no reported averages below 3.0.

The survey also asked open-ended questions that were analyzed using word counts to determine common themes in the responses by experimental group (D’Andrade, 1995). These data were organized by experimental group due to the uniqueness of each training program. The open-ended questions included:

1. What was your favorite and least favorite game and why?
2. Any suggestions on how to improve the Lumosity™ courses?
3. Do you feel like these games improved your reasoning and spatial skills on your chemistry class? Why?

The logic group ($n = 20$) on average developed the following themes from the questions: The students enjoyed playing Bird Watching game because it was challenging and were frustrated with Penguin Pursuit. The students wished there was greater variety of games; sometimes the games became repetitive and a little mundane. The students felt playing the games improved their time to take exams, mathematics skills, focus and deciphering between enantiomers and diasteriomers.

The spatial group ($n = 25$) analysis determined the following themes: The students favorite games were Bird Watching and Monster Garden, they found these games fun and challenging. The least favorite games were Monster Garden and Penguin Pursuit, because the students reported they became easily frustrated with these games.
The students also felt the games needed more variety because they would become repetitive. The students felt the cybergame training definitely improved their spatial skills in the class, and in addition, focus and memorization on exams.

The combination group (n = 23) analysis discovered the following themes: The students favorite game was Bird Watching and their least favorite games were Name Tag and Penguin Pursuit (each of these games deal with spatial memory.) Most students suggested the study needed a more variety of games as seen in other experimental groups. The students felt the games improved their organic chemistry skills, visualization of molecules and memorization skills.

Discussion

Overall the students seemed to develop no negative feelings on average concerning the Lumosity™ training project, though they also did not have any strong positive feelings. The strongest feelings towards the study were that the games became very repetitive. This thought was also prevalent in the open-ended questions: Each group reported they would like to see more variety in the games. The students on average enjoyed the Bird Watching game: A game that practiced peripheral vision and allowed students to “shoot” birds with their cursor. The least liked games on average were Monster Garden and Penguin Pursuit; each of these games practices spatial memory. Most of the students disliked the complexity of these games and were easily frustrated. Most students reported that they saw an affect of playing the games within the chemistry classroom. Some specific examples include: Increased focus, memory, processing speed and spatial visualization of molecules. The students seemed to like the
Experiment 2

Experiment 2 provided evidence that an intensive combination logic and spatial training regime can be used to improve classroom success as measured by the CA Dx and the final grade in the gen chem I course. It was decided that a combination of logic and spatial training would benefit the students the most in the gen chem I classroom because historically both are important for chemistry success and the results from the first experiment supported this impression.

First Research Question

What do student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group?

Data Analysis

The investigative purpose was to determine the effect of participating in a more intensive cybergame training over time to increase chemistry success in the classroom. The within variable was time and the between variables were experimental groups who did participate in the cybergaming intervention and those who did not. The treatment group was subject to an intensified combination logic-spatial training treatment where the training focused on both logic ability and spatial skills. The methods used to determine chemistry success were final course averages and the scores on the
California Chemistry Diagnostic Exam (CA Dx). The pre-CA Dx exam was given on the first day of class and the post-CA Dx was given the week before final exams were administered.

Descriptive data for all variables were determined and can be found in Table 21, \(N = 88: n_{\text{experimental}} = 28 \ n_{\text{control}} = 60\).

Table 21

*Descriptive Statistics for Chemistry Success Variable on CA Dx and Final Course Averages in Gen Chem I Class*

<table>
<thead>
<tr>
<th>Variable Group by Group</th>
<th>Description</th>
<th>(\bar{x}) Max score = 44</th>
<th>National Norm* (SD)</th>
<th>Kurtosis</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-CA Dx Control</td>
<td>Chemistry prior knowledge</td>
<td>21.667 (7.300)</td>
<td>20.45 (7.56)</td>
<td>-0.163</td>
<td>0.249</td>
</tr>
<tr>
<td>Experimental Overall</td>
<td>Chemistry prior knowledge</td>
<td>20.500 (7.035)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>21.290 (7.198)</td>
<td></td>
<td>-0.163</td>
<td>0.249</td>
</tr>
<tr>
<td>Post-CA Dx Control</td>
<td>Chemistry success</td>
<td>31.286 (5.779)</td>
<td>20.45 (7.56)</td>
<td>0.702</td>
<td>0.250</td>
</tr>
<tr>
<td>Experimental Overall</td>
<td>Chemistry success</td>
<td>32.000 (5.569)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>31.091 (5.730)</td>
<td></td>
<td>0.702</td>
<td>0.250</td>
</tr>
<tr>
<td>Final average Control</td>
<td>Chemistry Success</td>
<td>82.332 (14.536)</td>
<td>1.983</td>
<td>-1.284</td>
<td></td>
</tr>
<tr>
<td>Experimental Overall</td>
<td>Chemistry Success</td>
<td>89.357 (13.646)</td>
<td>84.575 (14.562)</td>
<td>1.983</td>
<td>-1.284</td>
</tr>
</tbody>
</table>

*National norm found at American Chemical Society Division of Chemical Education Exam Institute, 2010: [http://chemexams.chem.iastate.edu/](http://chemexams.chem.iastate.edu/)

Skewness was found to be near an absolute value of 1 for all variables. Kurtosis was found to be below 2.0 for all variables. The results from both the skewness and kurtosis
statistics suggest a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997). The bivariate correlation between the post CA Dx exam and the final course grade was computed and found to be, $r = .613; \rho = .001$, implying that it is a good indicator of success.

The null hypothesis being tested for the first questions is:

$H_{o1.2}^o$: There is no significant difference between students participating in the cybergaming intervention group of combination logic-spatial as measured by scores on the California Chemistry Diagnostic Test 1997 (CA Dx) and the final course grades compared to the control (non-gaming) group in general chemistry I on average and over the 10-week intervention period.

Table 22 gives the test results for this hypothesis for CA Dx scores. The difference between the CA Dx score over the 10-week intervention time comparing experimental groups was statistically significant, $F = 4.426 (1, 82); \eta^2 = .051; p = .038$. The average differences between the groups was not statistically significant, $F = 0.090 (1, 82); \eta^2 = .001; p = .765$. Therefore the null hypothesis is rejected and there is a statistical difference in CA Dx scores between subjects over time. However, between groups the null hypothesis failed to be rejected and there is no statistical average difference between experimental groups. The effect size is considered be close to moderate ($\rho^2 = .051$) comparing between group differences over time on the CA Dx exam indicating that there is a reasonable chance for practical significance (Huck, 2008).
Table 22

Repeated Measures ANOVA Results for the CA Dx Exam Scores in Gen Chem I Class

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>6.528</td>
<td>1</td>
<td>6.528</td>
<td>0.090</td>
<td>.765</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
<td>5927.966</td>
<td>82</td>
<td>72.292</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>4165.641</td>
<td>1</td>
<td>4165.641</td>
<td>301.182</td>
<td>.001</td>
<td>.786</td>
</tr>
<tr>
<td>Time*Group</td>
<td>61.213</td>
<td>1</td>
<td>61.213</td>
<td>4.426</td>
<td>.038</td>
<td>.051</td>
</tr>
<tr>
<td>Error</td>
<td>1134.139</td>
<td>82</td>
<td>13.831</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11295.487</td>
<td>167</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The line graph below (Figure 8) illustrates the pre- and post-scores for the CA Dx exam scores. The difference in height between the pre/post scores is the gain score over time. The average gain score over time was significant. The experimental group improved their CA Dx ($\Delta = 11.5$) exam significantly more than the control group ($\Delta = 9.6$).

![CA Dx Gain Scores](image)

*Figure 8. CA Dx pre/post scores compared by experimental group.*

Table 23 gives the results of the hypothesis employing the final course average in the class as the predictor for success using a one-way ANOVA, ($N = 88$: $n_{\text{experimental}} = \ldots$)
The null hypothesis is: There is no statistical significant difference between students participating in the cybergaming intervention group of combination logic-spatial as measured by the final course grades compared to the control (non-gaming) group in general chemistry I. The differences between the control and treatment groups was significant, $F = 5.338 \ (1, \ 86); \ \eta^2 = .058; \ p < .023$. Therefore the null hypothesis is rejected and there is a statistical difference between subjects in the experimental groups and final course averages in the chemistry classroom. The effect size is considered close to moderate ($\eta^2 = .058$) so there is a reasonable chance that treatment group differences explains an average amount of variance on the final grade.

Table 23

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1115.857</td>
<td>1</td>
<td>1115.857</td>
<td>5.338</td>
<td>.023</td>
<td>.058</td>
</tr>
<tr>
<td>Error</td>
<td>17978.180</td>
<td>86</td>
<td>209.049</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19094.038</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9 shows the averages of the final course averages compared to treatment group in a histogram representation. The vertical axis represents the final course averages based on 100% and the horizontal axis separates each average by experimental group. The histogram below indicates the highest final average was achieved in treatment group ($\bar{X} = 89.4$) compared to the control group ($\bar{X} = 82.3$). The results are statistically significant suggesting that Lumosity™ treatment is better than having no treatment.
In Table 24, the final course grade data were analyzed further by experimental group and course letter grade received (A, B, C, and D, F).

Table 24

ANOVA Results Comparing Grade Received in Class (Grade Group) and Experimental Group in Gen Chem I Class

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>(\rho)</th>
<th>(\eta^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradegroup</td>
<td>11019.931</td>
<td>3</td>
<td>3745.991</td>
<td>136.771</td>
<td>0.001</td>
<td>0.837</td>
</tr>
<tr>
<td>Group</td>
<td>179.374</td>
<td>1</td>
<td>203.538</td>
<td>6.679</td>
<td>0.012</td>
<td>0.077</td>
</tr>
<tr>
<td>Gradegroup*Group</td>
<td>590.866</td>
<td>3</td>
<td>213.937</td>
<td>7.33</td>
<td>0.001</td>
<td>0.216</td>
</tr>
<tr>
<td>Error</td>
<td>2148.583</td>
<td>80</td>
<td>26.753</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19094.038</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The grades of D and F were combined due to the fact that these are usually grouped as students who are unsuccessful and will not be continuing with general chemistry the following semester in gen chem II. Grades of A, B, and C (students usually classified as successful) were analyzed separately. An ANOVA was conducted and a statistical
significant result was found for students who received a grade of C in the class, $F = 7.333 (3, 80); \eta^2 = .216; p = .001$. The effect size for this result is considered large ($\eta^2 = .218$); therefore, the results for this statistic has more practical significance compared to previous results and indicates a good possibility for a real situation.

In Figure 10 a histogram was constructed to visualize the data by grade received and experimental group. Percentage course grade is on the y-axis and the letter grade received in class is on the x-axis. The different blocks represents the control and treatment groups. On average the students who were in the C group and participated in the Lumosity™ study ($\bar{X} = 77.4$) received a statistically significantly higher grade compared to the control group ($\bar{X} = 72.5$). The other letter grade groups received statistically equivalent grades when comparing the two experimental groups.

![Final Grade*Grade Group](Image)

*Figure 10.* Histogram comparing letter grade received in the gen chem I class by experimental group.

**Discussion**

There was a statistically significant result when comparing the experimental
groups over time versus gain score on the CA Dx exam. The treatment Lumosity™ group significantly improved their score on the CA Dx exam compared to the control (non-gaming) group. The effect size for this result is considerate borderline moderate ($\eta^2 = 0.051$) (Huck, 2008). This implies that the results were statistically significant and reasonably practically significant because it explains about 5.0% of the variance in the CA Dx score when comparing between experimental groups.

Chemistry success as defined by final course averages in the class was statistically significant. The control group had the lowest final course average ($\bar{X} = 82.3$) and the treatment group had the highest final course average ($\bar{X} = 89.4$). This implies that the Lumosity™ training statistically enhanced students' ability to receive a higher grade in the classroom for this study. Further analysis comparing letter grade in the class and experimental group revealed that the grade group benefiting the most from the Lumosity™ training belonged to the students receiving a C in the classroom. This is an important group to be able to target because they are the borderline students struggling in the class; it is outstanding that Lumosity™ training can enhance their chemistry experience and final course average. The effect size for this statistic is relatively high ($\eta^2 = 0.216$); therefore, 21.6% of the variance in the final course grade can be explained by treatment group and letter grade received in the gen chem I class. It appears that the more intensive Lumosity™ games have a greater chance of producing results that provide students with transferable skills that can be used in this general chemistry classroom.
Second Research Question

When students participate in cybergame training over the span of 10 weeks, how is student performance on logic ability as measured by the Group Assessment of Logic Thinking (GALT) affected?

Data Analysis

The investigative purpose was to determine how the effect (if any) of participating in cybergame training over time would improve logic ability. The within variable was time and the between variables were gender and training group. The methods used to determine logic ability improvement were pre/post GALT exams. The pre-GALT exam was given on the first day of class and the post-GALT was given the week before the class final exams.

Descriptive data for all variables were determined and can be found in Table 25, \((N = 80: n_{\text{experimental}} = 26 n_{\text{control}} = 54)\).

Table 25

Descriptive Statistics for Logical Thinking Variable on the GALT in the Gen Chem I Class

<table>
<thead>
<tr>
<th>Variable by Group</th>
<th>Description</th>
<th>(X(SD))</th>
<th>Kurtosis</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-GALT</td>
<td></td>
<td>Max Score = 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>Logical thinking</td>
<td>8.692 (2.738)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>prior knowledge</td>
<td>8.796 (2.587)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>8.762 (2.739)</td>
<td>1.162</td>
<td>-1.246</td>
</tr>
<tr>
<td>Post-GALT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>Logical thinking</td>
<td>9.539 (2.565)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>success</td>
<td>8.759 (2.753)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>9.012 (2.702)</td>
<td>2.356</td>
<td>-1.276</td>
</tr>
</tbody>
</table>

Skewness was found to be near an absolute value of 1 for all variables. Kurtosis was
found to below 2.0 for all variables, except post-GALT exam. The results from both the skewness and kurtosis statistics suggest a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997).

The null hypothesis being tested for the second questions is:

\[ H_{0,2.2}: \text{There is no significant difference between students participating in the cybergaming intervention group of combination of logic-spatial and the control (non-gaming) group in logic ability as measured by the GALT exam on average and over the 10-week intervention in general chemistry I.} \]

Table 26 displays the test results for this hypothesis for the GALT gain scores. There were no statistically significant results reported.

Table 26

*Repeated Measures ANOVA Results for GALT Scores in the Gen Chem I*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial ( \eta^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>4.001</td>
<td>1</td>
<td>4.001</td>
<td>0.313</td>
<td>.577</td>
<td>.004</td>
</tr>
<tr>
<td>Error</td>
<td>995.974</td>
<td>78</td>
<td>12.769</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>5.745</td>
<td>1</td>
<td>5.745</td>
<td>2.755</td>
<td>.101</td>
<td>.034</td>
</tr>
<tr>
<td>Time*Group</td>
<td>6.845</td>
<td>1</td>
<td>6.845</td>
<td>3.282</td>
<td>.074</td>
<td>.040</td>
</tr>
<tr>
<td>Error</td>
<td>162.655</td>
<td>78</td>
<td>2.085</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1175.220</td>
<td>159</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The difference between the GALT scores over the 10-week intervention period when comparing the control and treatment groups was not statistically significant, \( F = 2.474 \) \( \chi^2 (1, 90); \eta^2 = .007; p = .119 \). The difference between the groups was also not
statistically significant, $F = 0.698 (3, 91); \eta^2 = .131; p > .406$. Therefore I rejected the null hypothesis and there is no statistical difference on the GALT scores between groups over the 10-week intervention time or on average. The effect size for comparing experimental groups over time results is low therefore this further implies there is no practical significance.

A line graph is shown (Figure 11) illustrates the gain scores in the GALT by control and treatment groups. The vertical axis is the averaged raw score on the GALT and control and pre/post exam periods on the horizontal axis. The lines in the graph represent pre/post scores; the differences in height and slope give the gain scored over time. Though not statistically significant, the treatment group had the highest gain score ($\Delta = 0.85$) compared to the control group ($\Delta = 0.04$).

![GALT Gain Scores](image)

*Figure 11. GALT pre/post scores compared by experimental group.*

**Discussion**

There were no statistically significant results when between experimental groups over time or on average when comparing gain scores on the GALT. Therefore, it cannot be definitively stated that the treatment group increased logical thinking compared to
the control group over time. When comparing gain scores over time, the control group had the lowest gain score compared to the treatment group. Despite the difference in gain scores, the results on the repeated measures ANOVA were not significant therefore I failed to reject the null hypothesis. The effect sizes for each statistic was considered low so the treatment group training does not explain a lot of variance in the GALT score.

Third Research Question

When students participate in cybergame training over the span of 10 weeks, how is student performance on spatial ability as measured by the Purdue Visualization of Rotations (ROT) test affected?

Data Analysis

The investigative purpose of this research questions was to determine the effect (if any) of participating in cybergame training over time and gather how spatial skills would be improved. The within variable was time and the between variables were gender and experimental group. The methods used to determine spatial skills improvement were pre/post ROT tests. The pre-ROT test was given on the first day of class and the post-ROT was given the week before the class' final exams.

Descriptive data for all variables were determined and can be found in Table 27, \((N = 81: n_{\text{experimental}} = 27 \ n_{\text{control}} = 54)\). Skewness was found to be near an absolute value of 1 for all variables. Kurtosis was found to below 2.0 for all variables. The results from both the skewness and kurtosis statistics suggest a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997).
Table 27
Descriptive Statistics for Spatial Thinking Variables on the ROT Test in the Gen Chem I Class

<table>
<thead>
<tr>
<th>Variable Group</th>
<th>Description</th>
<th>$\bar{x} (SD)$</th>
<th>Kurtosis</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-ROT</td>
<td>Spatial thinking prior knowledge</td>
<td>12.814 (4.342)</td>
<td>-0.647</td>
<td>-0.452</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>12.278 (4.771)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>12.456 (4.612)</td>
<td>-0.647</td>
<td>-0.452</td>
</tr>
<tr>
<td>Post-ROT</td>
<td>Spatial thinking success</td>
<td>15.888 (2.044)</td>
<td>0.007</td>
<td>-0.668</td>
</tr>
<tr>
<td>Experimental</td>
<td></td>
<td>15.296 (3.340)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>15.494 (2.971)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The null hypothesis being tested for the third questions is:

$H_{0.3.2}$: There is no significant difference between students participating in the cybergaming intervention of combination of logic-spatial and the control (non-gaming) group in spatial skills as measured by the ROT test on average and over the 10-week intervention in general chemistry I.

Table 28 presents the test results for this hypothesis analyzing ROT test scores. There were no statistically significant results when comparing ROT test scores over time and on average. The difference between the ROT test scores over time comparing control and treatment groups was not statistically significant, $F = 0.004 (1, 79); \eta^2 = .001; p = .953$. The differences between the experimental groups was also not statistically significant, $F = 0.510 (1, 90); \eta^2 = .006; p = .477$. Therefore the null hypothesis failed to be rejected, and there is no statistical difference in ROT tests scores between control and treatment groups over the 10-week span or on average. In
addition, both results produced a small effect size further implying little statistical or practical significance.

Table 28

Repeated Measures ANOVA Results for ROT test Scores in Gen Chemistry I

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>11.485</td>
<td>1</td>
<td>11.485</td>
<td>0.510</td>
<td>.477</td>
<td>.006</td>
</tr>
<tr>
<td>Error</td>
<td>22.512</td>
<td>79</td>
<td>22.512</td>
<td>0.028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>334.077</td>
<td>1</td>
<td>334.077</td>
<td>42.677</td>
<td>.001</td>
<td>.351</td>
</tr>
<tr>
<td>Time*Group</td>
<td>0.028</td>
<td>1</td>
<td>0.028</td>
<td>0.004</td>
<td>.953</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
<td>618.417</td>
<td>79</td>
<td>7.828</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>987.519</td>
<td>161</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A line graph is shown (Figure 12) illustrating the averaged gain scores in the ROT test by experimental group. The vertical axis is the raw score on the ROT test and pre/post exam times are arranged on the horizontal axis. The lines in the graph represent pre/post scores; the differences in height and slope gives the averaged gain scored over time. The averaged gain score for the experimental group ($\Delta = 3.07$) and the control group ($\Delta = 3.01$) were statistically the same.

Figure 12. ROT pre/post scores compared by experimental group.
Discussion

There was no statistically significant result when comparing control and treatment groups over time on the ROT test scores. There was no difference in improving spatial skills using the Lumosity™ training compared to the control group. The experimental groups had the same averaged gain score over time. The students improved their spatial skills over time but it was not due to group differences. The estimated effect size ($\eta^2 = 0.001$) is very low so the result does not explain much of the variance in the ROT scores indicating the practical significance of the results is poor.

Fourth Research Question

What are the effects when participating in cybergame training over the span of 10 weeks between genders as measured by the outcomes on the content diagnostic exams (GOB and CA Dx), GALT and ROT, and final course grade?

Data Analysis

All variables were examined for missing data due to dropouts prior to conducting any analysis, and as a result any cases with missing data were deleted. Skewness was previously determined and found to be near an absolute value of 1 for all variables. Kurtosis was found to below 2.0 for all variables. The results from both the skewness and kurtosis statistics suggest a close to normal distribution of data and therefore no data transformations were needed (Pisani & Roger, 1997).
The descriptive data for gender and CA Ex exam are listed below in Table 29, \( N = 84: n_{\text{male}} = 45 \ n_{\text{female}} = 39 \). The null hypothesis being tested for the fourth questions is:

\[ H^{0.4.2}: \text{There is no significant difference between genders in general chemistry I as measured by the scores on the CA Dx, GALT and ROT, and final course averages and grades.} \]

Table 29

Descriptive Statistics Comparing Genders for CA Dx Exam in the Gen Chem I Class

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>Pre CA Dx ( \bar{x} ) (SD)</th>
<th>Post CA Dx ( \bar{x} ) (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max Score = 44</td>
<td>Max Score = 44</td>
</tr>
<tr>
<td>Male</td>
<td>22.377 (7.408)</td>
<td>31.955 (5.608)</td>
</tr>
<tr>
<td>Female</td>
<td>19.641 (6.830)</td>
<td>30.717 (6.004)</td>
</tr>
</tbody>
</table>

Table 30 gives the Repeated Measures ANOVA results for gender differences on the CA Dx exam \( N = 84: n_{\text{male}} = 45 \ n_{\text{female}} = 39 \). The between gender differences over time was not statistically significant, \( F = 1.643 \ (1, \ 82); \ \eta^2 = .020; \ p = .204 \). The between average difference comparing gender was not statistically significant \( F = 2.345 \ (1, \ 82); \ \eta^2 = .028; \ p > .130 \). Therefore the null hypothesis failed to be rejected and there is no statistical difference in CA Dx gained score analyzing between genders.
Table 30

Repeated Measures ANOVA Results Comparing Genders for the CA Dx Exam in Gen Chem I Class

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>165.007</td>
<td>1</td>
<td>165.007</td>
<td>2.345</td>
<td>.130</td>
<td>.028</td>
</tr>
<tr>
<td>Error</td>
<td>5769.487</td>
<td>82</td>
<td>70.360</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>4456.621</td>
<td>1</td>
<td>4456.621</td>
<td>311.845</td>
<td>.001</td>
<td>.792</td>
</tr>
<tr>
<td>Time*Gender</td>
<td>23.478</td>
<td>1</td>
<td>23.478</td>
<td>0.204</td>
<td>.204</td>
<td>.020</td>
</tr>
<tr>
<td>Error</td>
<td>1171.874</td>
<td>82</td>
<td>14.291</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11586.467</td>
<td>167</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Final Course Grade

The descriptive data for gender and final course grade are listed below in Table 31, $(N = 88; n_{male} = 45, n_{control} = 43)$. The null hypothesis being tested for the fourth questions is:

$H^o_{4,2}$: There is no significant difference between genders in general chemistry I as measured by the scores on the CA Dx, GALT and ROT, and final course averages and grades.

Table 31

Descriptive Statistics for Final Course Grade Comparing Gender in Gen Chem I Class

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>$\bar{x}$ % (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>83.113 (14.622)</td>
</tr>
<tr>
<td>Female</td>
<td>85.881 (15.053)</td>
</tr>
</tbody>
</table>

Table 32 gives the statistics for the final course grade compared by gender $(N = 88; n_{male} = 45, n_{female} = 43)$. The between gender differences over time was not
statistically significant, $F = 0.766$ ($1, 87$); $\eta^2 = .009$; $p = .384$. Therefore the null hypothesis failed to be rejected and there is no statistical difference in final course grade analyzing between genders. In addition the effect size is small so most of the variance in the final grade is not due to gender differences.

Table 32

ANOVA Results for the Final Course Grade Comparing Genders in Gen Chem I Class

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>168.481</td>
<td>1</td>
<td>168.481</td>
<td>0.766</td>
<td>.384</td>
<td>.009</td>
</tr>
<tr>
<td>Error</td>
<td>18925.557</td>
<td>86</td>
<td>220.065</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19094.038</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GALT

The descriptive data for gender and GALT scores are listed below in Table 33, ($N= 80$: $n_{\text{experimental}} = 40$ $n_{\text{control}} = 40$). The null hypothesis being tested for the fourth questions is:

$H_{0,4,2}$: There is no significant difference between genders in general chemistry I as measured by the scores on the CA Dx, GALT and ROT, and final course averages and grades.

Table 33

Descriptive Statistics for GALT Scores Comparing Genders in Gen Chem I Class

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>Pre GALT $\bar{X}$ (SD)</th>
<th>Post GALT $\bar{X}$ (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max Score = 12</td>
<td>Max Score = 12</td>
</tr>
<tr>
<td>Male</td>
<td>8.950 (2.659)</td>
<td>9.025 (2.939)</td>
</tr>
<tr>
<td>Female</td>
<td>8.575 (2.836)</td>
<td>9.000 (2.480)</td>
</tr>
</tbody>
</table>
Table 34 gives the statistical analysis for GALT scores compared by gender. The gender *between* differences over time was also not statistically significant, $F = 0.568$ (1, 79); $\eta^2 = .007; p = .453$. The inferential average results *between* genders as a unit was not significant $F = 0.125$ (1,79); $\eta^2 = .002; p = .725$. Therefore the null hypothesis failed to be rejected and there is no statistical difference in averaged GALT scores analyzing over time or on average. The effect sizes are small so little of the variance in the GALT scores is explained by gender differences.

Table 34

*Repeated Measures ANOVA Results for the GALT Scores Comparing Genders in the Gen Chem I Class*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>1.600</td>
<td>1</td>
<td>1.600</td>
<td>0.725</td>
<td>.725</td>
<td>.002</td>
</tr>
<tr>
<td>Error</td>
<td>998.375</td>
<td>78</td>
<td>12.800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>2.500</td>
<td>1</td>
<td>2.500</td>
<td>1.159</td>
<td>.285</td>
<td>.015</td>
</tr>
<tr>
<td>Time*Gender</td>
<td>1.225</td>
<td>1</td>
<td>1.225</td>
<td>0.568</td>
<td>.453</td>
<td>.007</td>
</tr>
<tr>
<td>Error</td>
<td>168.275</td>
<td>78</td>
<td>2.157</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1171.975</td>
<td>159</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ROT

The descriptive data for gender and final course grade are listed below in Table 35, $(N = 81: n_{\text{male}} = 42 \ n_{\text{female}} = 39)$. The null hypothesis being tested for the fourth questions is:

$H^o_{4.2}$: There is no significant difference *between* genders in general chemistry I as measured by the scores on the CA Dx, GALT and ROT, and final course averages and grades.
Table 35

*Descriptive Statistics for ROT Scores Comparing Genders in the Gen Chem I Class*

<table>
<thead>
<tr>
<th>Variable by Gender</th>
<th>Pre-ROT (SD) Max Score = 20</th>
<th>Post-ROT (SD) Max Score = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>11.538 (4.621)</td>
<td>15.717 (2.615)</td>
</tr>
</tbody>
</table>

Table 36 gives the statistical results for the ROT exam scores compared by gender. The *between* gender differences over time was statistically significant, $F = 6.811$ ($1, 79$); $\eta^2 = .079$; $p = .011$. The inferential average results *between* genders was statistically significant $F = 0.808$ ($1, 79$); $\eta^2 = .010$; $p = 0.371$. Therefore, the null hypothesis is rejected and there is a statistical difference *between* genders over the 10-week time span and on average. The other null sub-hypothesis failed to be rejected, and there is no statistical difference *between* genders on average. The effect size for the *between* gender over time explains a moderate in the ROT scores (8%) variance (Huck, 2008).

Table 36

*Repeated Measures ANOVA Results for the ROT Scores Comparing Genders in the Gen Chem I Class*

<table>
<thead>
<tr>
<th>Source</th>
<th>$SS$</th>
<th>$df$</th>
<th>$MS$</th>
<th>$F$</th>
<th>$p$</th>
<th>Partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>18.124</td>
<td>1</td>
<td>18.112</td>
<td>0.808</td>
<td>.371</td>
<td>.010</td>
</tr>
<tr>
<td>Error</td>
<td>1771.777</td>
<td>79</td>
<td>22.428</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>383.134</td>
<td>1</td>
<td>383.134</td>
<td>53.161</td>
<td>.001</td>
<td>.402</td>
</tr>
<tr>
<td>Time*Gender</td>
<td>49.085</td>
<td>1</td>
<td>49.085</td>
<td>6.811</td>
<td>.011</td>
<td>.079</td>
</tr>
<tr>
<td>Error</td>
<td>569.360</td>
<td>79</td>
<td>7.207</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2781.473</td>
<td>161</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussion

There was no statistical difference between male and female students on the CA Dx exam. The effect size for this result is low indicating that the variance in the CA Dx scorers is not explained completely by gender differences. When comparing gender differences and final grade, again the results were not statistically or practically significant. This implies that male and female students had an equal chance at succeeding in the classroom for this sample.

When comparing differences by gender on the GALT exam there were no statistical significant results on average or over time. In addition, the effect size was small indicating gender differences do not explain a lot of the variance in the GALT scores. When analyzing gender differences on the ROT exam there were no statistical differences between group on average but there was a statistical results between genders over time. This implies that on average male and female students have equivalent spatial ability but this is due to the statistically significant improvement of females (+4.179) in spatial ability over time compared to male students (+1.976). The female students had an inferior spatial ability compared to male students on the pre-ROT exam but over time they were able to drastically improve their spatial ability through practice and exposure. The gender differences over time was able to explain a moderate amount of variance in the ROT exam scores.

Fifth Research Question

What are the experiences and attitudes of general chemistry I and organic chemistry I students using the logic and spatial cybergame training intervention for a
span of 10 weeks as measured on a Likert-scale and responses to questions on an open-ended questionnaire?

**Data Analysis**

To determine the experience of the students using the Lumosity™ training tool a survey was distributed containing closed- and open-ended questions. The close-ended questions (see Appendix C) were analyzed using a Likert-type scale. The averages of each can be found in Table 37. The answers were based on a 5-point scale where 5: *strongly agree*, 4: *agree*, 3: *neutral*, 2: *disagree*, 1: *strongly disagree*.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you feel that the Lumosity™ courses improved your everyday reasoning skills?</td>
<td>3.67</td>
</tr>
<tr>
<td>2. Did you enjoy playing each game?</td>
<td>3.71</td>
</tr>
<tr>
<td>3. Did you feel the games became repetitive?</td>
<td>3.90</td>
</tr>
<tr>
<td>4. Would you continue playing these courses beyond this study?</td>
<td>3.38</td>
</tr>
<tr>
<td>5. Did you find these games motivating?</td>
<td>3.42</td>
</tr>
<tr>
<td>6. Do you feel like your spatial skills improved?</td>
<td>3.95</td>
</tr>
<tr>
<td>7. Do you feel like your logic ability improved?</td>
<td>3.85</td>
</tr>
<tr>
<td>8. Did these Lumosity™ games aid in improving your chemistry classroom grade?</td>
<td>2.90</td>
</tr>
<tr>
<td>9. Did you improve your memorization skills playing the games?</td>
<td>4.00</td>
</tr>
<tr>
<td>10. Were you able to better visualize chemistry molecules after playing these games?</td>
<td>3.05</td>
</tr>
<tr>
<td>11. Did you feel your chemistry test response time improved?</td>
<td>3.05</td>
</tr>
</tbody>
</table>

After analyzing the data evident was that the average of each question was about 3.5, which can be interpreted as the students *somewhat agreeing* with the
question statement. The statement the students felt most strongly about asked if the
Lumosity™ games helped with their memorization skills ($\bar{X} = 4.00$). The question the
students had the most neutral opinion about asked if Lumosity™ training improved their
chemistry skills in the classroom ($\bar{X} = 2.90$). On average the students did not have any
negative complaints about the Lumosity™ study.

The survey also asked open-ended questions that were analyzed using word
counts to determine common themes in the responses by experimental group
(D'Andrade, 1995). The open-ended question included:

1. What was your favorite and least favorite game and why?
2. Any suggestions on how to improve the Lumosity™ courses?
3. Do you feel like these games improved your reasoning and spatial skills on your
chemistry class? Why?
4. Did you feel like playing the Lumosity™ games improved your testing ability?
Why or Why not?

The experimental group on average developed the following themes from the
questions: The most enjoyed games where Route to Sprout and Familiar Faces. The
Route to Sprout game deals with logically planning a tactic out of a maze in the least
amount of moves possible and the Familiar Faces is a game that deals with memory
recall. The least favorite games were Penguin Pursuit and Rain Drops. The game
Penguin Pursuit deals with spatial ability and recall and Rain Drops deals with
mathematics logic ability. When students were asked if there were any suggestions on
improving the Lumosity™ study, 50% of the students suggested having more variety in
the games so they would not become so repetitive. When the students were asked if they felt if the study improved their logic ability and spatial skills in the classroom, 50% of the students replied they witnessed no effect while 50% replied “yes” that it helped with memorization and visualization of molecules. Finally, the students were asked if the Lumosity™ study helped with their test taking ability, approximately 50% of the students replied “No” while 50% replied yes it helped with test anxiety, processing speed and memorization.

Discussion

Overall the students seemed to develop no negative effects on average about the Lumosity™ training project, though they also did not have any strong positive feelings. The strongest feelings towards the study were that the Lumosity™ study helped with their memorization skills. This thought was also prevalent in the open-ended questions; the treatment group felt the Lumosity™ games helped improve their memorization skills on chemistry exams. The students on average enjoyed the Route to Sprout and Familiar Faces games; the least liked games on average were Rain Drops and Penguin Pursuit. Most of the students disliked the complexity of these games and were easily frustrated. Approximately 50% students reported that they saw an affect of playing the games within the chemistry classroom. The students also felt the Lumosity™ games helped improve their test-taking skills especially test anxiety, memorization and processing skills. The students seemed to like the project but the biggest improvement could be creating more games so the students would not become bored in learning spatial and logic skills.
Summary

Statistical analyses were completed to explain all the research questions for both experiments. The research questions for each experiment were the same outside of the fact that they were applied to different courses. The first question asked what student scores from pre/post content placement exams and chemistry course averages indicate about the performance of students belonging to the experimental groups who participated in the cybergaming intervention for 10 weeks and the control (non-gaming) group. In experiment 1, organic chemistry I classroom, analysis using Repeated Measures ANOVA did not produce a significant result on the first question when chemistry success is defined by the GOB exam when comparing between group. Additionally the effect sizes for these results were considered small. Also in the first experiment when using an ANOVA to analyze the results comparing final course grade there was no significant result, and all effect sizes produced were small.

In the second experiment, general chemistry I, analysis using the CA Dx exam as a measure of chemistry success there were statistically significant results when comparing treatment groups over time. The result comparing treatment group over time explained 6% of the variance that is considered a moderate result (Huck, 2008). When comparing ANOVA results in Experiment 2 using final course grade as the measure of success, there were statistically significant results when comparing the groups over time but the effect size produced is considered small (Huck, 2008). When the analysis of the final course grade was investigated deeper, a significant result was found when comparing letter grade received in the class of those receiving a grade of C
in the classroom; the result produced a high effect size explaining 21.6% of the variance.

The second research question asked if student participation in cybergame training over the span of 10 weeks would have affected student performance on logic ability as measured by the GALT. In both experiments using o-chem I and gen chem I data, the results were not significant over time and the effect sizes were all considered small (Huck, 2008).

The third research question for both experiments asked if students participating in cybergame training over the span of 10 weeks, would have affected different groups of student performances on spatial ability as measured by the ROT test. The first experiment produced a significant result when comparing between experimental groups over time. Additionally the effect size for the result explained 7.7% of the variance, which is considered a moderate effect (Huck, 2008). The second experiment did not produce significant results over time comparing control and treatment groups. The female students did statistically improve their spatial skills over time compared to male students, implying female students can benefit from spatial training.

The final research question inquired about the experiences and attitudes of general chemistry I and organic chemistry I students who had used the logic and spatial cybergame training intervention for a span of 10 weeks as measured on a Likert-scale and on responses to an open-ended questionnaire. The results indicated that students would like more variety in the games they played so they would not become so
mundane. Also, the students felt there was a transfer effect using the Lumosity™ games on their processing speed, test anxiety, memorization and visualization skills.
CHAPTER V

CONCLUSION

This chapter explores the conclusions drawn from the Lumosity™ cybertraining study. The chapter includes a summary of the results, discussion and practical applications ensuing from the study. The remainder of this chapter examines the overall themes determined by the results of the statistical analyses and the limitations encountered along with suggestions for further research.

In today’s society with wide-ranging cybertechnology access, the teaching community should incorporate cybergames, like the one evaluated in this study, to help our students think critically and apply the information learned in the classroom. The question central to this study has been: Can chemistry students enhance their learning using cybertechnology games that focus on improving basic logic and spatial skills as a supplement to classroom instruction? The answer to this question from this study informs educators on ways that the use of the cybergames in this study improved students' success in the lower-division chemistry classrooms.

Learning how to improve students' success in the chemistry classroom was the ultimate goal of this study. Investigated was the relationship of using Lumosity™ training games to enhance students' logic and spatial skills and how use of cybertechnology games contributed to academic success. Students’ successes in the chemistry classroom were measured using the final course averages in organic chemistry I (o-chem I) in the first experiment and pre/post California Diagnostic exam (CA Dx) scores and final course averages and grades in general chemistry I (gen chem
I) in the second experiment. Also measured in both experiments were students’ logical thinking abilities and spatial skills using the Group Assessment of Logical Thinking (GALT) and Prudue Visualizations of Rotations Test (ROT) instruments, respectively. Finally, students’ experiences during this study were considered using an investigator-developed survey of open- and closed-ended questions.

The study was performed using a small sample of students from two lower-division chemistry courses during the 2010 spring and fall semesters. The classes chosen for the study were samples of convenience. It is not unusual for small sample sizes to produce significant results (e.g., studies reported by Baker & Talley (1972) and Wu & Shah (2004). However, to improve the validity in this research, students were systematically randomly selected to participate in each experimental group from o-chem I and gen chem I. The educational cybertechnology tool used in this study was provided free of charge by Lumosity™: A website dedicated to using cutting edge science to develop tools to exercise the brain and enhance learning (Hardy, 2010). The use of Lumosity™ cybertechnology to train students’ minds in logic and spatial skills has been found highly motivating and supportive of improving students' capacity to learn (Feng, 2007; Kumta et al., 2003; Tracy, 1987).

As mentioned above, to determine if the Lumosity™ cybergames contributed to improved success in the chemistry classroom, final averages and standardized chemistry assessments were used to depict the student populations evaluated. In the organic chemistry classroom, the cybertraining did not statistically improve the students' final averages according to the ANOVA results. In the general chemistry classroom both
the students' final averages and the standardized CA Dx exam averages were statistically improved when students participated in the Lumosity™ training. The difference in the results could be attributed to the idea that general chemistry is considered a “killer course” (Rowe, 1983) that "weeds out" students entering organic chemistry and therefore the o-chem students in this study were simply better prepared to succeed without the use of the cybergaming. General chemistry enrollment tends to be much larger compared to the organic chemistry enrollment due to students having trouble completing general chemistry and therefore needing to retake the courses and the fact that a significant percentage of the general chemistry students at UNT do not continue with their studies in chemistry after successfully completing gen chem I. In this study the sample size used in experiment 2 (gen chem I) was about half the size of the sample in experiment 1 (o-chem) because only the students with a complete dataset were evaluated, and as is very well known attendance in gen chem I is often a contributing factor to the high DFW (grades of D, F, and withdrawals) rate. In this study, students were eliminated from analyses if they failed to take both the pre- and post-assessments, since no opportunity for make-ups was provided.

Non-published historical data (Fall 2004-Fall 2009) from Dr. Mason's classes at UNT suggests the average DFW rate in her gen chem I class is 46.4% (N = 1104). Including the data from this study into the overall picture, the DFW rate fell to 45.4% (N = 1238), which in and of itself may suggest that the students in this particular class may have benefited from the intervention. However, as previously stated nearly half the students in this course will not continue with their studies in chemistry even though
successful since some degree plans, like those in engineering, do not require courses beyond general chemistry I. Nevertheless, at least in this general chemistry class, it appears that Lumosity™ training skills might have been effectively transferred to improve student performance because upon further investigation into student-received letter grades, those who earned grades of C had the greatest benefit from using the Lumosity™ training tools. Simply looking at the pre/post CA Dx gain for the overall class, the mean rose by over 11 points out of the possible 44 points (more than 1 standard deviation), but 40 (30.8%) of the initial enrollment of 130 still withdrew. Therefore, this training tool may be a viable intervention for the borderline students to improve their success, but as the only intervention it does not appear to be the answer.

When comparing the results by gender, the organic classroom resulted in no statistically significant effect. The gen chem I classroom did have significant results appear when comparing the ROT and gender differences over time. The female students were drastically able to improve their spatial ability over time. Though a definite statement cannot be made since the experiments in o-chem I and gen chem I had different treatment conditions, overall it seems that students in the general chemistry classroom benefited more from the Lumosity™ cybertraining than those in the organic class. Since the general chemistry students participated in a more intense cyber-learning regime, it is possible that the more targeted intervention could have resulted in the statistically significant results. Also as previously mentioned, organic chemistry is the class that typically follows general chemistry, and historically it has been found that almost 50% of the students ceased to enroll in chemistry courses past

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the first semester of general chemistry. Consequently, organic chemistry courses enroll stronger students who are proven able to complete a rigorous curriculum in chemistry where additional treatment using a cybergaming protocol might not be as beneficial.

To determine if the Lumosity™ cybertraining could be used to enhance logical thinking ability and spatial skills as proposed by the study, the GALT and ROT tests were used as measures. Neither the organic or general chemistry experiments resulted in statistically significant gains in logical thinking when intervention groups were compared to the control groups. This suggests that the Lumosity™ labs are poor at improving logic ability as measured by the GALT exam. Though not statistically significant, in the first study (organic experiment), the logic group resulted in the most improvement for the male students and the combination group resulted in the most improvement for the female students. When analyzing improvement in spatial skills, the organic chemistry students statistically improved their ability when they participated in the spatial training. The general chemistry students did not improve their spatial skills when participating in the more intensive combination training, but there was a difference when comparing results by gender. The male students did statistically better than female students over time on the ROT test that was used to measure spatial skills. This is reasonable outcome because historically male students have performed better on spatial exams compared to females (Bodner & Guay, 1997; Arlington et al., 1992; Baenniger & Newcombe, 1989; Brownlow et al., 2003).

The final aspect of the study analyzed the students’ feelings experienced while participating in the Lumosity™ study. It is important to to understand how students’ are
enjoying the study to determine if the Lumosity™ Website is intrinsically motivating. The survey found that students overall had no negative feelings towards the Lumosity™ cybertechnology study. The biggest complaint was that the Lumosity™ games could become repetitious. The Lumosity™ Website is constantly working on improving the Website by including new cybertechnology games every year so the gaming options will continue to progress. The students in both organic and general chemistry agreed the study enhanced their test taking ability and molecular visualizations utilized in the courses.

Overall it is evident that the Lumosity™ cybertechnology Website is minimally effective in enhancing chemistry success within the general chemistry classroom. These students had a more intensive cybertechnology schedule that proved beneficial. It is predicted that almost half of these students will not continue onto organic chemistry courses; therefore, the self-selecting organic students tend to have a higher level chemistry-oriented aptitude. The students receiving a grade of C in the general chemistry classroom statistically improved the most in the course when they participated in the cybergaming intervention group. This implies the Lumosity™ games can help improve students' success for those students who are borderline unsuccessful in the course. The Lumosity™ cybergames seem to improve spatial skills but have no statistical effect on improving logic ability. As suggested by the survey results, other possible affordances that could be influencing success rates are lowering test anxiety and improving memory and processing speed.
Limitations of Study and Recommended Further Study

The results of this study cannot be generalized to other studies unless similar samples are compared. The results may vary at different types of universities and regions. This study allowed a more naturalistic approach where students were allowed to complete the Lumosity™ cybergames on their own time and at locations of their choosing, so implementing a more controlled study could yield different results. Also, confounding variables such as test anxiety, memory and processing speed could be contributing factors to the measured success of students in the chemistry classroom instead of just the suggested benefits of logical and spatial training. These results were evident in the student surveys. Investigation of these affordances in the future could help eliminate these confounding variables.

Other ideas to consider for further research are comparing the more intensive Lumosity™ training to both classroom settings (organic I and general chemistry I) and increasing the sample size. The general chemistry results from the intensive Lumosity™ cybertraining appeared to be positive but will similar results be found in the organic classroom when students use a more intensive protocol? Would incorporating the Lumosity™ cybertraining at an earlier developmental stage (middle school or high school) enhance the effects of playing these games in the science classroom? Possibly if the Lumosity™ games are introduced at an earlier academic level, the effects will be evident in the science classroom and more students will be able to succeed in the college-level science courses. Also, it would be beneficial to compare results using the Lumosity™ cybertraining in basic logic and spatial skills to a program specifically
designed and directed towards specific chemistry logic and spatial skills. If educators are to create meaningful change in the chemistry classroom all of these questions are worth answering.
APPENDIX A

IRB APPROVALS AND STUDENT CONSENT FORM
Carissa Manrique  
Department of Chemistry  
University of North Texas

RE: Human Subjects Application No. 09321

Dear Ms. Manrique:

The UNT Institutional Review Board has reviewed and approved the extension you requested to your project titled “Empirical Research on Emerging Cyberlearning Topics.” Your extension period is for one year, September 3, 2010 through September 2, 2011. Federal policy 45 CFR 46.109(c) stipulates that IRB approval is for one year only.

Enclosed is the consent document with stamped IRB approval. Please copy and use this form only for your study subjects.

The UNT IRB must re-review this project prior to any modifications you make in the approved project. It is your responsibility according to U.S. Department of Health and Human Services regulations to submit annual and terminal progress reports to the IRB for this project. Please mark your calendar accordingly.

Please contact Sheila Bourne, Research Compliance Analyst, ext. 3940 or Boyd Herndon, Director of Research Compliance, ext. 3941 if you need additional information.

Sincerely,

[Signature]

Patricia L. Kaminski, Ph.D.  
Associate Professor  
Chair, Institutional Review Board

PK/15
University of North Texas Institutional Review Board

Informed Consent Form

Before agreeing to participate in this research study, it is important that you read and understand the following explanation of the purpose, benefits and risks of the study and how it will be conducted.

**Title of Study:** Empirical Research on Emerging Cyber learning Topics (ERECT)

**Principal Investigator:** Carissa Manrique, a graduate student in the University of North Texas (UNT) Department of Chemistry

**Purpose of the Study:** You are being asked to participate in a research study that involves understanding how playing different cyber games will affect your spatial ability and academic success in your chemistry course.

**Study Procedures:** You will be asked to play various cyber games for 3 total hours a week.

**Forseeable Risks:** There are no foreseeable risks involved in this study.

**Benefits to the Subjects or Others:** We expect the project to benefit you by improving your spatial ability, a skill related to academic success in chemistry. This study will also benefit future students through the results that are generated by this study. Specifically, it could benefit future students who struggle in science classes by offering them fun science cyber games that improve their scores.

- Your decision to participate or to withdraw from the study will have no effect on your standing in this course or your course grade

**Compensation for Participants:** There will be no monetary compensation or direct benefit beyond the expansion of personal knowledge by participating in the exercises. In addition, extra credit will be given to those who participate fully through the study.

**Procedures for Maintaining Confidentiality of Research Records:** The confidentiality of participant information will be maintained in any publications or presentations regarding this study as well as the doctoral dissertation. Data files to be analyzed will be generated from paper and pencil, Blackboard Vista Assessment Tool, and Cyber Learning Objects available to participating students. All scores and comments will be transcribed to a MS Word document for further analysis. All originally completed forms and the separate list of names will be stored in a locked office/cabinet in Dr. Mason’s office in SRB 240 for a minimum of three years after the completion of the study. No names or personal information will be given out as a result of this study.

**Questions about the Study:** If you have any questions about the study, you may contact Carissa Manrique at telephone number or the faculty.

Office of Research Services
University of North Texas
Last Updated: August 9, 2007
advisor, Dr. Mason, UNT Department of Chemistry, at her email: dmason@unt.edu

Review for the Protection of Participants: This research study has been reviewed and approved by the UNT Institutional Review Board (IRB). The UNT IRB can be contacted at (940) 565-3940 with any questions regarding the rights of research subjects.

Research Participants' Rights: Your signature below indicates that you have read or have had read to you all of the above and that you confirm all of the following:

- Carissa Manrique has explained the study to you and answered all of your questions. You have been told the possible benefits and the potential risks and/or discomforts of the study.
- You understand that you do not have to take part in this study, and your refusal to participate or your decision to withdraw will involve no penalty or loss of rights or benefits. The study personnel may choose to stop your participation at any time.
- You understand why the study is being conducted and how it will be performed.
- You understand your rights as a research participant and you voluntarily consent to participate in this study.
- You have been told you will receive a copy of this form.

Printed Name of Participant

Signature of Participant ___________________________ Date ____________

I will participate in playing weekly games: _____yes _____no

Email address: ________________________________

For the Principal Investigator: I certify that I have reviewed the contents of this form with the participant signing above. I have explained the possible benefits and the potential risks and/or discomforts of the study. It is my opinion that the participant understood the explanation.

Signature of Principal Investigator ___________________________ Date ____________

Office of Research Services
University of North Texas
Last Updated: August 9, 2007
OFFICE OF THE VICE PRESIDENT FOR RESEARCH AND ECONOMIC DEVELOPMENT

September 3, 2009

Carissa Manrique
Department of Chemistry
University of North Texas

Re: Human Subjects Application No. 09321

Dear Ms. Manrique:

As permitted by federal law and regulations governing the use of human subjects in
research projects (45 CFR 46), the UNT Institutional Review Board has reviewed your
proposed project titled "Empirical Research on Emerging Cyberlearning Topics." The
risks inherent in this research are minimal, and the potential benefits to the subject
outweigh those risks. The submitted protocol is hereby approved for the use of human
subjects in this study. Federal Policy 45 CFR 46.109(e) stipulates that IRB approval is
for one year only, September 3, 2009 to September 2, 2010.

Enclosed is the consent document with stamped IRB approval. Please copy and use this
form only for your study subjects.

It is your responsibility according to U.S. Department of Health and Human Services
regulations to submit annual and terminal progress reports to the IRB for this project. The
IRB must also review this project prior to any modifications.

Please contact Shelia Bourns, Research Compliance Administrator, or Boyd Herndon,
Director of Research Compliance, at extension 3940, if you wish to make changes or need
additional information.

Sincerely,

Patricia L. Kaminski, Ph.D.
Associate Professor
Chair, Institutional Review Board

PK:ab

CC: Dr. Diana Mason
University of North Texas Institutional Review Board

Informed Consent Form

Before agreeing to participate in this research study, it is important that you read and understand the following explanation of the purpose, benefits and risks of the study and how it will be conducted.

**Title of Study:** Empirical Research on Emerging Cyber learning Topics (ERECT)

**Principal Investigator:** Carissa Manrique, a graduate student in the University of North Texas (UNT) Department of Chemistry

**Purpose of the Study:** You are being asked to participate in a research study that involves understanding how playing different cyber games will affect your spatial ability and academic success in your chemistry course.

**Study Procedures:** You will be asked to play various cyber games for 3 total hours a week.

**Foreseeable Risks:** There are no foreseeable risks are involved in this study.

**Benefits to the Subjects or Others:** We expect the project to benefit you by improving your spatial ability, a skill related to academic success in chemistry. This study may benefit future students through the results that are generated by this study. Specifically, it could benefit future students who struggle in science classes by offering them fun science cyber games that improve their scores.

* Your decision to participate or to withdraw from the study will have no effect on your standing in this course or your course grade.

**Compensation for Participants:** There will be no monetary compensation or direct benefit beyond the expansion of personal knowledge space developed by participating in exercises designed to link existing neural connection. In addition, extra credit will be given to those who participate fully through the study.

**Procedures for Maintaining Confidentiality of Research Records:** The confidentiality of participant information will be maintained in any publications or presentations regarding this study as well as the doctoral dissertation. Data files to be analyzed will be generated from paper and pencil, Blackboard Vista Assessment Tool, and Cyber Learning Objects available to participating students. All scores and comments will be transcribed to a MS Word document for further analysis. All originally completed forms and the separate list of names will be stored in a locked office/cabinet in Dr. Mason’s office in SRB 240 for a minimum of three years after the completion of the study. No names or personal information will be given out as a result of this study.

Office of Research Services
University of North Texas
Last Updated: August 9, 2007
Questions about the Study: If you have any questions about the study, you may contact Carissa Manrique at telephone number 832-344-7441 or the faculty advisor, Dr. Diana Mason, UNT Department of Chemistry, at her email: dmosan@unt.edu

Review for the Protection of Participants: This research study has been reviewed and approved by the UNT Institutional Review Board (IRB). The UNT IRB can be contacted at (940) 565-3940 with any questions regarding the rights of research subjects.

Research Participants’ Rights: Your signature below indicates that you have read or have had read to you all of the above and that you confirm all of the following:

- Carissa Manrique has explained the study to you and answered all of your questions. You have been told the possible benefits and the potential risks and/or discomforts of the study.
- You understand that you do not have to take part in this study, and your refusal to participate or your decision to withdraw will involve no penalty or loss of rights or benefits. The study personnel may choose to stop your participation at any time.
- You understand why the study is being conducted and how it will be performed.
- You understand your rights as a research participant and you voluntarily consent to participate in this study.
- You have been told you will receive a copy of this form.

Printed Name of Participant

Signature of Participant Date

For the Principal Investigator: I certify that I have reviewed the contents of this form with the participant signing above. I have explained the possible benefits and the potential risks and/or discomforts of the study. It is my opinion that the participant understood the explanation.

Signature of Principal Investigator Date

Office of Research Services, University of North Texas, Last Updated: August 9, 2007
APPENDIX B

STUDENT LUMOSITY™ HANDOUTS
How to Register:

2. Insert the code I sent you
3. Click activate
4. Enter an e-mail address, username, and password (anything you want). Click "Apply to New Account."
5. Enter your demographic data and Click “Continue.”
6. When prompted to enter credit card information, click “No Thanks.”

7. You are done!
1. Your computer screen needs to be displaying exactly what you want to take an image of.
2. Hold down (fn) button and then press (prt sc) while still holding the (fn) button.
3. Copy and paste image taken into the word document for that assignment:
   a. Right click and select paste

If you’re a Mac person, you can use the Grab function.

1. Open Grab.
2. Under Capture pull down menu on top bar highlight Selection.
3. Use you mouse to drag the red box around what you want to capture.
   a. Make sure all you need is inside the box and then release mouse.
   b. Save file and send to the assignment file.

Alternative Mac:

1. Hold down COMMAND and click Shift and then the number 4.
2. Drag around the area you want to print screen and let go (hold left click and move mouse).
3. The image is automatically saved on the desktop

The following screen is needed after you complete your weekly training session, this screen will show up after each daily game session is finished: (below)
Please copy and paste this screen each Weekly Experiment Assignment page. Its important I see which session you are on. In addition I will need copy of the two additional games played each week.
<table>
<thead>
<tr>
<th>Week</th>
<th>Basic Training</th>
<th>Additional Games</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Sept 13 - 19)</td>
<td>Sessions 1-4</td>
<td>Rotation Matrix &amp; Brain Shift</td>
</tr>
<tr>
<td>2 (Sept 20 - 26)</td>
<td>Sessions 5-9</td>
<td>Space Junk &amp; Route to Sprout</td>
</tr>
<tr>
<td>3 (Sept 27 - Oct 3)</td>
<td>Sessions 10-13</td>
<td>Rotation Matrix &amp; Brain Shift</td>
</tr>
<tr>
<td>4 (Oct. 4 - 10)</td>
<td>Sessions 14-17</td>
<td>Space Junk &amp; Route to Sprout</td>
</tr>
<tr>
<td>5 (Oct 11 – 17)</td>
<td>Sessions 18-21</td>
<td>Rotation Matrix &amp; Brain Shift</td>
</tr>
<tr>
<td>6 (Oct 18 – 24)</td>
<td>Sessions 22-25</td>
<td>Space Junk &amp; Route to Sprout</td>
</tr>
<tr>
<td>7 (Oct. 25 – 31)</td>
<td>Sessions 26-29</td>
<td>Rotation Matrix &amp; Brain Shift</td>
</tr>
<tr>
<td>8 (Nov. 1 – 7)</td>
<td>Sessions 30-33</td>
<td>Space Junk &amp; Route to Sprout</td>
</tr>
<tr>
<td>9 (Nov. 8 – 14)</td>
<td>Sessions 34-37</td>
<td>Rotation Matrix &amp; Brain Shift</td>
</tr>
<tr>
<td>10 (Nov. 15 - 21)</td>
<td>Sessions 38-40</td>
<td>Space Junk &amp; Route to Sprout</td>
</tr>
</tbody>
</table>
APPENDIX C

LUMOSITY™ SURVEY

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Open-ended questions:

1. What was your favorite and least favorite games and why?

2. Any suggestions on how to improve the Lumosity™ courses?

3. Do you feel like playing these games improved your reasoning and spatial skill in your chemistry class? Why or Why not?

4. Did you feel like playing the Lumosity™ games improved your testing ability? Why or Why not?
REFERENCES


