

THE IMPACT OF VIRTUAL REALITY-BASED LEARNING ENVIRONMENT
DESIGN FEATURES ON STUDENTS' ACADEMIC ACHIEVEMENTS

A Dissertation

by

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ABSTRACT

Virtual reality-based instruction such as virtual worlds, games, and simulations are becoming very popular in K-12 and higher education. Three manuscripts that report the results of investigations of these increasingly prevalent instructional media were developed for this dissertation. The purpose of the first study, a meta-analysis, was to analyze the instructional effectiveness of virtual reality-based instruction when compared to the traditional methods of instruction. In addition, this study also explored selected instructional design features of the virtual learning environment that moderated the relationship between instructional method and the academic achievements. Analyses of 63 experimental or quasi-experimental studies that studied learning outcomes of virtual reality-based instruction in K-12 or higher education settings yielded a mean effect size of $g = 0.47$ ($SE = 0.02$) suggesting that virtual reality-based instruction is an effective medium of delivering instruction. Further analyses examined factors that influence its effectiveness.

The purpose of the second study was to examine a model of the impact of a 3-D desktop virtual reality environment on the learner characteristics (i.e. perceptual and psychological variables) that can enhance chemistry-related learning achievements in an introductory college chemistry class. A theoretical model of the relationships of features of 3-D virtual reality environments and students' experiences in the environments to outcomes on a chemistry learning test and measures of spatial ability and self-efficacy was tested using structural equation modeling. Usability strongly mediated the relationship between 3-D virtual reality features, spatial orientation, self-efficacy, and

presence. Spatial orientation and self-efficacy had a statistically significant, positive impact on the chemistry learning test.

The purpose of the third study was to investigate the potential of Second Life® (SL), a 3-D virtual world, to enhance undergraduate students' learning of a foundational chemistry concept, spatial ability, and self-efficacy. A quasi-experimental pretest-posttest control group design was used. A total of 387 participants completed three assignment activities either in Second Life or using 2-D images. The difference between the scores of 3-D virtual environment-based group and the 2-D images-based group was not statistically significant for any of the measures.

DEDICATION

This work would not have been possible without the following people. With my deepest appreciation, I dedicate this dissertation to:

Almighty Lord, who gave me the courage, strength, and resources to pursue this degree in United States of America.

My adorable father Husseinali Merchant (deceased), who always inspired me to have a vision and set high goals in life. My loving mother Zarina Merchant, who always stood by me during rough times. Her effort and sacrifice in completing my education in the USA are priceless. I feel blessed to have such wonderful parents. My maternal aunt, Sakkar Pirani and Shirin Pirani (deceased). They played a role of no less than that of being my mother. They have been perfect role models of facing life with faith, patience, and perseverance.

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TABLE OF CONTENTS

	Page
ABSTRACT	ii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF FIGURES.....	viii
LIST OF TABLES	ix
 CHAPTER	
I INTRODUCTION.....	1
Proliferation of Desktop-Based Virtual Environments	1
Research Reported in this Dissertation	3
II EFFECTIVENESS OF VIRTUAL REALITY-BASED INSTRUCTION ON STUDENTS’ LEARNING OUTCOMES IN K-12 AND HIGHER EDUCATION: A META ANALYSIS	6
Defining Simulations, Games, and Virtual Worlds.....	6
Summary of Previous Reviews and Need for the Current Meta-analysis	8
Purpose	11
Method	11
Results	23
Discussion and Conclusion	32
III THE LEARNER CHARACTERISTICS, FEATURES OF DESKTOP 3D VIRTUAL REALITY ENVIRONMENTS AND COLLEGE CHEMISTRY INSTRUCTION: A STRUCTURAL EQUATION MODELING ANALYSIS	51
Learner Characteristics and Science Achievement	51

	Method	63
	Results	71
	Discussion	80
	Conclusions	85
IV	EXPLORING 3-D VIRTUAL REALITY TECHNOLOGY FOR SPATIAL ABILITY, SELF-EFFICACY, AND CHEMICAL ACHIEVEMENT	87
	Introduction	87
	Purpose	92
	Method	92
	Results	100
	Discussion	102
V	SUMMARY AND CONCLUSION	105
	REFERENCES	111
	APPENDIX A	135

LIST OF FIGURES

	Page
Figure 1 Profile Plot of 63 Effect sizes.....	24
Figure 2 Profile Plot of the Variable Grade Level.....	38
Figure 3 Profile Plot of the Variable Discipline	39
Figure 4 Profile Plot of the Variable Continent.....	40
Figure 5 Profile Plot of the Variable Type of Publication.....	41
Figure 6 Profile Plot of the Variable Virtual Reality Tool	42
Figure 7 Profile Plot of the Variable Control Group Treatment.....	43
Figure 8 Profile Plot of the Variable Time of Administration.....	44
Figure 9 Profile Plot of the Variable Domain Knowledge	45
Figure 10 Profile Plot of the Variable Feedback	46
Figure 11 Profile Plot of the Variable Teacher Access	47
Figure 12 Profile Plot of the Variable Collaboration.....	48
Figure 13 Profile Plot of the Variable Mode of Instruction.....	49
Figure 14 Profile Plot of the Variable Design Quality	50
Figure 15 Theoretical Model.....	55
Figure 16 An Example of Test Question from Purdue Visualization of Rotation Test	66
Figure 17 Activity Station in Dr. K's Chemistry Corner in Second Life	69
Figure 18 Results of Structural Model Analysis	79
Figure 19 An Example of Test Question from Purdue Visualization of Rotation Test.....	97

LIST OF TABLES

	Page
Table 1 ANOVA Analysis of Sixteen Categorical Moderator Variables.....	26
Table 2 Regression Analysis of Five Continuous Moderator Variables	29
Table 3 Demographic Statistics of the Study's Participants included in the SEM Analysis	64
Table 4 Descriptive Statistics of the Variables included in the SEM Model	72
Table 5 Results of Measurement Model Analysis.....	74
Table 6 Descriptive Statistics of the Study's Participants Included in the ANCOVA Analysis.....	93
Table 7 Pretest and Posttest Scores Analysis	101

CHAPTER I

INTRODUCTION

The advent of highly immersive virtual reality technology can be traced back to the 1960's in the entertainment industry with Morton Heiling's single-user console called *Sensorama*, designed to captivate audience attention (Heiling, 1998). In the 1980's, there was a major uptake of interest in using virtual reality technology in professional education and training. Particularly, virtual reality technologies were frequently used for flight simulator training and exercises (Hawkins, 1995). The introduction of virtual reality technology in K-12 and higher education began in the early 1990's with projects such as Science Space, Safety World, Global Change, Virtual Gorilla Exhibit, Atom World, and Cell Biology (Youngblut, 1998). Designers of these projects used various peripheral devices such as head-mounted display gear, data gloves, and body suits for a fully immersive learning experience. In addition, displaying techniques of these virtual environments ranged from using specially designed glass cubicles called cave automatic virtual environments to projecting on the walls of a room (Cruz-Neira, Sandin, & DeFanti, 1993).

Proliferation of Desktop-Based Virtual Environments

The rapid increase in the processing power of the computer led to the deployment of desktop-based virtual environment in K-12 and higher education. The drastic reduction in the cost of technology and availability of high speed internet connection further increased the use of this less immersive form of virtual reality technology (Dickey, 2005; McLellan, 2004). Although desktop-based 3-D virtual environment

cannot afford the fully immersive environment, the graphically rich representations in these less immersive virtual worlds have been shown to enhance instructional quality (Dickey, 2003). In addition, advances in the technology have made it possible to increase the immersiveness of the 3-D virtual environment using peripheral devices such as headphones, shutter glasses, and data gloves; and the advances of Web technologies make it possible for multiple users to experience a virtual environment simultaneously and work collaboratively (Chen & Teh, 2000; Kamel, Boulos, & Wheeler, 2007). Consequently, the popularity of desktop-based virtual environment over fully immersive virtual reality technology is due to its low cost of procurement, rich graphical representation, use of less cumbersome devices, and simultaneous multi-user capabilities.

The underlying assumption of the use of the use of 3-D virtual environments in K-12 and higher education is that these technologies have unique affordances that can enhance learners' cognitive skills. Many educators have integrated a variety of virtual reality technologies into their instruction. For example, educators have used Second Life, a 3-D virtual world, to create replicas of real life places wherein users, who are digitally represented in form of avatars, engage in discourse or learning activities such as role playing (Warren & Wakefield, 2012). Other educators have used the ability to build 3-D objects for teaching abstract concepts (Merchant, Goetz, Keeney-Kennicutt, Kwok, Cifuentes, & Davis, 2012). River City is an interactive computer simulation for middle school science students to learn scientific inquiry and 21st century skills (Galas & Ketelhut, 2006). Other simulations are Vfrog™ to teach frog dissection (Lee, Wong, &

Fung, 2009) and MAT^{3-D} to teach high school students mathematical concepts (Pasqualotti & Freitas, 2002). DimensionMTM is a 3-D video game that embarks students on a journey where they accomplish series of mission applying mathematics principles (Kebritchi, Hirumi, & Bai, 2010). Another video game is designed by students of mechanical engineering to race a simulated car around the track. In this designing process students write a computer program and learn about the concepts such as thermo dynamics (Coller & Shernoff, 2009).

The literature attests to the instructional effectiveness of desktop-based virtual environments (Inoue, 2007; Kim, Park, Lee, Yuk, & Lee, 2001; Zhang & Yang, 2009). Educational benefits virtual environments suggested in the literature include the ability to view and manipulate representation from multiple perspectives (Bricken, 1990), perform learning tasks in authentic environments (Pantelidis, 1993), and experience phenomena that are impossible to experience in real life (Bricken & Byrne, 1994). However, currently, literature synthesizing the effects of 3-D virtual environment on learning outcomes is limited. Presently, in the field of 3-D virtual environment, the results of studies testing the effects of this medium on learning outcomes are equivocal. Not only there is a need to pool the estimates of studies that research on the instructional effectiveness of the virtual environment but also explore the underlying instructional design principles that governs the effectiveness of this learning environment.

Research Reported in this Dissertation

Three manuscripts, employing three different quantitative approaches to the study of learning in 3-D virtual reality-based, are presented in this dissertation: a meta-

analysis of instructional effectiveness of 3-D virtual reality-based instruction in promoting learning in K-12 and higher education, a test of a theoretical model of the impact of a 3-D desktop virtual reality environment on the learner characteristics (i.e. perceptual and psychological variables) that can enhance chemistry-related learning achievements in an introductory college chemistry class using structural equation modeling, and a quasi-experimental study of the effectiveness of an implementation of a 3-D virtual reality environment in the learning of a major concept in college chemistry.

Chapter II presents a meta-analysis of the studies conducted to test the instructional effectiveness of the virtual reality-based instruction on learning outcome measures in K-12 or higher education settings. It also discusses the effect of design features that moderates the effect of instruction on learning achievement. Often there is a tendency to focus on the technological features without understanding the instructional need. It is imperative that instructional designers of virtual environments understand how the technological features available within the virtual environment can lend itself to learning needs. Therefore, the main purpose of this section was to identify design features by which instructional designers can embed in virtual reality-based instruction to enhance learning effectiveness.

Chapter III introduces a theoretical model of the relationships of features of 3-D virtual reality environments and students' experiences in the environments (i.e., representational fidelity, presence, learners' interaction, perceived meaningfulness, perceived ease of use) to outcomes on a chemistry learning test and measures of spatial ability and self-efficacy. Data were collected from undergraduates in a chemistry course

in which a 3-D virtual world constructed using Second Life® was used to present instruction on a key concept in the class. These data were then used to test the model is then tested using structural equation modeling analysis. This approach to theory building had not previously been used in the research in this area.

Chapter IV reports the results of an investigation of the potential of a Second Life® environment to enhance undergraduate students' learning of a major chemistry concept. A quasi-experimental research design was used to examine whether there was a difference between the academic achievements of students who were given 3-D virtual reality-based intervention vs. those given 2-D images.

The diversity and complexity of 3-D virtual worlds, experiences that learners have in them and what the learners take away from those experiences is daunting. Consequently, building an understanding of the effectiveness of this form of instructional technology require diverse and sophisticated approaches. The three studies reported in this dissertation represent three different paths that can be taken toward that goal.

CHAPTER II

EFFECTIVENESS OF VIRTUAL REALITY-BASED INSTRUCTION ON
STUDENTS' LEARNING OUTCOMES IN K-12 AND HIGHER EDUCATION: A
META-ANALYSIS

Defining Simulations, Games, and Virtual Worlds

Simulations are interactive digital learning environments that imitate a real-life process or situation. Simulations allow learners to test their hypotheses of the effects of input variables on the intended outcomes(De Jong, 1991; Lee, 1999; Tobias & Fletcher, 2010). Simulation can provide cost-effective practice of procedures using virtual apparatus that in real life could be cost prohibitive. For example, frog dissection is a commonly used procedure to teach anatomy in high school biology classes. Vfrog™ is a popular simulation that allows students to conduct frog dissection numerous times using virtual apparatus. Conducting dissection procedure physically in a laboratory not only may impose financial burden, but also may be inconsistent with students' personal beliefs of conducting the dissection. Simulations also are advantageous because they can allow learners to practice skills that otherwise could be dangerous to practice in the real life situation, in a safe environment. For example, in the medical field, Mr.Vetro™ is a commonly used simulation of several medical scenarios that provides students the opportunity to sharpen their skills before practicing it on real life patients. In this way, medical students can avoid the risk of applying certain procedures directly on the patient without having sufficient practice, which may endanger patients' life.

Researchers have assigned games for learning as a special category of simulation (Tobias & Fletcher, 2010). Research suggests that in order to promote learning, games must have design elements where players have a sense of autonomy, identity, and interactivity (Gee, 2003). These elements provoke long-lasting motivation and prolonged engagement with the learning materials, which can lead to improved learning outcome (Gee, 2007). Csikszentmihályi's (2002) flow theory has been provided a framework for interpreting the effectiveness of games to engage players and motivate them to sustain play. If the game is too challenging, the player will be frustrated, and if it's too simple, the player will lose interest. In either case players are very likely to become disengaged and quit the game play.

Virtual worlds, according to Dickey (2005) and Hew and Chung (2005), may contain one or more of the following features: the illusion of being in a 3-D space, ability to build and interact with the 3D objects, digital representation of learners in form of avatar, and ability to communicate with other learners in the virtual worlds. Contrary, to the structured environment of simulations and games, virtual worlds are open-ended environment in which users design and create their own objects.

The rapid increase in the technological sophistication, diversity of, and pervasiveness of 3D virtual learning environments, along with the proliferation of research on their effectiveness in educational settings, necessitate frequent systematic analytical syntheses of their effectiveness. Few meta-analyses or other reviews have been conducted to date.

Summary of Previous Reviews and Need for the Current Meta-analysis

A search of the literature revealed three meta-analyses (Lee, 1999; Sitzmann, 2011; Vogel, Vogel, Cannon-Bower, Bowers, Muse, & Wright, 2006) and a systematic review summarizing qualitative research on 3D virtual worlds (Hew & Cheung, 2010). Lee conducted a meta-analysis of 19 studies and found a positive impact of using simulation on learning outcomes but negative impact on students' attitudes towards using this form of technology for learning. The major focus of Lee's meta-analysis was on moderator variables such as mode of simulation (presentation or practice), pure (incorporating expository instructional features) versus impure (absence of expository instructional features) simulation, and specific guidance versus general guidance. According to the results of this meta-analysis, simulations are always effective for both presentation and practice if used in hybrid form. Lee also found that specific guidance is more effective to improve students' performance.

More recently, Sitzmann (2011) and Vogel et al. (2006) conducted meta-analyses in which they analyzed the effects of interactive computer-based games and simulations and found statistically significant positive impacts on learning outcomes. Vogel et al. studied the moderation effects of gender, learner control, age, realism, and learner collaboration on learning outcomes. According to their report, students performed better when they were in control of navigating through the learning environment compared to when the teacher controlled the virtual learning environment. In addition, students in the traditional group outperformed the students in the virtual learning environment when the

sequence of learning activities was controlled by the computer programs compared to when students could select the sequence.

Sitzmann (2011) focused on the effects of games and simulations in enhancing work-related knowledge and skills, examining entertainment value, control group treatment, access level, mode of instruction, and methodological variables. According to the outcome of this study, Sitzmann reported the highest gain in the measure of self-efficacy (20%) as compared to procedural knowledge (14%), declarative knowledge (11%), and retention (9%). The virtual environmental characteristics such as active presentation of materials, unlimited access level to the learning materials, and presentation of the materials in a supplemental format were more effective.

Hew and Cheung (2010) conducted a systematic literature review on the use of virtual worlds in the context of K-12 and higher education (primarily, university or polytechnic settings) in which 14 out of the 15 studies included were descriptive in nature. Their review examined virtual worlds' literature in three areas: uses of virtual worlds by students and teachers, types of research methods applied to study the effects of 3-D virtual worlds, and kinds of topics researched in 3-D virtual worlds. The results of this review indicated that 3D virtual worlds are used as communication spaces, simulation spaces, and experiential spaces. The research methods are mostly descriptive in nature. Several different kinds of topics are researched in 3-D virtual worlds categorizes into participants' affective domain, learning outcomes, and social interaction.

Our study contributes to the field of virtual reality technologies for instructional use in several ways. First, Lee's (1999) meta-analysis focused on assessing the effectiveness of simulations. Moreover, Sitzmann (2011) collapsed both simulations and games into a single category and called it "simulation games". This may pose some concerns because simulations and games have different design features, and it is important to study possible differences in their effects on the learning outcomes. Unlike, Sitzmann, Vogel et al. (2006) identified simulations and games into separate categories. Like Vogel et al., we differentiated between simulations and games. In addition, we extended the range of a virtual learning environments studied by including virtual worlds, one of the most rapidly emerging and popular forms of virtual reality technology.

Second, Sitzmann (2011) focused on synthesizing the effects of games and simulations in the area of enhancing work-related knowledge and skills. On the other hand Vogel et al. included studies related to both work place and educational settings; however, their study did not decompose the effects of each setting. We believe that both work-related training and education training differ and should be studied independently. Therefore, our meta-analytical examination focused on instructional effectiveness in K-12 and higher education settings. Third, we also analyzed the moderating effects of variables central to the field of instructional design discussed in the following section that were not covered in the previous meta-analysis such as feedback and students' level of collaboration. We also examined possible variance in effects resulting from the quality of the research design.

Finally, the most recent studies included in the previous meta-analyses were published in 2009 (Sitzmann, 2011), and one of the meta-analyses is more than a decade old (Lee, 1999). Our review included studies conducted as recent as 2011. This will not only provide the insight about the current literature on virtual reality technologies but will also serve as a comparative analysis for examining the rapid changes in the power of computer technology and the enhancement of learning effectiveness afforded by the technology power.

Purpose

We undertook a meta-analysis new to address some of the limitations of the previous reviews. The primary purposes were (a) to examine the overall effectiveness of virtual reality technology in K-12 or higher education settings and (b) to identify key instructional design principles in the context of virtual reality based- instruction on the learning outcomes.

Method

In the current meta-analysis, we integrated available studies that assessed the relationship between virtual reality-based instruction and learning outcomes in K-12 and higher education. We followed the meta-analytical procedure suggested by Glass, McGaw, and Smith (1981). Their procedure requires a meta-analyst to (a) collect studies, (b) code characteristics of studies, (c) calculate effect sizes of each study's outcome measure on a common scale, and (d) investigate moderating effects of study's characteristics on the outcome measure.

Data Sources and Search Strategies

The following strategies were employed to identify empirical studies to include in the meta-analyses:

1. Electronic searches were performed on the following databases: PsycINFO (EBSCO), Medline (Pub Med), Dissertation and Theses, Eric (EBSCO), Education Full Text, PaperFirst, and CINHAL (The Cumulative Index to Nursing and Allied Health).
2. Manual searches were performed in relevant journals including *Educational Technology, Research and Development, British Journal of Educational Technology, Australian Journal of Educational Technology, Computers & Education, Educational Technology and Society, International Journal of Computer-Supported Collaborative Learning, Journal of Computer Assisted Learning, VR in Schools, Virtual Reality, Presence, Journal of Technology Education, and Journal of Virtual World Research.*
3. Web searches were conducted using the Google Scholar search engine.
4. Branching searches were performed using forward and backward search procedures from the reference lists of the empirical studies that were located in earlier stages of the review.
5. Compiled reference lists available online on the topic of virtual reality were searched. This includes Youngblut (1998), Emerson & Revere (1997), and Fallman (n.d) as well as relevant reviews found during the electronic database search.

6. Scholars who have conducted extensive research in the field of virtual reality technologies were personally contacted by the first author.
7. Search terms for empirical studies included *virtual reality*, *virtual worlds*, *virtual learning environments*, *computer assisted learning*, *artificial intelligence*, *mixed reality*, *synthetic environment*, *virtual classrooms*, *augmented reality*, *immersive learning environment*, *computer games*, *game-based learning environment*, *serious games*, *simulations*; these were combined with other terms such as *education*, *learning*, *instruction*, and *instructional design*.

Inclusion and Exclusion Criteria

Studies were either included or excluded based on their consistency with the following criteria.

The following criteria were used to include studies in the meta-analysis:

1. Studies found until November 2011.
2. Studies that used samples from a population of K-12 or higher education settings.
3. Studies that used virtual reality-based instruction in form of games, simulation, or virtual worlds.
4. Studies that measured learning gains as an outcome variable using test instruments, observation of student's performance, and student's work samples.

5. Studies that used experimental control group research design to measure relationships between virtual reality-based instructions with learning gains.

The following criteria were used to define the set of studies to be excluded from the meta-analysis:

1. Studies that were published in languages other than English.
2. Studies that used virtual reality technologies as an assessment, diagnostic, or therapeutic tool.
3. Studies that did not provide sufficient data for effect size calculation.

Study Sample

An initial search yielded an outcome of 7078 articles that matched the key word searches criteria. After judging the abstract of these articles, 102 were included for further consideration in the study. Each full-text article was read by the first author to conclude the process of selecting the qualifying studies. Finally, a total of 63 studies qualified to be included in the meta-analysis study.

Dependent Variable and Effect Size Calculation

The dependent variable in all 63 studies was a learning outcome measure. A two-step procedure described by Hedges and Olkin (1985) was used: first, effect size per study was calculated, and second, optimal weights based on the standard error of the effect sizes were computed. As a result, effects sizes so calculated are then comparable across all the studies included in the meta-analysis. We primarily selected F ratio because it's possible to control for pretest scores as a covariate. When F ratio was not available, effect sizes were calculated based on means and standard deviation, or t test

and as such pretest covariate could not be accounted for in the effect size calculation.

This difference in the studies where covariates could not be accounted for was reflected in the scores of design quality.

While calculating the meta-analysis effect sizes, we included only one effect size per study in the analysis. According Lipsey and Wilson (2001), when a study contributes more than one effect sizes in the analysis, it leads to statistical dependence that biases the overall effect size. We adopted the procedures recommended by Lipsey and Wilson (2001), to circumvent the issue of statistical dependence and include one effect size per study in the meta-analysis.

1. We averaged the effect sizes when a study assessed the same construct using more than one outcome measure (e.g., Ainge, 1996; Antonietti, & Cantoia, 2000; Hauptman, 2010; Michael, 2001; Rafi & Samsudin, 2009; Sun, Chan, & Meng, 2010). For example, Rafi and Samsudin (2009) used mental rotation accuracy and mental rotation speed tests as measures of assessing their study participants' spatial ability levels. We averaged the effect sizes of these two measures and included as one in the meta-analysis.
2. Below are the rules of selecting one effect size per study that allowed greater variability in coding a study's feature:
 - A. We selected effect size of one type of control treatment method when a study had used multiple control groups (e.g., Codd & Choudhury, 2011; Copolo & Hounshell, 1995; Farrokhnia, 2010; Jaakkola & Nurmi, 2008). For example, Copolo & Hounshell (1995) had compared the effects of virtual reality treatment

against three different control group treatments. We selected the control group that was given “combination treatment” using both computer-based 3D models and 3D concrete models of molecular structures.

B. We selected effect size of a particular measure of learning gains over the other, when a study had used more than one kind of learning outcome measure (e.g., Hu, Yu, Shao, Li, Wang, & Wang, 2009; Nicholson, Chalk, Funnell, & Daniel, 2006). For example, Hu et al. provided effect sizes for theory exam test and the quality of work samples. We included the effect sizes for the quality of work samples.

C. We selected effect size of a particular grade level over the other when a study had used the virtual reality-based instruction at more than one grade level. The article by Urhahne, Nick, and Schanze (2009) reported studies conducted with the samples from freshman and high school students. We included the effect size calculated based on the data from the freshman students.

Moderator Variables

Twenty-one variables were coded for each study in the present analysis. These variables are divided into three categories of: study characteristics, design characteristics, and methodological characteristics.

Study’s Characteristics. We coded the studies on the variables of grade level, discipline, continent, year of publication, and publication type. The first three variables (i.e., grade level, discipline, and continent) in this category were coded to detect the moderating effects of participants’ background on study’s outcome measure. The

variable of grade level included three sub-categories of elementary (1-5 grades), middle school (6-9 grades), high school (10-12 grades), and undergraduates (post high school). We created four sub-categories within the variable of discipline science, medicine, mathematics, and other allied fields. The last two variables in this category were coded to assess the changes in the outcome measure related to time (i.e., year of publication) and sources of information (i.e., publication type). The years of publication ranged from 1993- 2011, and within source of information, we had the categories of peer-reviewed journal articles, dissertations, and conference proceedings within publication type. According to Glass et al. (1981), including only peer reviewed journal articles in a meta-analysis can inflate the overall effect size of the study.

Design Characteristics. We created the variable “type of virtual reality (VR) tool” to distinguish studies into three categories: simulations, games, and virtual worlds. Vogel et al. (2006) categorized the studies into simulation, games, or both. Sitzmann (2011), on the other hand collapsed simulation and games into one category of “simulation games”. Although currently there is ambiguity regarding the definition of each of these tools, we derived a definition based on the literature to guide us through the process of categorization. We categorized studies as using “virtual worlds” for instruction when learning environment afforded the learners ability to build 3D virtual objects, zoom, manipulate, and view it from different directions (Hew & Cheung, 2010). Studies were categorized as games when the environment engaged the learners with one or more game elements such as challenge, goal, rewards, punishment, hurdles, or characters (Fullerton, 2004). Studies were treated as “simulation” when a virtual reality-

based instruction allowed the learners to interactively test cause and effect relationships between two variables by changing the parameters (Lee, 1999).

Sitzmann (2011) coded studies on the variable of “measures of learning outcomes” as declarative knowledge, procedural knowledge, retention, or transfer. We coded the studies on into three categories knowledge-based, abilities-based, or skill-based measures. We compared the instructional effectiveness of virtual reality-based instruction with the methods used to instruct the control group. Both Lee (1999) and Sitzmann (2011) coded their studies on the variable of instruction imparted to the control group, but our categories were broader and covered more forms of control group instructional methods. The categories created for coding the control group treatment were traditional, multimedia, combination, or no treatment. Studies were classified as using “traditional” method for instruction when they employed one or more form of the methods: lecture, textbook, paper-based exercise, 3D concrete models, or physical lab sessions. Studies were assigned to the category of “multimedia” when they used instructional modalities such as videos, graphics, or tutorials. Studies that imparted instruction partially using virtual reality-based instruction and traditional or multimedia methods were assigned to the category of “combination”. For studies in which control group was only administered test of learning outcomes measures were used for the purposes of comparing the scores of learning outcomes measures for instructional effectiveness of virtual reality-based instruction were assigned to the category of “no treatment”.

We coded the study based on the time of administration of learning outcome measures. Studies on this variable were coded into four categories of immediate, delayed, repetitive, or transfer. Studies were coded as immediate, when learning outcome measure was administered immediately after the intervention. Studies were categorized as “delayed” when there was a time interval between the instructional activity and the administration of learning outcome measure. This time interval ranged between next day, 40 days later, or at the end of semester. We categorized the studies as “repetitive” when measures were administered twice (i.e., immediate and delayed). Studies were categorized as “transfer” when a context different than the one presented in virtual reality-based instruction was presented to the learners for applying the concept learnt. The studies were coded either as specific or general on the variable of “domain knowledge”. On the “learning tasks”, studies were coded either as declarative or procedural tasks. Studies categorized as declarative, when the task involved gaining conceptual understanding. We classified studies as procedural when they involved learners to understand a procedure.

We coded the studies on the variable of “feedback” learners received during their interaction with the virtual environment. According to McNamara, Jackson, and Graesser (2009), feedback is a unique characteristic of virtual learning environments that are specifically designed for teaching and learning purposes. We categorized studies into four different categories. The categories were knowledge of result or response, elaborate explanation, or visual clues. We also coded the studies on whether teacher’s access was available during the instructional activity or if it was a student directed learning activity.

The studies were also coded on whether students had completed the learning task working in collaboration with each other or had worked individually.

We coded the studies on the variable of “mode of instruction” based on the sequence in which the virtual reality-based instruction was presented. We coded the studies into three categories: presentation, practice, or stand-alone on this variable (Lee, 1999). Studies were categorized as “presentation” when virtual reality-based instruction was used for introducing the concept. Studies were categorized as “practice” when learners used virtual reality-based instruction to apply the concept introduced to them using other forms of instruction prior to using virtual reality tools. Finally, studies were classified as “stand-alone” when previous form of instructional method was completely replaced by virtual reality-based instruction.

According to Clark (1985), higher learning gains may not be achieved due to the instructional methods used but due to the presence of “novelty effect” in the computer-based instruction. According to this preposition, if there is presence of “novelty effect” of the virtual environment, instructional effectiveness diminishes as the number of hours spent by the students within the virtual environment increases. In order to discern the presence of this effect, we coded the studies on three different but related variables: number of treatment sessions, duration of each session in minutes, and amount of total time spent in minutes.

Methodological Characteristics. We coded the studies on the variables of research design quality, sample size, and reliability co-efficient to assess their methodological rigor. According, Lipsey and Wilson (2001), it is likely that substantive

effects found by a meta-analyst are actually artifacts of confounded methodological variables. Therefore, it is important that the studies are assessed on their methodological strength. We used the model developed by Allen, Chen, Willson, and Hughes (2009) to assess the research design quality of the studies included in the meta-analysis, with some modifications to their model to suit the context of our study. According to our revised model, a study that employed “true experimental” research design were treated as “high quality”. The studies employing other forms of design (i.e., quasi-experimental or biased) were further screened on two criteria to determine the quality of their methodological design. These two criteria include “quality of control group treatment” and “quality of statistical control”. The variable reliability co-efficient were adopted from Cooper (2010) coding list of the methodological features. In addition, we also coded the studies on the kind of instruments they used to measure the learning outcomes, the categories were researcher-developed or standardized instruments. Studies in which measuring instrument was developed specifically for that study were categorized as “researcher-developed” and studies that used pre-validated instruments were treated as “standardized”.

Coder Reliability. To ascertain the reliability of the coded variables, the first author coded all the studies and the second author coded 25% (63) of all the studies included in this meta-analysis. The inter-rater reliability of the studies coded by both coders ranged between 80 - 100% on the coded variables. Any disagreements on the coded variables were discussed until a mutually acceptable decision was agreed by both the coders.

Homogeneity Analysis and Test of Moderators

We conducted an examination of the distribution of effect sizes using the graphical technique of funnel plot to detect the variability among studies based on their sample size (Elvik, 1998; Light, Singer, & Willett, 1994; Wang & Bushman, 1998). If the studies included in the meta-analysis consisted of unbiased samples from the same population, there should be greater variability among studies with smaller sample sizes, and the graph should take the shape of a funnel. The presence of studies that fall out of the confidence interval also indicates presence of heterogeneity. Homogeneity analysis also was conducted using statistical procedure to assess whether the amount of variability among effect sizes exceeded the level of “by chance alone”. A statistically significant Q statistic indicates that studies included in the analysis are heterogeneous in nature. Lipsey and Wilson (2001) recommend using both mathematical and graphical techniques to understand effect-size distributions. When, the analyses indicate the existence of a high level of heterogeneity among studies, this warrant for examining moderator analysis.

In addition, we tested the moderating main effects of different features of the studies statistically using ANOVA procedures for categorical variables and regression for continuous variables: We analyzed the main effects and 53 pair wise comparisons to detect group differences. We applied Bonferroni correction to control the inflation of experimental error rate for testing pairwise comparisons (Thompson, 2006). We calculated a new α level, 0.0009 by dividing the original α level of 0.05 by a total 53

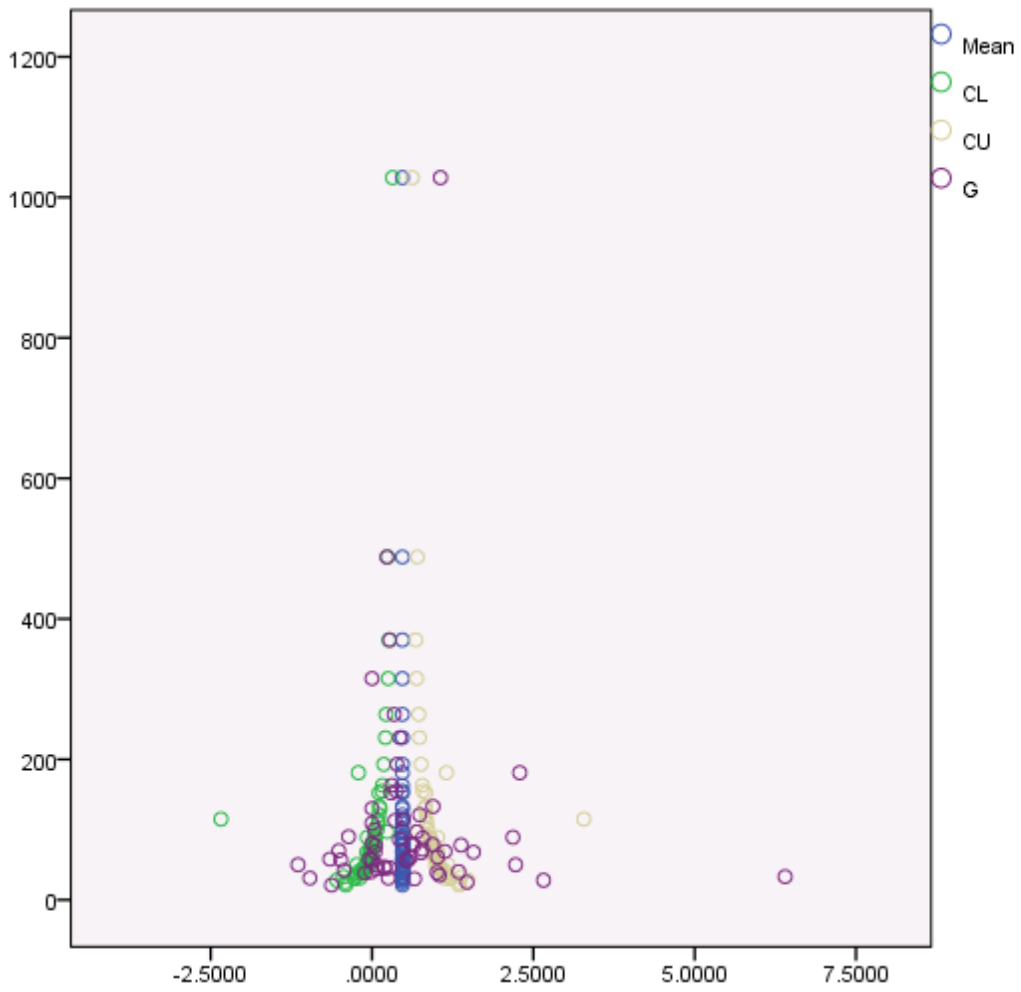
paired comparisons tested in the study. We concluded that there were group differences when the t test for each pair wise comparisons were statistically significant.

Results

We included 63 studies with a total of 6868 participants in the final meta-analysis. Of the 63 studies, 26 (42%) came from North America, 16 (26%) from Asia, and 15 (25%) from European countries. Of the remaining, 3 (5%) studies came from Eurasian countries and 1 (2%) from Australia. The studies came from a variety of sources including 58 (92%) peer-reviewed journal articles, 2 (3%) dissertations, and 3 (5%) conference proceedings. Thirty-seven (60%) studies came from the discipline of science. Eleven (19%) studies were from fields such as marketing, business administration, and psychology. There were 10 (14%) studies from medicine and 5 (7%) from mathematics. In the category of virtual reality tools, 29 (48%) were simulations, 23 (36%) virtual worlds, and 11 (16%) games.

The weighted mean effect size for the relationship between virtual reality-based instruction and learning outcomes was 0.47 ($SE = 0.02$), $p < 0.001$. The effect sizes ranged from -1.14 – 6.40 with 42 (67%) in the positive direction (i.e., virtual reality-based instruction increased learning gains), 11 (17%) were negative, and 10 (16%) with no significant effects. The 95% confidence interval of the weighted mean effect size was 0.41– 0.52. The funnel plot analysis of the meta-analysis effect sizes displayed in Figure 1 represents presence of heterogeneity among the studies. In addition, homogeneity analyses indicated that the effect sizes of virtual reality-based instruction on learning outcomes were significantly heterogeneous, $Q_T(62) = 612.41$, $p < .001$.

Figure 1
Profile plot analysis of 63 effect sizes



This result warranted further analyses to examine the reasons for heterogeneity among studies. Therefore, we conducted moderator analyses with the variables selected in coding the studies to test for statistically significant differences in the effectiveness of virtual reality learning environments. Table 1 presents the results of the ANOVAs for the 21 categorical variables. Results of the regression analyses for the six continuous variables are displayed in Table 2. Results of the moderator analyses are graphical depicted in Figure 2 through Figure 14.

Table 1
ANOVA Analysis of Sixteen Categorical Moderator Variables

Moderators	Weighted <i>ES</i>	<i>N</i>	<i>F</i>	Moderators	Weighted <i>ES</i>	<i>N</i>	<i>F</i>
Grade			32.61***	Discipline			7.85***
Elementary _A	0.05	8		Science _A	0.60	37	
Middle School _B	1.10	12		Medicine _B	0.62	10	
High School _C	0.69	12		Mathematics _C	0.71	5	
Undergraduate _d	0.52	28		others _D	0.33	11	
A – B ns; A- C****; A-D****; B – C ns; B – D ns; C – D ns				A – B ns; A- C****; A-D****; B – C ns; B – D ns; C – D ns			
Continent			3.365187**	Publication Type			4.377008*
North America _A	0.34	26		Articles _A	0.58	58	
Asia _B	0.60	16		Dissertation _B	0.47	3	
Europe _C	0.90	15		Conference _C	0.13	2	
Australia _D	0.25	1		A – B ns; A – C ns; B – C ns;			
Eurasia _E	1.08	3					
A – B ns; A- C ns; A-D ns; A-E****; B – C ns; B – D ns; B – E ns; C – D ns; C – D ns; D – E ns							

Table 1. Continued

Moderators	Weighted <i>ES</i>	<i>N</i>	<i>F</i>	Moderators	Weighted <i>d ES</i>	<i>N</i>	<i>F</i>
Type of Tool			16.23371 ***	Measures of Learning outcome			2.365987*
Virtual World _A	0.51	23		Knowledge _A	0.4884	48	
Games _B	0.37	11		Abilities _B	0.57	7	
Simulation _C	0.68	29		Skills _C	1.11	8	
A – B***; A- C ns; B – C***				A – B ns; A- C ns; B – C ns			
Control Group treatment			76.137179***	Time of Administration			6.114647***
Traditional _A	0.58	40		Immediate _A	0.68	37	
2-D multimedia _B	1.05	6		Delayed _B	0.21	21	
Combination _C	-0.59	5		Repetitive _C	0.33	2	
No treatment _D	0.93	12		Transfer _D	1.72	3	
A – B ns; A- C***; A-D ns; B – C***; B – D ns; C – D***				A – B ns; A- C ns; A-D***; B – C ns; B – D***; C – D ns			
Domain of Knowledge			10.235698*	Learning Tasks			125.8816***
Specific _A	0.63	49		Declarative _A	0.61	35	
General _B	0.37	13		Procedural _B	0.53	28	
A – B ns				A – B***			

Table 1. Continued

Moderators	Weighted <i>ES</i>	<i>N</i>	<i>F</i>	Moderators	Weighted <i>ES</i>	<i>N</i>	<i>F</i>
Feedback			24.90347 ***	Teacher access			0.600921 ***
Knowledge of Correct Response _A	1.29	2		Yes	0.54	7	
Elaborate Explanation _B	1.48	8		No	0.57	12	
Visual _C	0.29	5		A – B****			
A – B****; A- C****; B – C****							
Students Collaboration			17.353351***	Mode of Instruction			37.04416 ***
Yes	0.85	10		Presentation _A	0.35	13	
No	0.57	35		Practice _B	0.57	43	
A – B****;				Stand-alone _C	1.14	7	
A – B****; A- C ns; B – C****							
Design Quality			40.282655***	Kind of Instrument			4.963465*
Low _A	0.36	17		Researcher-developed _A	0.63	52	
Medium _B	1.09	20		Standardized _B	0.27	11	
High _C	0.32	24		A – Bns			
A – B ns; A- C****; B – C****							

****. Co-efficient is significant at the 0.009 level after the Bonferroni correction (2-tailed).

***. Co-efficient is significant at than 0.001 level (2-tailed).

**. Co-efficient is significant at the 0.01 level (2-tailed).

*Co-efficient is significant at the 0.05 level (2-tailed).

ns = non-significant

Table 2
Regression analysis of five continuous moderator variables

Moderator variables	N	Corrected t-test	<i>p-values</i>
Year	63	0.084	0.53
Number of treatment sessions	43	4.77274	0.99
Duration of each session	29	10.77808	1.00
Total time spent	33	6.059458	0.99
Sample size	63	6.322394	1.00
Reliability	20	1.660004	0.95

Study Characteristics

We analyzed the moderator effects of five variables that characterized a study: grade level, discipline, continent, year of publication, and publication type. Overall, the effects of virtual reality-based instruction varied across different grade levels. When we conducted pairwise comparison, we found that the effects of learning environment at the elementary level ($g = 0.05$) were significantly less than for high school ($g = 0.69$) or undergraduate ($g = 0.52$). We also found varied effects of virtual reality-based instructions across different disciplines. When we conducted pairwise comparisons of the effects across discipline, we found statistically significant difference between the

discipline of science ($g = 0.60$), and other fields ($g = 0.33$) as well as science and mathematics ($g = 0.71$). The studies did vary according to the continent in which they were conducted. There was statistically significant differences in the studies conducted in the continent of North America ($g = 0.34$), and Eurasia ($g = 1.08$) with studies conducted in Eurasia reporting higher effect size. There were no statistically different differences in effect sizes related to year of publication or publication type.

Design Characteristics

We analyzed the variables of type of VR tool, measures of learning outcome, control group treatment, time of administration, domain knowledge, type of learning tasks, feedback, mode of instruction, number of treatment session, duration of treatment session, total amount of time spent. Both simulations ($g = 0.68$) and virtual worlds ($g = 0.51$) were equally effective and more effective than games ($g = 0.37$). The students' performance in virtual reality-based instruction did not vary according to the type of the learning outcome measure that was administered. Students performed equally well on knowledge-based, abilities-based, and skill-based learning outcomes measures. There was a statistically significant difference between students based on the type of treatment that was given to the control group. Students in the control group performed better when in the control group when they received a combination of the treatments ($g = -0.59$) compared to the students who received only the virtual reality-based treatment. However, students who were given virtual reality treatment showed higher gains when compared against the students who were given 2-D multimedia ($g = 1.05$) or no

treatment ($g = 0.93$) than against the students who were given traditional treatment ($g = 0.58$).

With regard to the time of administration, students who were administered a learning outcome measure that allowed them to apply their learning in a different context than the one they were taught, performed better ($g = 1.72$) than those who were either administered the measure immediately ($g = 0.68$), at a later time or both ($g = 0.21$). With regard to students' performance based on the domain of knowledge, students performed equally well irrespective of whether the domain of knowledge was specific or general. Students who performed declarative learning tasks showed greater gains ($g = 0.61$) in the learning outcome than those students who performed procedural tasks ($g = 0.53$).

Overall, there was variability in the effects of different kinds of feedback on learning outcome measures. The elaborate explanation feedback ($g = 1.48$) was found more effective than knowledge of correct response type of feedback ($g = 1.29$) and visual feedback ($g = 0.29$). There was a statistical difference between the learning outcome of students who had teacher's access ($g = 0.54$) during the virtual reality-based instruction compared to ones who did not have teacher's access ($g = 0.57$). With regards to students' collaboration during virtual reality-based learning activity, there was statistically significant difference between the studies where students could work individually and where students worked collaboratively. Students who worked in collaboration ($g = 0.85$) performed better than those who worked individually ($g = 0.57$).

In general, the impact of virtual reality-based instructions was higher when it was used as stand-alone instructional material to teach the concepts ($g = 1.14$) compared to

when they used virtual reality-based instructions for presenting ($g = 0.35$) or practicing a topic ($g = 0.57$). The learning gains were not moderated by the duration of each of session, total number of sessions or duration of each session.

Methodological Characteristics

The variables of reliability co-efficient and sample size did not moderate the relationship between virtual reality-based instruction and learning outcome measure. On the variable of design quality, the studies differed significantly based on their level of quality, with the studies rated as high quality had the lowest effect size value ($g = 0.32$). This indicates presence of error due to the poor design quality of the studies that spuriously inflated the effect size value. There was statistically no significant difference between students who were administered researcher-developed or standardized instruments.

Discussion and Conclusions

More and more resources in the form of time and money are devoted to designing and developing virtual reality-based instruction for teaching K-12 and higher education curriculum. Deploying virtual reality-based instruction in schools and colleges not only involves financial cost but also the efforts to train the teachers to use them effectively. Therefore, it is critical that instructional designers make careful decisions in the design and development of instructional materials utilizing virtual reality technologies. Although previous meta-analyses shed some light on the ambiguity regarding the instructional effectiveness of virtual reality-based instruction (Lee, 1999; Sitzmann, 2011; Vogel et al., 2006), our meta-analysis examined all three forms of

virtual reality technologies and also assessed the instructional effectiveness of several design features such as feedback, students collaboration, and teacher access that can guide K-12 and higher education teachers in designing instruction using virtual reality technologies.

Our meta-analysis makes a significant contribution because we analyzed the impact of virtual reality-based instruction on different disciplines and found that the instruction was effective in most of the disciplines (i.e., science, mathematics, medicine, and other fields), but its highest potential was found in the field of mathematics. None of the previous meta-analysis has analyzed the effects of the disciplines. Moreover, the results are very encouraging for the mathematics educators who are considering technology integration into mathematics curriculum. The area of virtual reality-based instruction in the field of mathematics is quite under researched; therefore, results of this meta-analysis can provide impetus to initiate more virtual reality-based integration in field of mathematics.

The virtual reality-based instruction was quite effective at the high school level. This meta-analysis did not provide any evidence that VR enhances the learning of students in elementary school. This is contrary to the results found by Vogel et al. (2006), who reported significant effects of virtual reality-based at all the four grade levels; elementary, middle school, high school and college level. The effects of virtual reality-based instruction may have been mitigated at the elementary level because of the cognitive load these technologically sophisticated learning environments imposed on the limited computer skills of the elementary students. According to Sweller (1994),

extraneous load imposed due to external learning environment features may impose unnecessary demand on the cognitive resources, which may hinder the learning gains. Several studies have found positive results when the learning environments were designed to reduce cognitive load (Bobias, 1993). Therefore, it is of paramount importance that instructional designers evaluate the design of the virtual environment that guides and supports the learners rather than those that impose unnecessary load and frustration. In addition, instructional designers must assess their students' computer self-efficacy level and accordingly scaffold their learning experiences in these virtual environments.

In general, virtual reality-based instructions were more effective when used in simulations than in games or virtual worlds. This is a key contribution in the field of using virtual reality technologies for instruction because there is limited evidence of their effectiveness. Although, Lee's (1999) meta-analysis found a positive effect of using simulation that meta-analysis was conducted several years ago. Therefore over time of several years with the improved power of computer technology designing highly interactive learning environment is now possible then before.

We found no difference between studies assessing students' achievement levels using a variety of measures; knowledge, ability, or skill-based measures. This suggests that virtual reality-based instruction is highly effective for imparting instruction on a variety of different learning goals including higher order thinking skills among students. Our study found promising results of virtual reality-based instruction with regard to the level of retention. This is consistent with the results of meta-analysis reported by

Sitzmann (2010) who found 9% higher retention rates in the trainees who received simulation games-based intervention. Not only were students able to retain the learning gains, they were also able to transfer their learning. Little literature discusses the instructional effectiveness of virtual reality-based instruction in the context of retention and transfer of learning from virtual to the real environment (Bossard, Kermarrec, Buche, 2008). To date, there is no systemically analyzed evidence of the instructional effectiveness virtual reality-based instruction at different levels of retention. Although Sitzmann (2011) did include retention as a category for coding her studies, we included a whole spectrum of retention level from immediate to the delayed transfer.

Our study made a significant contribution by delineating the instructional effectiveness of different kinds of feedback. None of the previous reviews discussed in this paper analyzed the effects of feedback in a virtual reality-based instruction; also, Sitzmann (2011) discussed this as a limitation of her review. According to Hattie and Timperley (2007), feedback has tremendous impact on learning gains, both positive and negative. Therefore, it is essential that teachers are made knowledgeable about the features and situations that make feedback effective. Our analysis found positive effects for the three kinds of feedback but elaborate explanation was the most effective form of feedback. This result resonates with the findings of several past reviews conducted to assess the effectiveness of feedback in computer-based interventions (Azevedo & Bernard, 1995; Pridemore and Klein, 1991; Whyte, Karolick, Neilsen, Elder, Hawley, 1995). Our study contributed to this research literature by further synthesizing the results of the studies. These results can provide useful guidelines to teachers in designing

feedback strategies that will maximize learning gains in virtual reality-based environments. In addition, future analysis can be conducted by analyzing the suitability of a form of feedback for a type of learning task.

Our study also contributed in the area of collaborative learning environments and their effectiveness. We found that students performed better when they worked collaboratively rather than individually. This is contrary to the results found by Vogel et al. wherein there was no statistically significant difference between the studies that used collaborative versus non-collaborative design for the learning environment. However, our results are consistent with the results reported of the studies that used collaborative design and their benefits such as opportunities for students to obtain alternative perspectives, offer personal insights, and engage in meaning making is more effective within a collaborative environment (Bonk & King, 1998; Wan, & Johnson, 1994). We also analyzed the effects of teacher access and found that there was a higher gain on the learning outcome of the students who had no teacher's access versus the one who had teacher's access. This is contrary to the results of Lee (1999) which reported higher gains on teacher guided instruction. Hence this area needs further investigation in terms of analyzing design features.

Our meta-analysis results differed from that of Sitzmann (2011) in that students learned better when virtual reality-based instructions were used in the form of practice session. We found that students performed better when they were instructed using the hybrid mode of virtual reality instruction. Our result was consistent with Lee (1999) who only analyzed the difference between presentation and practice mode and found practice

was better than presentation. These guidelines can be useful to designers in designing virtual reality-based instruction more effectively.

Literature presents numerous advantages of using virtual reality-based instruction for learning. The results of this meta-analysis are encouraging in that they provide evidence that virtual reality-based instruction is an effective means to enhance learning outcomes. Educational institutions planning to invest time and financial resources are likely to see the learning benefits in their students. This meta-analysis also sheds light on the effectiveness of several instructional design principles that improve the effectiveness of the learning environments. Future studies can be designed to test specific interaction effects of design features to further inform about the design of virtual learning environments.

Figure 2:
Profile plot analysis of the variable grade level

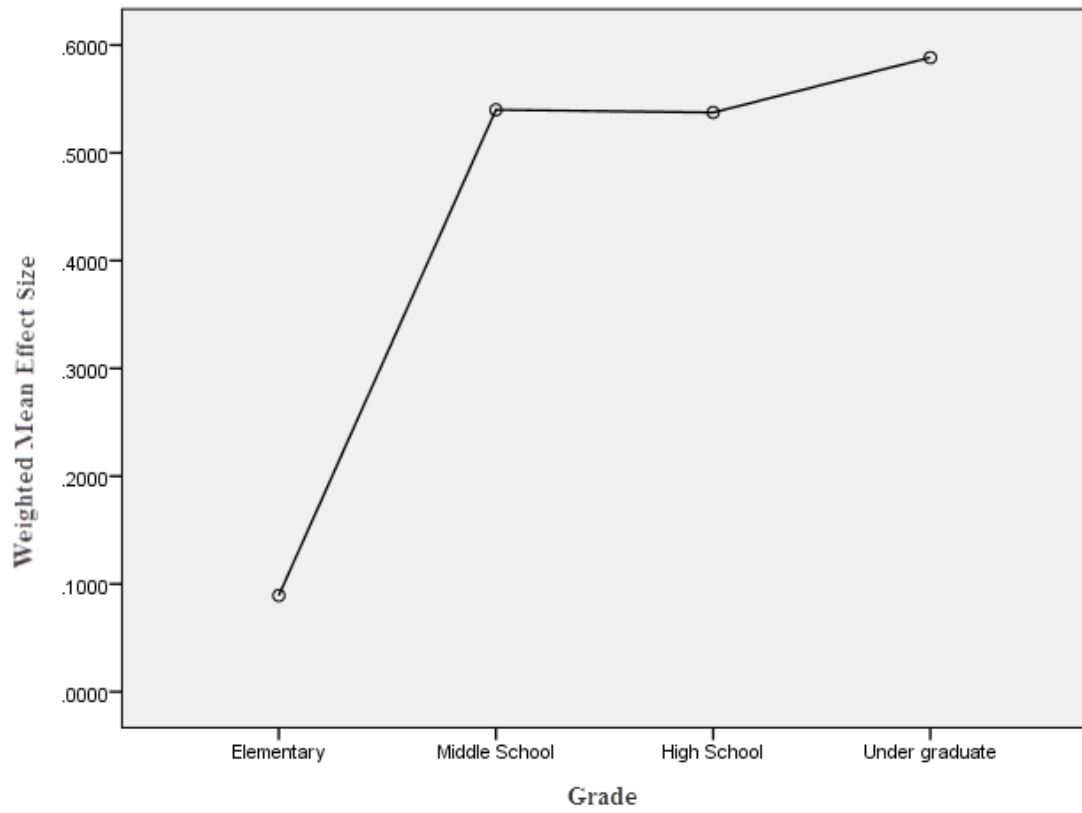


Figure 3:
Profile plot analysis of the variable discipline

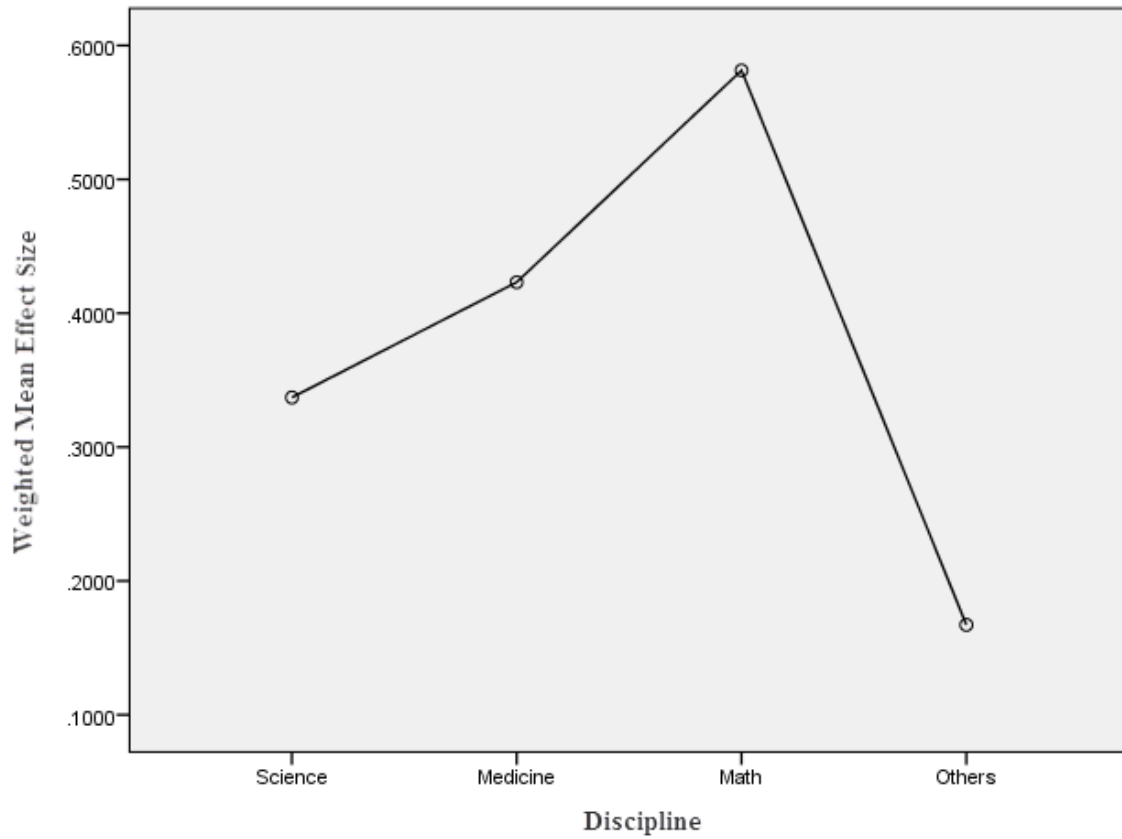


Figure 4:
Profile plot analysis of the variable continent

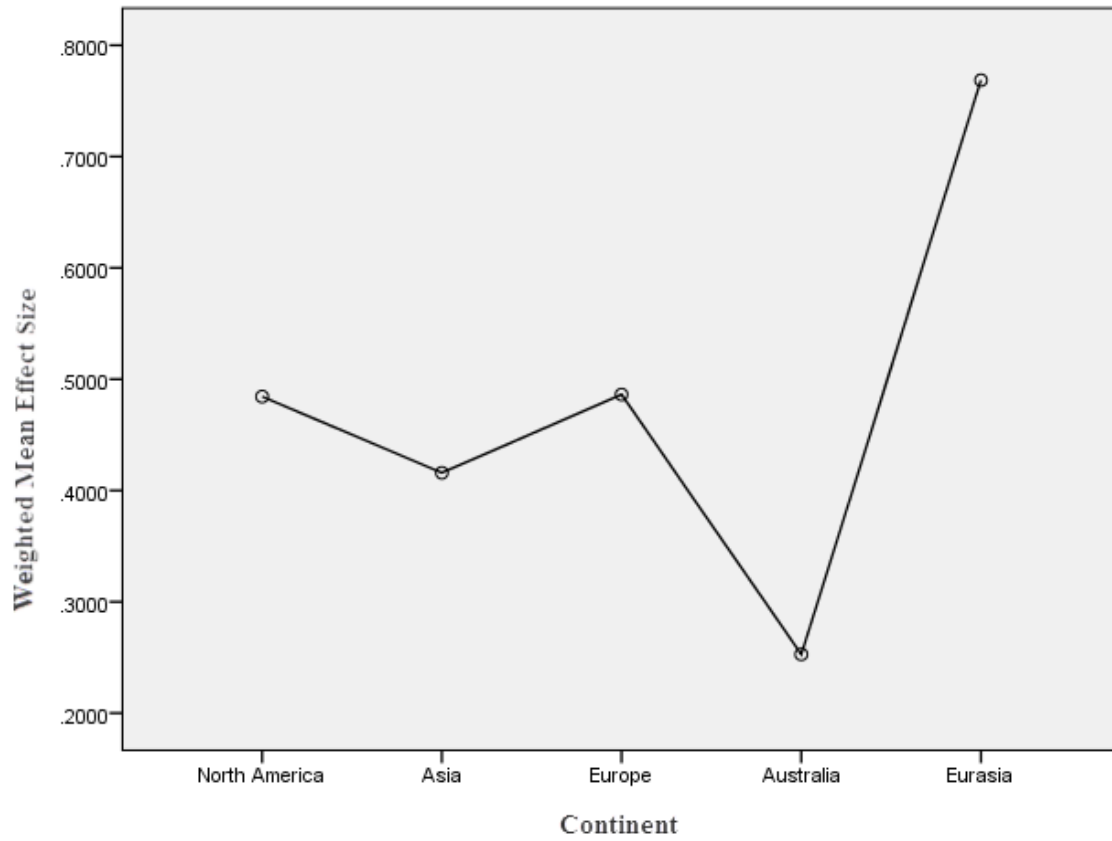


Figure 5:
Profile plot analysis of the variable type of publication

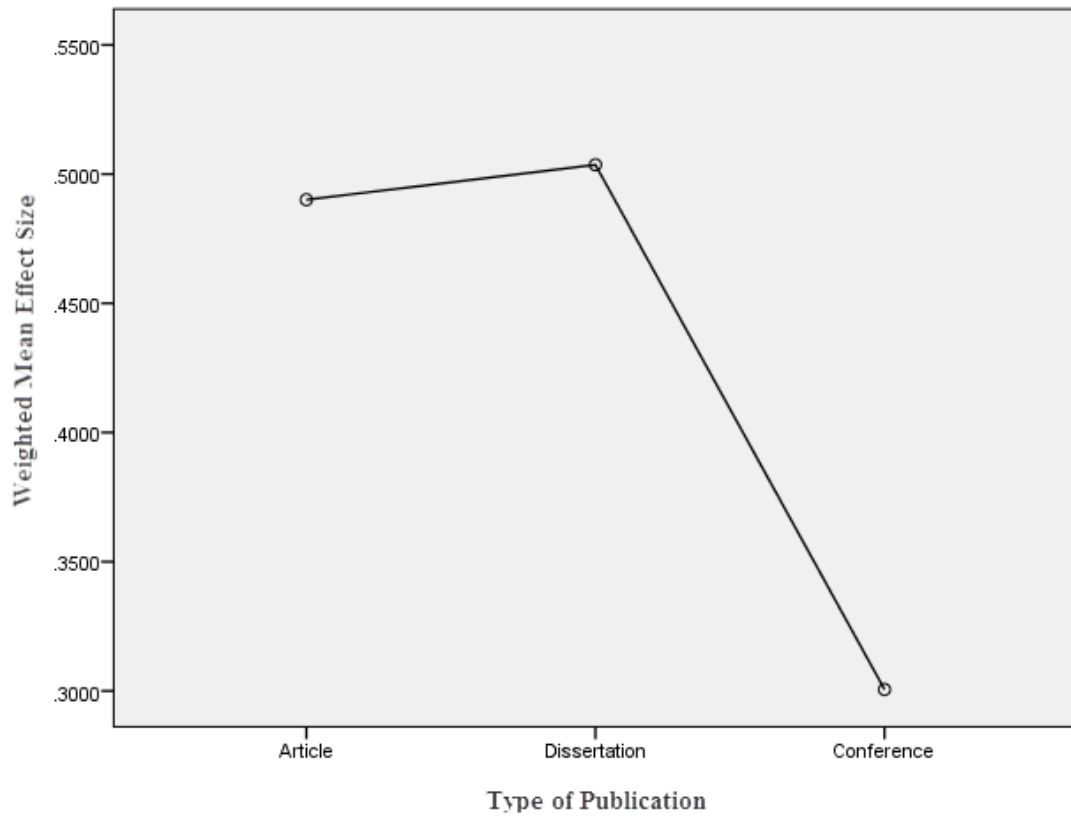


Figure 6:
Profile plot analysis of the variable type of virtual reality tool

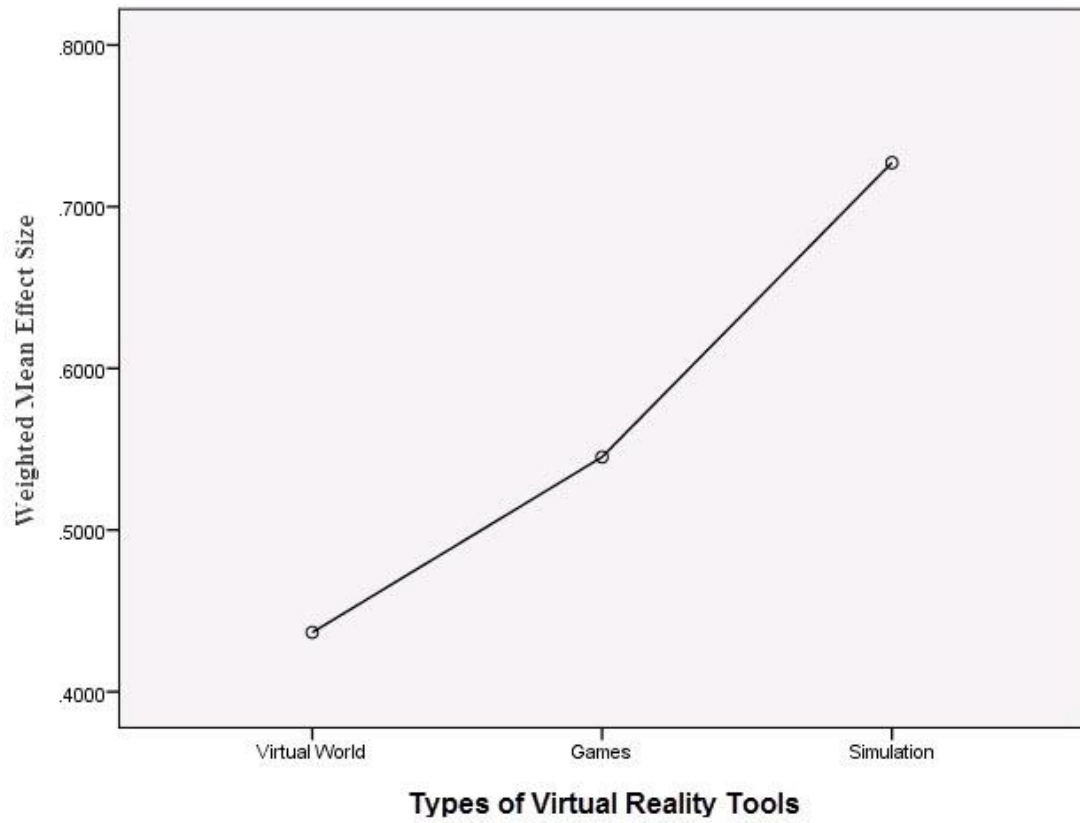


Figure 7:
Profile plot analysis of the variable control group treatment

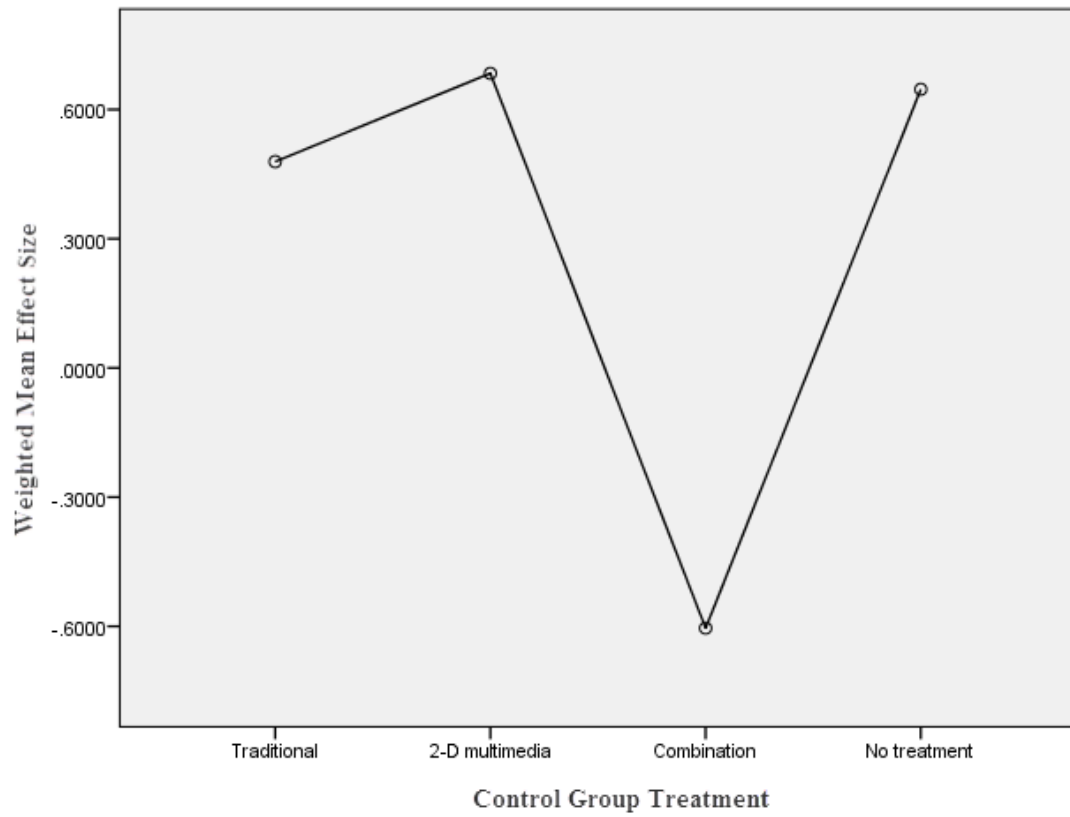


Figure 8:
Profile plot analysis of the variable time of administration

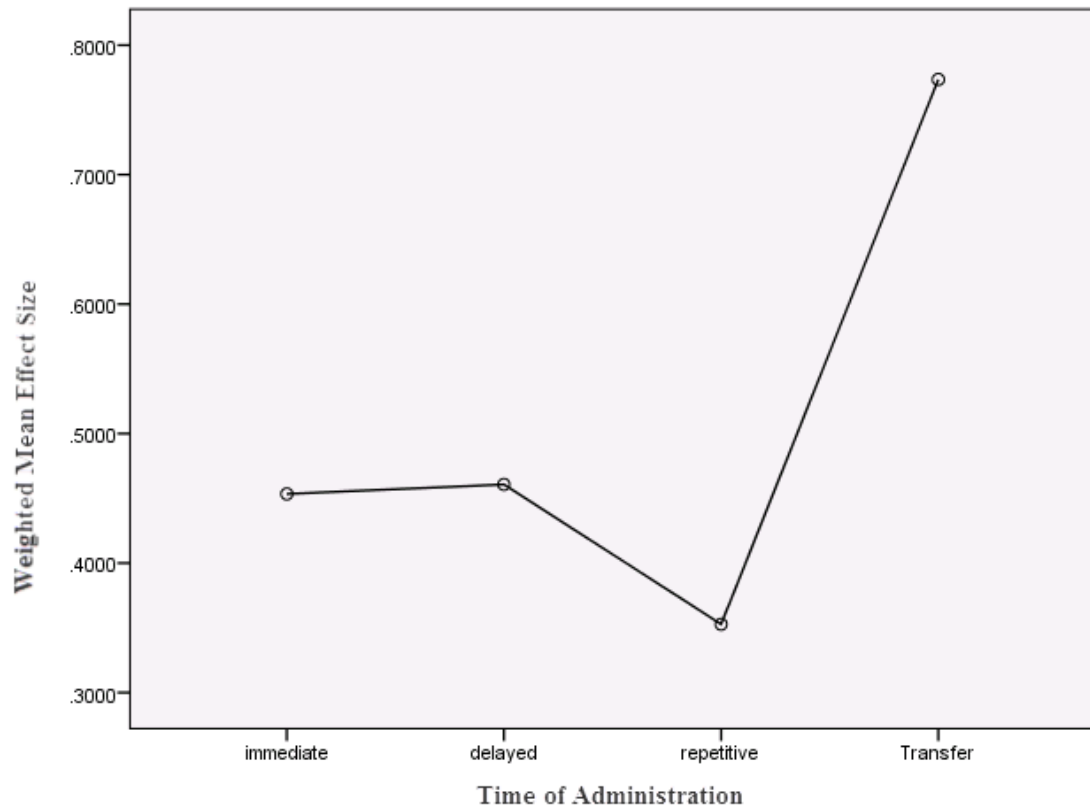


Figure 9:
Profile plot analysis of the variable domain knowledge

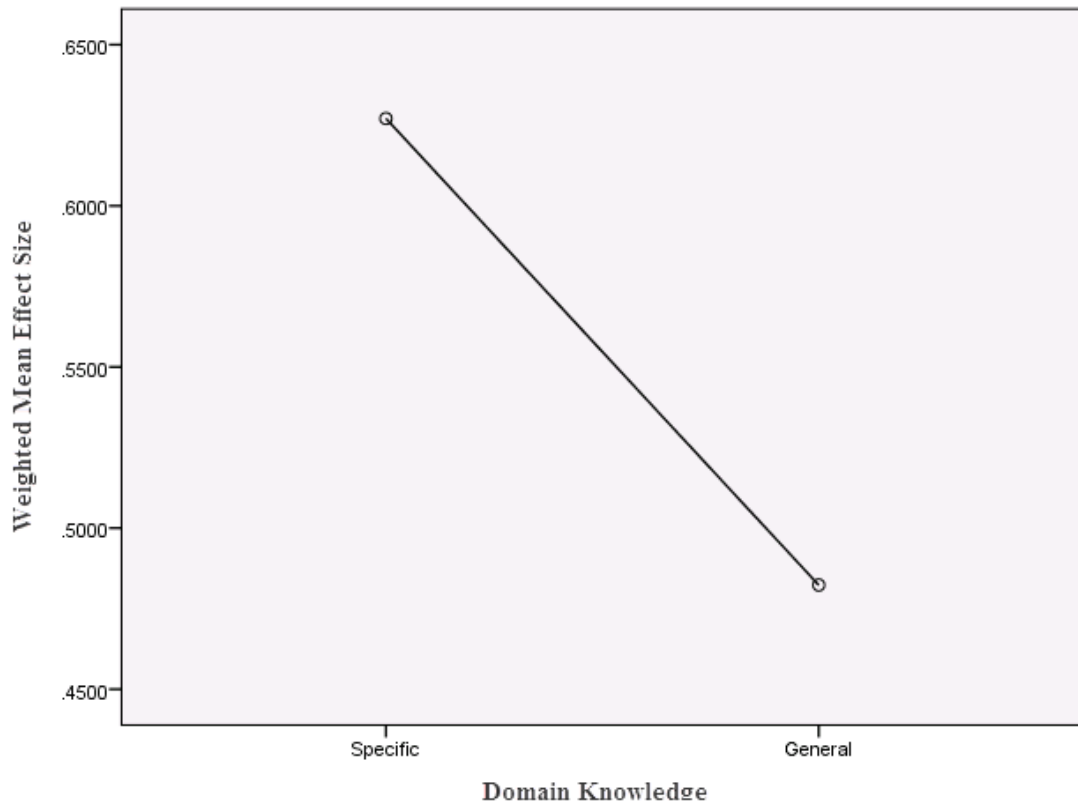


Figure 10:
Profile plot analysis of the variable feedback

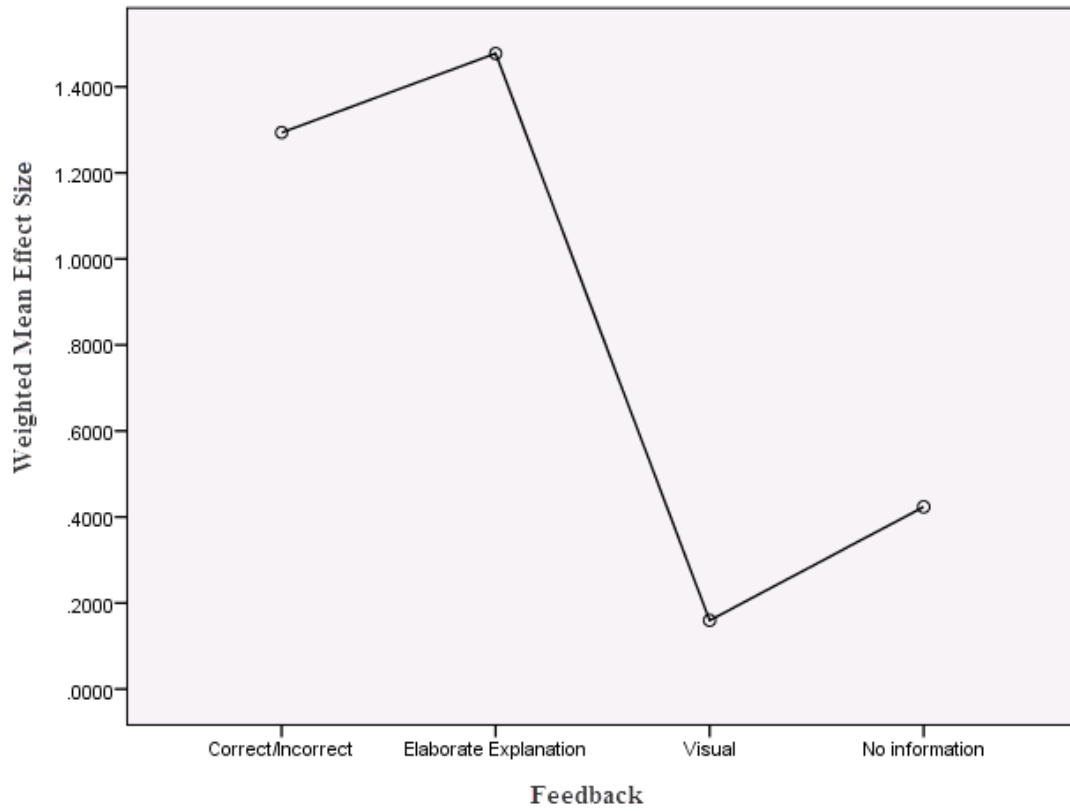


Figure 11:
Profile plot analysis of the variable teacher access

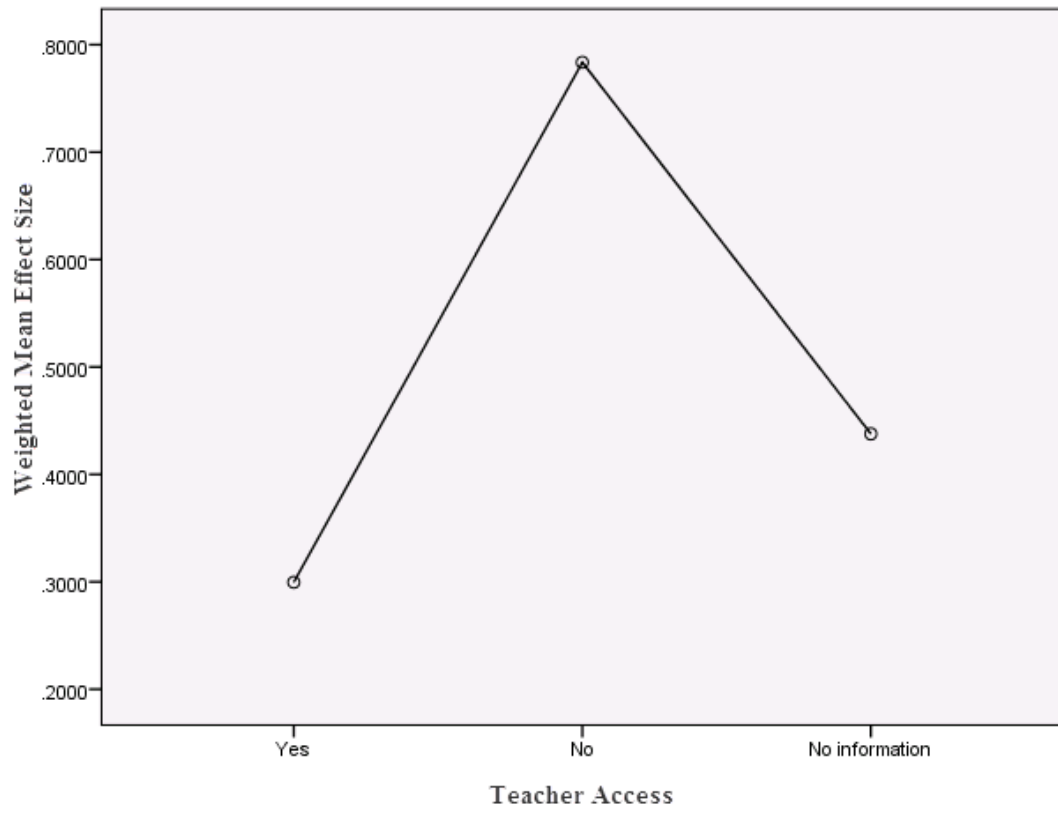


Figure 12:
Profile plot analysis of the variable collaboration

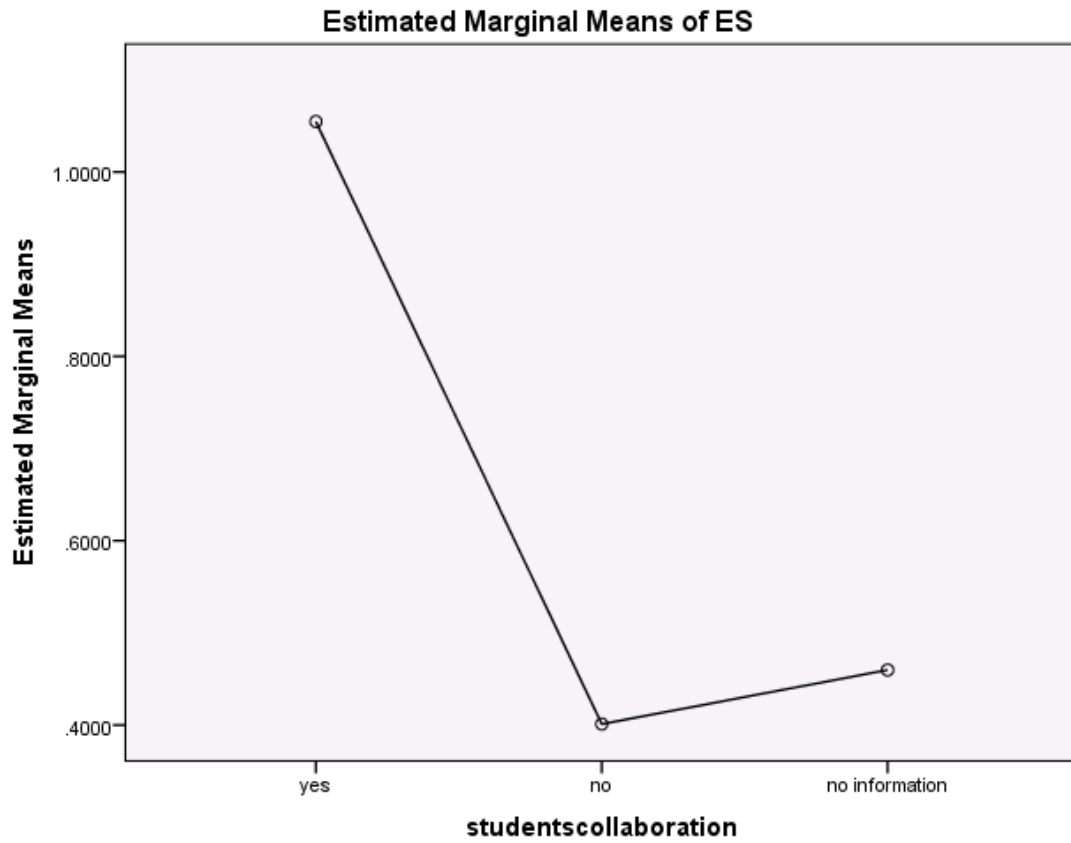


Figure 13:
Profile plot analysis of the variable mode of instruction

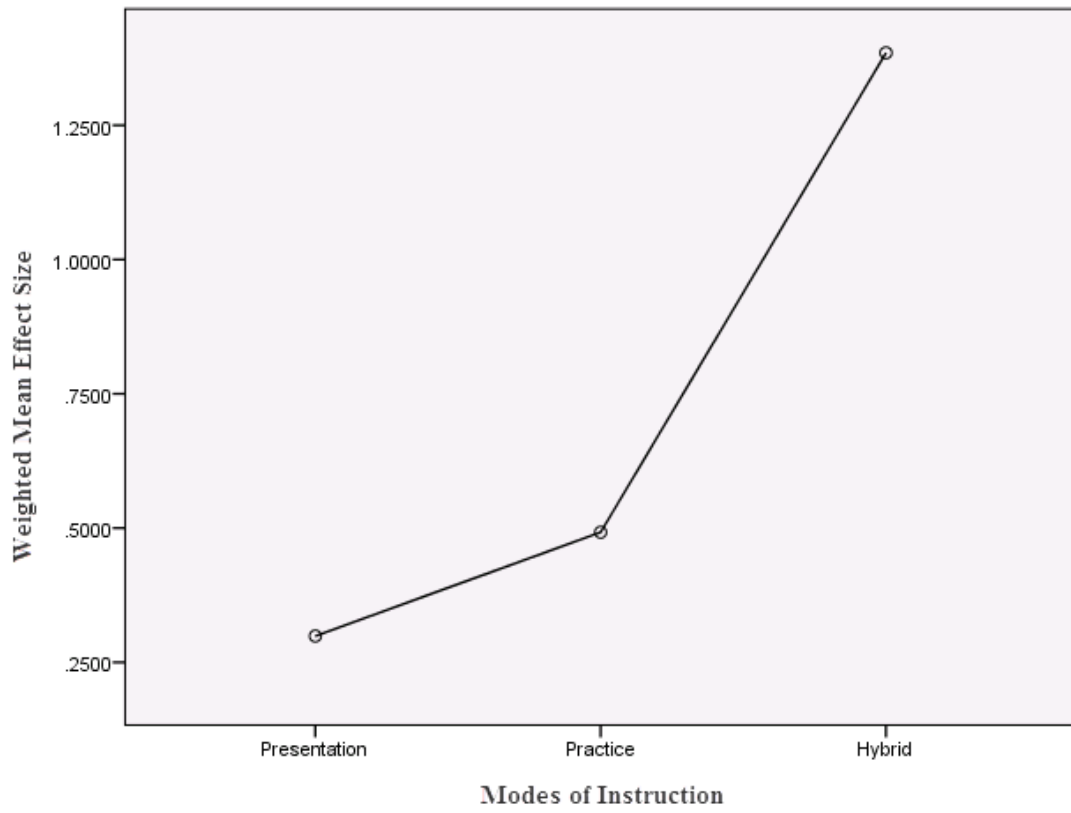
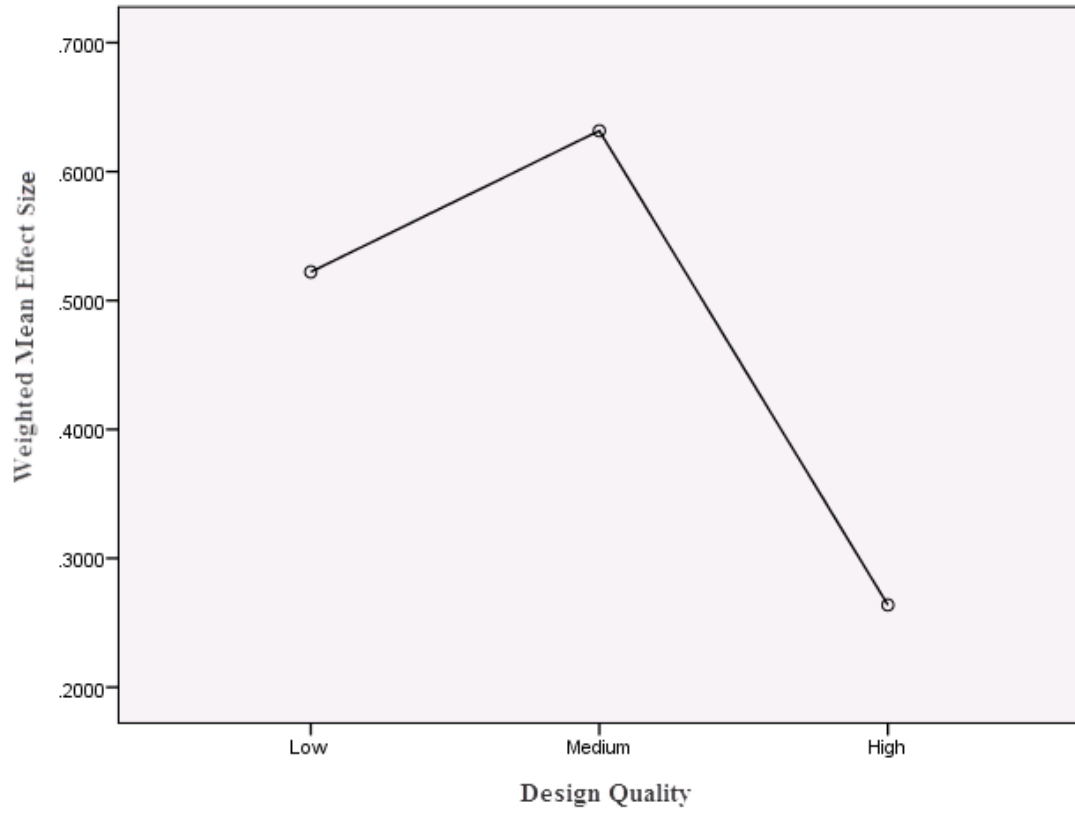


Figure 14:
Profile plot analysis of the variable design quality



CHAPTER III

THE LEARNER CHARACTERISTICS, FEATURES OF DESKTOP 3D VIRTUAL REALITY ENVIRONMENTS, AND COLLEGE CHEMISTRY INSTRUCTION: A STRUCTURAL EQUATION MODELING ANALYSIS*

Learner Characteristics and Science Achievement

Many concepts in the field of science require the understanding of spatial relationships. For example, in the field of medicine, understanding human anatomy in a 3D perspective plays a critical role during surgery. In the field of chemistry, a chemist must visualize the arrangement of atoms in a 3D space to know the shape of molecules. Recent reviews indicate that lack of spatial instruction makes learning of a concept highly challenging for the students, which in turn, adversely affects their achievements (Gilbert & Boutler, 2000; Harle & Towns, 2011). Students' difficulty in learning chemistry concepts may also influence their self-efficacy (House, 1993; Oliver & Simpson, 1988). Research reports suggest that self-efficacy acts as a catalyst in expediting the learning process (Lapan, Shaughnessy & Boggs, 1996; Tymms, 1997). Therefore, embedding spatial training in chemistry instruction using desktop 3D virtual reality environments' features can play a mediating role in enhancing students' chemistry achievement.

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The 3D Virtual Reality Features and Science Achievement

Desktop virtual reality can be defined as a simulation of a real environment or a 3D representation of an abstract concept created using computer technology, wherein users have the ability to interact with the virtual environment in real time using various control devices (Ausburn & Ausburn, 2004; Slater & Usoh, 1994). Users can explore desktop virtual reality applications on a high resolution conventional PC using keys or a mouse for navigation (Simpson, 2003; WhatIs, 2005). With the massive increase in the computer processing power and rapid proliferation of the World Wide Web, many 3D virtual reality technologies are now commonly available (Dickey, 2005; McLellan, 2004). Educators are finding this technology useful to teach many academic concepts (Buchanan, 2003). Studies conducted to test the effectiveness of the 3D virtual reality learning environment have shown positive results. Therefore, researchers are attesting to the learning effectiveness of this environment in fields such as medicine (Riva 2003), occupational and technical education (Ausburn & Ausburn, 2008), and engineering (Sorby, 2009).

One of the most vital and promising affordances of the virtual reality technologies is to provide spatial instruction. According to Moore (1995) "...by teaching the students to think in 3D using visualization techniques, their spatial cognition can be enhanced" (p. 5). Similarly, Hedberg and Alexander (1994) who emphasized the benefit of using 3D virtual reality environment stated, "As ideas are represented in a three dimensional world, three dimensional thinking can be enhanced, and the mental transformation of information from two to three dimensions can be

facilitated” (p. 216). Dalgarno, Hedberg, and Harper (2002) propose that “If 3D environment is a metaphorical representation of abstract ideas, it may be that by developing an integrated database of two dimensional views of a three dimensional model of the concepts, we are better able to make sense of the concepts than through other instructional approaches” (p. 8). As espoused by these scholars, one of the critical features of 3D virtual reality environments is the ability to visually depict and interact with spatial representations of abstract concepts. Therefore, this feature of 3D virtual environments can be useful in providing instruction for developing spatial ability.

Need for Conducting Sophisticated Statistical Analysis

Many studies conducted to examine the effectiveness of virtual reality technologies in the field of chemistry have found positive effects (Barnea & Dori, 1999; Pribyl & Bodner, 1987; Urhane, Nick, & Schanze, 2009). However, researchers must focus attention on analyzing the role of the mediating variables between the effects of 3D virtual reality technologies based instruction and chemistry learning. According to Waller, Hunt, and Knapp (1998), 3D virtual reality technology researchers should consider exploring perceptual and psychological variables that influence learning. Understanding the role of mediator variables can guide instructional designers, as they create learning tasks in response to the instructional need appropriately, utilizing virtual reality features. Lee, Wong, and Fung (2010) addressed this issue by developing a model of high school, biology students’ learning processes and testing it using structural equation modeling (SEM). Lee et al.’s study represents an important advancement in the field of virtual reality technology, but more research of this type is needed. Therefore, in

this paper, we propose a model that will examine the underlying perceptual and psychological variables involved during 3D virtual reality based instruction for learning chemistry and evaluate the model for an introductory college chemistry class using SEM analyses.

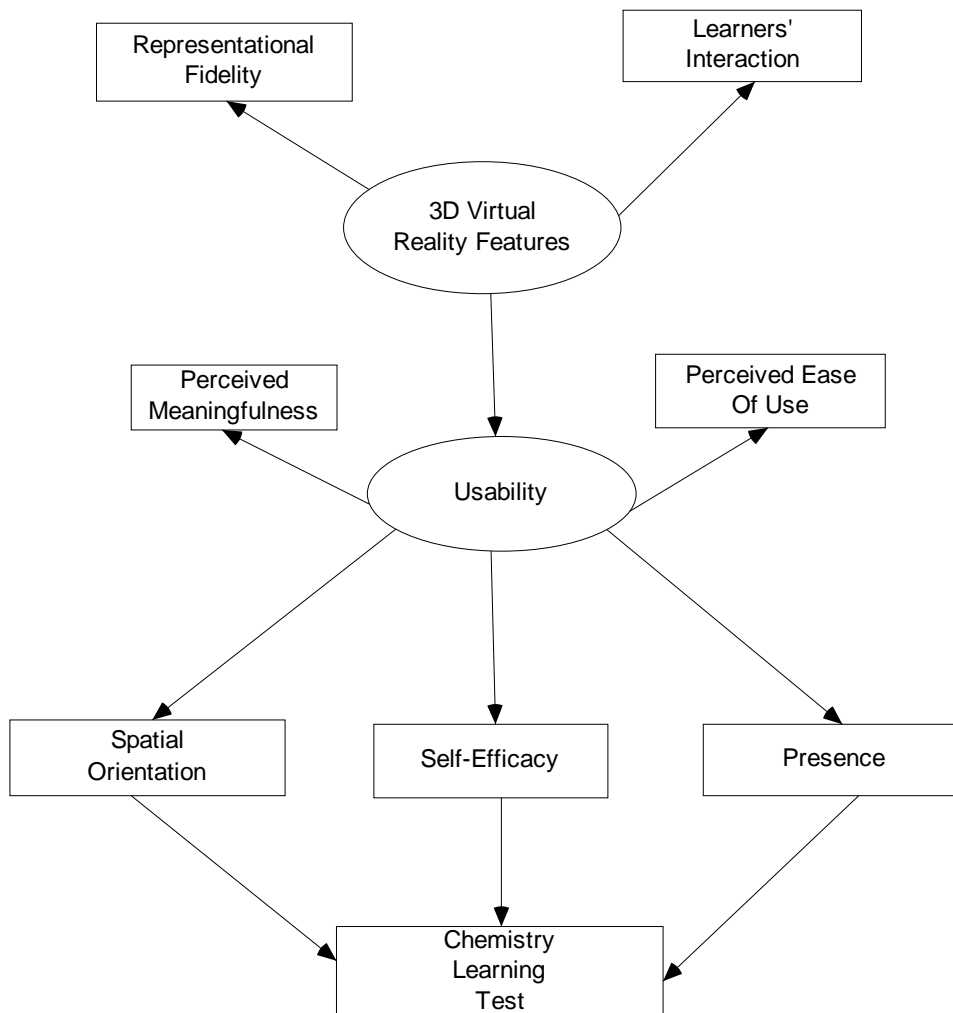
Many researchers have studied the impact of virtual reality technologies in chemical education because it is believed that students can form appropriate mental models of a concept by visualizing and interacting with the representation of the phenomenon (Antonoglou, Charistos, & Sigalas, 2011; Chiu & Wu, 2009; Phillips, Norris, & Macnab, 2010). A major contribution of this research is that it is the most comprehensive investigation to date of chemistry students' perceptual and psychological processes while interacting with a desktop 3D virtual reality learning environment, encompassing perceived usability of the features of the environment, learners' sense of presence in the environment, spatial orientation skills, and self-efficacy. In addition, an extensive search of the literature (Authors, 2011) did not reveal any studies of 3D virtual environments that used SEM analysis to study chemistry learning in 3D virtual reality environments. The understanding of the perceptual and psychological processes provided by a theoretical model such as the one proposed here may help to guide the design and development of 3D learning environments and the effectiveness of employing them in instruction.

Theoretical Framework

The general model of virtual reality proposed by Salzman, Dede, Loftin, and Chen (1999), which highlights the importance of 3D virtual reality features, concept

taught, and learners' characteristics (i.e., learning and interaction experience) for learning outcomes in a virtual environment, served as a starting point for the development of our model. Using Salzman et al.'s (1999) model, Lee, et al. (2010) developed a general model examining the underlying psychological processes of reflective thinking, cognitive benefits, motivation, active control, and presence in the 3D virtual reality based instruction for high school science students.

Figure 15:
Theoretical Model



They found that virtual reality features were significantly influential in impacting the learning outcomes via the psychological processes included in their model. Our model is focused on testing the impact of perceptual and psychological processes associated with the learning of science concepts that involve understanding spatial relationships. For this study, we proposed and tested the model presented in Figure 15, which represents hypothesized relationships (H1-H7) between 3D virtual reality learning environment features (representational fidelity and learner's interaction) and a chemistry learning test as mediated by selected perceptual (spatial orientation and usability) and psychological (self-efficacy and presence) variables. More description of each variable is provided below.

Description of 3D Virtual Reality Features

Many researchers of 3D virtual reality technologies have identified distinctive characteristics of this environment (Hedberg & Alexander, 1994; Steuer, 1992; White-lock, Brna, & Holland, 1996). We concur with Dalgarno and Lee (2010)'s conceptualization of 3D virtual reality features because they derived their model based on a comprehensive synthesis of the literature available on this theme. According to them, there are two main features of 3D virtual reality environment, "representational fidelity" and "learners' interaction". Representational fidelity refers to the realistic display of the virtual environment that can be attained by physical characteristics of the environment such as rich graphics, smooth temporal changes, and consistent object behavior. For example, a photo-realistic display of a 3D molecule can create a perception of viewing a real molecule. Learners' interaction is the ability of users to

influence the occurrences of events in the virtual environment by their actions. These would entail the capabilities of exploring, manipulating, rotating, and viewing objects from multiple perspectives. For example, a molecule can be rotated over a 360° angle to view the different bond angles.

Perceptual and Psychological Variables

We delineated perceptual and psychological variables underlying the learning of the chemistry concept. One of the perceptual variables included in this model was spatial orientation, a component of spatial ability. It is important that college instructors pay special attention to students' misconceptions about chemistry concepts. One of the critical reasons why students find learning science concepts challenging is that they have preconceived, erroneous notions that have become entrenched and are difficult to eradicate. Many studies have found positive results when they addressed students' misconceptions using spatial training-based instruction (e.g., Trindade, Fiolhais, Almeida, 2002; Yeziarski & Birk, 2006). Spatial orientation ability permits students to imagine simple or rigid transformations of an object by mentally rotating it in their minds (Ekstrom, French, & Harman, 1976; Lohman, 1988). For example, while studying bond angles of molecular structures, students should be able to rotate a molecule dependent upon the number of atoms bonding together as well as the preferred perspective to view the bond angles.

In the 3D virtual reality environment employed in this study, students can view molecules with their bond angles from various perspectives using the zooming in and out feature. Moreover, they can also examine bond relationships between atoms within a

molecule using different capabilities within the environment such as rotating and manipulating a molecule. This kind of learning task is similar to the process of mentally manipulating or transforming an object into another arrangement, which students are expected to perform to improve their chemistry understanding. It is likely that students with high levels of spatial ability can perform the necessary mental manipulations of molecular arrangement efficiently. However, researchers have found that typically students' lack this ability to view and transform 3D molecular arrangements mentally (Halpern & Collaer, 2005; Wu & Shah, 2004). Hoffler and Leutner (2011) conducted a meta-analysis of the effects of animations on students with low spatial ability and found that students performed better when they were instructed using animations than with static pictures. Therefore, by using the 3D virtual reality environments to manually manipulate and view 3D representations of molecular structures may enhance learners' ability to perform these transformations "in their minds".

Usability was another perceptual variable included in the model. Usability includes two subcomponents: perceived meaningfulness and perceived ease of use. Davis (1989) conceptualized the technology acceptance model after conducting an extensive survey in the field of information technology to understand how and when users will accept a new technology presented to them. According to Davis (1989), several factors influence the decision of accepting a new technology but the most prominent and influential are perceived meaningfulness and perceived ease of use. Similarly, Dalgarno and Lee (2010) state that the virtual reality technology in and by itself cannot afford learning. On the contrary, a designer has to employ these features to

design a learning task, which can be perceived by the learners as meaningful and easy to conduct.

We considered including the variable of usability in our model because we designed the spatial instruction in a sophisticated 3D virtual environment of Second Life®. According to cognitive load theory (e.g., Schmidt-Weigand & Scheiter, 2011; Sweller, 1994; Van Merriënboer, & Sweller, 2005), when the presentation of instructional material is complex or inconsistent, it can produce extraneous cognitive load, reducing learners' capacity to adequately process learning tasks (i.e., germane cognitive load), and impeding the learning process (Kirschner, Kester, & Corbalan, 2011; Mayer & Moreno, 2003). Therefore, we were interested in exploring the dynamics of learners' perception of how easy it was to use Second Life® and how these perceptions were related to students' perceptual and psychological processes and learning outcomes. Often, researchers find that effectiveness of instruction disappears because learners' find the use of technology cumbersome. Understanding and seeking control over the technological features imposes an extraneous load on their cognitive resources. In such circumstances, merely redesigning the users' interface rather than the instruction can enhance learning gains. Therefore, it was essential for our study to assess the comfort level of the learners while using Second Life® for spatial instruction.

Self-efficacy was a psychological process included in our model. According to the social cognitive theory, self-efficacy influences students' academic achievement (Zimmerman, Bandura, & Martines-Pons, 1992). Self-efficacy can be defined as the beliefs a person has about his or her capabilities to successfully perform a particular

behavior or task. The issue of self-efficacy in the students majoring in the science-related fields has been a big concern of educators. Students' low self-efficacy has resulted into poor enrollment or attrition in the enrollment level after a few semesters (Chemers, Hu, & Garcia, 2001; Pajares, 1996). Moreover, development of self-efficacy in a computer mediated environment particularly with regards to virtual reality technologies is an under researched topic.

According to Bandura (1993), one of the key factors that influence learners' self-efficacy level is their perceived ability to interact and control the learning environment. The 3D virtual reality environment features of zooming in and out, rotating, and manipulating provides numerous opportunities for learners to acquire extensive control over their learning process. Learners can practice rotation of molecular structures to test their understanding of the chemistry concept. This opportunity of dynamically interacting with learning materials within the 3D virtual reality environment may prove influential in promoting learners' self-efficacy about learning chemistry concepts.

Presence was another psychological variable included in our model. Presence is defined "as the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998, pp. 225). In 3D virtual reality environments, users play an active role in dictating the occurrences of events utilizing various capabilities. For, example, in our spatial instruction, learners can break apart a molecule or bond atoms to form a molecule and thus enable them to examine its bond angles. This makes presence a process unique to the experience of the 3D virtual reality environment. According to some scholars, presence is an outcome of tangible 3D

virtual reality features such as realistic display of the environment and interactivity (Whitelock, Brna, & Holland, 1996; Wenzel, Wightman, and Kistler, 1991); other scholars view it as a consolidation of sensation arising from the psychological processes of being involved and immersed in the environment (Regenbrecht & Schubert, 2002; Witmer and Singer, 1998). However, more recently, with the availability of desktop based virtual reality technologies, presence has generated renewed interest among researchers. Currently, there is a debate on whether a desktop-based virtual reality environment, being a less sophisticated form of the high end 3D virtual reality technologies, is capable of creating a sense of presence (Nunez, 2004).

The purpose of this study was to examine the impact of 3D virtual reality features on chemistry learning outcomes in relation to the underlying selected perceptual (spatial orientation and usability) and psychological (self-efficacy and presence) variables. Delineating the impact of these constructs in conjunction with each other will provide insight in designing learning tasks involving spatial training. The results of this study will better inform science educators, instructional designers, and multimedia developers to optimize 3D virtual reality features for delivering science-based spatial instruction.

Testing the Model

Figure 15 depicts the hypothesized latent factor mediation model and the paths to be tested using structural equation modeling analysis. The independent latent factor variable includes the 3D virtual reality features that are hypothesized to have a positive and direct relationship with the chemistry learning outcomes. The latent factor of 3D

virtual reality features explains the observed variables of: representational fidelity and learners' interaction. Usability is another latent factor model factor that explains the observed variables of: perceived ease of use and perceived meaningfulness. Usability mediates the relationship between 3D virtual reality features, spatial orientation, self-efficacy, and presence. Spatial orientation, self-efficacy, and presence are observed variables hypothesized to have positive and direct relationships with the outcome variable, students' achievement on the chemistry learning test. We tested the following hypotheses to assess the fit of the hypothesized model.

Hypotheses for testing direct relationships

H1: The 3D virtual reality features are positively and significantly related to usability.

H2: Usability is positively and significantly related to spatial orientation.

H3: Usability is positively and significantly related to self-efficacy.

H4: Usability is positively and significantly related to presence.

H5: Spatial orientation is positively and significantly related to the chemistry learning test.

H6: Self-efficacy is positively and significantly related to the chemistry learning test.

H7: Presence is positively and significantly related to the chemistry learning test.

Hypotheses for testing indirect relationships

H₀₁: Usability will mediate the relationship between the 3D virtual reality features and spatial orientation.

H₀₂: Usability will mediate the relationship between the 3D virtual reality features and self-efficacy.

H₀₃: Usability will mediate the relationship between the 3D virtual reality features and presence.

Method

The data presented here were collected as part of a quasi-experimental study evaluating the effects of the 3D virtual environment treatment described in this paper. Only the data from the group that received instruction using Second Life® were relevant for the analyses reported in this study.

Participants

This study's participants were 238 undergraduates enrolled in the morning section of Chemistry 101 course at a large southern university in the United States of America during the spring 2011 semester. Of these 238 students, 2 chose not to participate in the study and another 8 dropped the class. Further, 24 students were dropped from the study because they completed the set of tasks out of order. The final sample consisted of 204 participants of whom 67% were female and 33% were male. Most of the participants' (92%) age ranged between 18-21 years. The weighted mean age of the students was 19.75 years and the weighted standard deviation was 0.09. They were mostly Caucasians (72%) or Hispanics (17%). More descriptive statistics can be found in Table 3. Students who were not included in the study did not differ from students who were included on the demographic variables.

Table 3:
Demographic Statistics of the Study's Participants included in the SEM Analysis

Variable Groups		N	Percentage
Gender	Female	136	33
	Male	68	67
Age	< 18	4	2
	18 – 21	188	92
	22 -25	9	4
	26 - 30	3	1
	31 - 35	3	1
Race/ Ethnicity	Caucasian	148	72
	Hispanic	34	17
	Asia/Pacific Islander	15	7
	African American	3	1
	American Indian/Native Alaskan	3	1

Measures

The measures in this study were the chemistry learning test, the Purdue Visualization of Rotations Test (PVRT), and a self-report measure consisting of items on six variables. The six variables were representational fidelity, learners' interaction, perceived ease of use and meaningfulness, self-efficacy, and presence. Participants completed all three measures using the online Qualtrics survey tool.

Test of Chemistry Learning

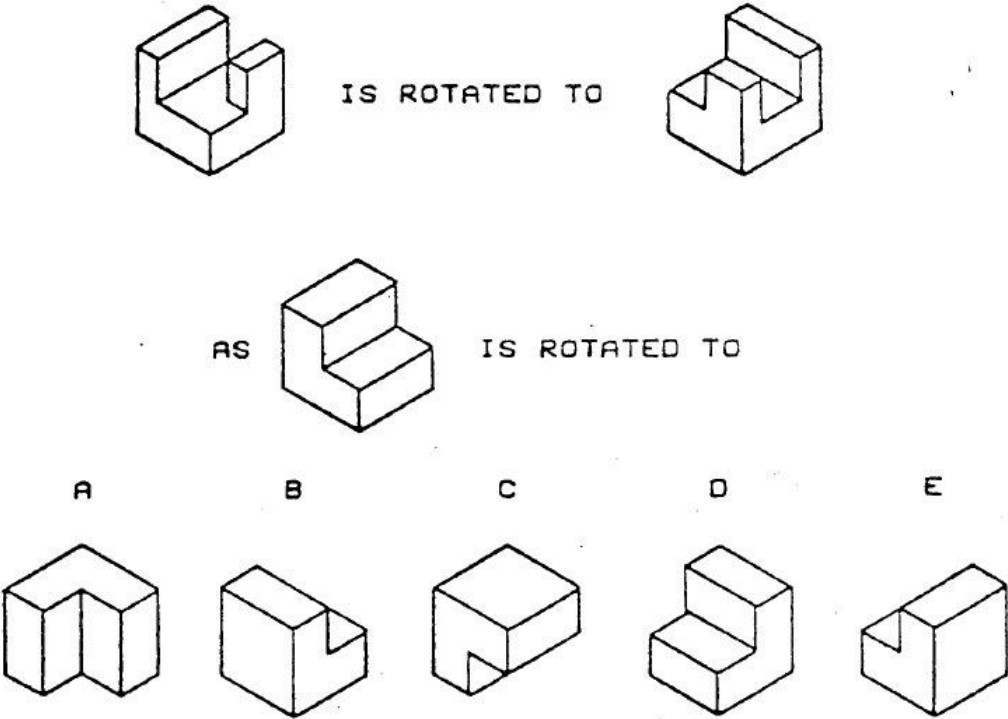
We selected the VSEPR (Valence-shell Electron Pair Repulsion) theory as a measure of chemistry learning because it is one of the most fundamental, abstract, and spatially demanding concepts in undergraduate chemistry courses, where students are expected to view molecules in a 3D space (Sorby, Charlesworth, & Drummer, 2006). Students draw a basic Lewis electron dot diagram to depict bonding and non-bonding electrons in a chemical species, which they then apply to determine its three dimensional shape. The instructor of the Chem101 course who has taught this class for the past 27 years developed a multiple choice test on VSEPR theory consisting of 12 questions on molecular angles, molecular geometry, and species identifications. Participants scored one point for every question answered correctly and zero for an incorrect answer. Three chemistry professors reviewed this test to ensure its content validity. A pilot study of this test was conducted with 53 students who took Chem102 from the same instructor in the fall of 2010. After conducting item analysis, all the questions demonstrated an acceptable discrimination index, except one. Therefore, that question was deleted yielding an 11 item test. The item difficulty index for the 11 questions ranged between 0.20 - 0.81 which is of moderate difficulty level. The reliability coefficient alpha for pilot test score was 0.87, which is higher than the acceptable level recommended for learning achievement tests (Reynolds, Livingston, & Wilson, 2009).

Purdue Visualization of Rotations Test (PVRT)

This 20 question test developed by Bodner and Guay (1997) is a widely used measure of spatial orientation in the field of chemistry. Figure 16 is a sample item from

the PVRT. PVRT items are analogy problems in which students are asked to perform the rotation that is shown at the top of the item, choosing from the five options shown at the bottom. Thus in the problem shown in Figure 16, option D is the correct answer. Each question in this test consists of a 3D object, participants are asked to select the correct rotated version of the object from the five alternatives provided. Participants are allotted ten minutes to complete all the 20 questions. Participants scored one point for every question answered correctly and zero for an incorrect answer. This test has consistently demonstrated a good reliability (KR-20) index ranging from 0.78 – 0.80 in a variety of research contexts.

Figure 16:
An example of test question from Purdue Visualization of Rotation Test



Self-report Measure

The self-report measure consisted of 41 items adapted from four different instruments measuring six variables of this study: representational fidelity (4 items), learners' interaction (3 items), perceived ease of use (8 items), perceived meaningfulness (10 items), self-efficacy (15 items), and presence (1 item). All the measures were adapted from previously validated instruments (See Appendix A) except for the measures of self-efficacy and presence because instruments available to measure these variables are very few. The instrument developed by Witt-Rose (2004) was considered the most comprehensive and appropriate to measure learners' self-efficacy level in the context of this study. We used the most popular and commonly used presence measure designed by Slater and Usoh (1994). Items for all the above measures were based on the Likert scale with strongly disagree (1) to strongly agree (5), except for the measures of 3D virtual reality features, perceived ease of use, and perceived meaningfulness which were originally based on the Likert scale from not at all (1) to very much (7). Thus measurement scale of these instruments' items was reduced to 5, strongly disagree (1) to strongly agree (5) to maintain consistency with the other instruments used in this study. The only other modification made to the instruments was to reflect the context of the study. For example, one of the questions in the original self-efficacy instrument was "I am confident I can understand the material taught in anatomy and physiology (A&P)" was revised to "I am confident I can understand the material taught about VSEPR theory". More details for each measure are provided in Appendix A.

Instructional Software

Second Life®, an innovative 3-D technology, launched by Linden Labs in 2003 was used to provide spatial instruction to this study's participants. This internet-based immersive virtual environment allows its users, who are called residents, to interact within this environment by creating their digital self-representation, called an "avatar" (Second Life.com). Second Life® also has the ability to build 3D virtual objects (molecules in this instance). Other interactive features include the ability to interact with the object by zooming in and out, rotating the object, and programming the objects to behave in a certain manner. Currently, there are two spaces in Second Life® that exhibit fundamental chemistry concepts: Drexel University's simulation on chemical solubility testing and Texas A&M University's Dr K's Chemistry Corner on molecular structures.

Texas A&M University's Dr K's Chemistry Corner

Dr. Wendy Keeney-Kennicutt from the Chemistry department has built a corner in Second Life® (<http://slurl.com/secondlife/12thMan/213/239/26>, February 8, 2012). Students were familiarized with the environment of Second Life® and its features, using seven introductory videos specifically developed for this study. Later students completed three assignments in Second Life® using the simulations called 1) Molecule Game 2) The Chemist as an Artist 3) The Tower of VSEPR Theory. Following is the detailed description of each simulation set up in Second Life® and three activities student's completed in Second Life®. Sample screen shorts are presented in Figure 17

Figure 17:
Activity Stations in Dr K's Chemistry Corner

Intervention 1: Molecule Game



Intervention 2: Chemist as an Artist



Intervention 3: Tower of VSEPR Theory



The Molecule Game

This game was designed for students to see the molecules in a 3D space from multiple perspectives. Students' had to "rezz" (i.e., to make an object appear in the Second Life® environment) molecules at five different stations to complete this assignment. After rezzing the molecules students were prompted to answer questions about the molecule they rezzed. For example, one of the stations had an ethane molecule. When students' rezzed the ethane molecule a note popped saying "How many hydrogen atoms does an ethane molecule have?" The students could view the ethane molecule, count the atoms, and rotate the molecule to view from different perspective in order to answer that question. On selecting their response, students received feedback and other supportive information to proceed further. Finally, students emailed a picture of their avatar taken at any one of the five stations to the instructor as a requirement to obtain credit for activity completion.

Chemist as an Artist

This simulation was designed to further develop students' ability to see molecules in a 3-D perspective. The participants were given three molecules to manipulate in Second Life®. They could rotate the molecule and link or unlink the atoms to thoroughly explore a molecule. For each molecule, they were required to provide a photograph of themselves with two orientations of their molecule, and a 2D drawing of each orientation using solid lines, wedges, and dashed lines.

The Tower of VSEPR Theory

This simulation was designed to enhance students' understanding of an important concept in chemistry called the Valence-shell Electron Pair Repulsion (VSEPR) Theory. Students were required to rezz 11 different molecules to complete a VSEPR theory report.

Procedure

The study began in the fifth week of the spring semester 2011. The instructor informed the students of CHEM 101 morning section about the study as a special project to be conducted during the semester. Participants received a syllabus handout containing all the details of the project (i.e., description and requirement to complete the assignments and credit assigned for the completion of the project). Beginning from the fifth week of the semester, participants had four weeks to complete the assignment of the "Molecule Game" and the "Chemist as an Artist". During the ninth week, participants could begin working on the assignment of "The Tower of VSEPR Theory", and they had three weeks to complete the two assignments in the specified order. Before students began the assignment of "The Tower of VSEPR Theory", they were instructed on this topic for three consecutive class periods by the instructor. In the 12th week participants took the PVRT Test, the chemistry learning test, and completed the self-report measure.

Results

The descriptive statistics of all the variables included in the model are presented in Table 4. The fit of the hypothesized model was assessed using the SEM approach. SEM is considered a highly reliable technique for model testing because 1) measurement

errors can be controlled using a latent factor model and 2) goodness of fit indices can be obtained to assess the relationship between the variables (Kline, 2010). Data were analyzed using MPlus Version 6.11 (Muthe`n & Muthe`n, 1998-2007). The maximum likelihood method of estimation was employed. A two-step procedure was undertaken to test the hypotheses.

Table 4:
Descriptive statistics of each variables included in the SEM model

	1	2	3	4	5	6	7	8
Mean	5.09	18.45	4.74	11.56	15.51	30.45	39.30	3.25
SD	1.48	3.89	4.16	4.12	5.54	9.70	9.07	1.26
1	1.00	-	-	-	-	-	-	-
2	0.47**	1.00	-	-	-	-	-	-
3	0.11	0.23**	1.00	-	-	-	-	-
4	0.01	0.17*	0.37**	1.00	-	-	-	-
5	0.42**	0.55**	0.26**	0.18**	1.00	-	-	-
6	0.51**	0.66**	0.25**	0.09	0.62**	1.00	-	-
7	0.18*	0.46**	0.46**	0.29**	0.43**	0.54**	1.00	-
8	0.44**	0.34**	0.14	0.03	0.45**	0.48**	0.21**	1.00

A three-step procedure was undertaken to test the hypotheses. We first examined whether the items we used to measure a construct did significantly relate/load on that construct. The relation between the items and the corresponding construct can be translated into a measurement model. We adopted confirmatory factor analysis (CFA) under the structural equation modeling (SEM) framework to examine the hypothesized measurement model for each construct. In testing the measurement models, we used scores obtained by each student on every item of the instrument. Once we had acceptable

model fit indices and factor loadings for each construct (as presented in Table 5), we then created the composite score of the construct which was the sum score of the corresponding items of that construct. This approach, also known as the unit weighting approach (Kline, 2010), is commonly used for creating a composite score that “has the advantage of simplicity and less susceptibility to sample-specific variation” (p.204). There are two reasons that led us to using composite scores instead of including the full measurement models for all the constructs in the hypothesized model: 1) the inclusion of the full measurement model in the hypothesized structural model would increase the model complexity (i.e., with more free parameters for estimation), which could result in potential convergence issue; 2) according to the recommended rule of thumb for sample size in structural equation modeling, 10:1 (i.e., 10 observations for every free parameter; Bentler, 1995; Jackson, 2003; Kline, 2010), the current sample size (N=204) was adequate to estimate the hypothesized model with composite scores given that it contained 19 free parameters (i.e., at least $19 \times 10 = 190$ students were needed to estimate this model based on the 10:1 rule of thumb, 204 were included in the analysis). The inclusion of the full measurement model would substantially increase the number of free parameters and based on the rule of thumb, our sample size would not be sufficient to estimate such a complex model. Given these reasons, we determined to use the composite scores in testing the hypothesized structural model. Testing indirect relationships between constructs has been used by researchers to understand the processes underlying the direct relationship among the constructs (e.g., Hughes & Kwok,

2006) and was deemed essential for the purpose of this study. All the hypothesized indirect relationships were examined using the Type=Indirect procedure in Mplus.

Table 5:
Results of Measurement Model Analysis

Factors	Model Fit Indices	Factor loadings	Cronbach's Alpha/Omega
Chemistry learning test	Chi-square = 139.037 df = 44, p = 0.001 N = 207 Normed chi-square = 3.159 CFI = 0.92 TLI = 0.89 SRMR = 0.05 RMSEA = 0.06	0.41-0.73	0.61/0.71
Spatial Orientation	Chi-square = 222.145 df = 170, p = 0.004 N = 204 Normed chi-square = 1.306 CFI = 0.94 TLI = 0.93 SRMR = 0.04 RMSEA = 0.02	0.54-0.73	0.77/0.89
Representational fidelity	Chi-square = 13.106 df = 2, p = 0.001 N = 204 Normed chi-square = 6.553 CFI = 0.92 TLI = 0.75 SRMR = 0.06 RMSEA = 0.16	0.21 – 0.40	0.49/0.58

Table 5: Continued
Factors

Factors	Model Fit Indices	Factor loadings	Cronbach's Alpha/Omega
Learners' interaction	Chi-square = 197.663 df = 3, p= 0.001 N = 204 Normed chi-square = 65.887 CFI = 1.00 TLI = 1.00 SRMR = 0.00 RMSEA = 0.00	0.65 – 0.77	0.78/0.78
PEU	Chi-square = 62.419 df = 14, p= 0.001 Normed chi-square = 4.4585 N = 204 CFI = 0.94 TLI = 0.91 SRMR = 0.05 RMSEA = 0.13	0.73-0.86	0.89/0.89
PM	Chi-square = 134.276 df = 35, p= 0.001 Normed chi-square = 3.836 N = 204 CFI = 0.96 TLI = 0.95 SRMR = 0.03 RMSEA = 0.11	0.78 – 0.91	0.97/0.97
Self-efficacy	Chi-square = 199.254 df = 65, p= 0.001 Normed chi-square = 3.06 N = 204 CFI = 0.92 TLI = 0.91 SRMR = 0.10 RMSEA = 0.05	0.51 – 0.91	0.93/0.93

Measurement Model

Each measurement model was assessed based on the model fit indices, standardized factor loadings, and reliability to confirm constructs validity. According to Hu and Bentler (1999), goodness-of-model must be determined based on combined evaluation of fit indices. They recommend that CFI (Comparison Fit Index) and TLI (Tucker Lewis Index) values closer to 0.96 and SRMR (Standardized Root Mean Square Residual) values close to 0.10 are needed. Moreover, RMSEA and SRMR values of 0.05 or 0.06 are also acceptable. Hair, Black, Anderson, and Tatham (2006) recommended that non-significant chi-squared statistics (χ^2) value, in combination with CFI and TLI values of 0.95 and above, and RMSEA and SRMR values less than 0.06 are needed. In addition, Browne and Cudeck (1993) and Hair, Black, Anderson, and Tatham (2006), both suggest that RMSEA and SRMR values less than 0.08 and CFI and TLI values of 0.90 constitute an acceptable level of model fit. All the measurement models met the required standards of a good model fit (see Table 5) except for the measurement model for representational fidelity.

Following Kline's (2010) guideline, the convergent validity can be shown by whether the observed variables are significantly related to the corresponding construct. According to the results of the measurement models, all the observed variables were significantly loaded on the corresponding constructs. The range of the factor loadings for each construct was presented in Table 5. Hair, et al. (2006) recommends that the factor loadings should be 0.50 or higher and ideally should be 0.70 or higher. All the items loaded significantly on their latent factors ($p < 0.01$) and most of the factors loadings

ranged between 0.51 – 0.91 indicating an overall high construct validity of the factors. Reliability coefficients alpha was calculated for the score of each observed variable. Most of the reliability coefficients were above the generally acceptable level of 0.70. McDonald's Omegas also were calculated and are presented in the Table 5. Overall, the omegas were either equal to or larger than the alphas. For measurement with a single item (e.g., presence in the current study), it is not possible to calculate the reliability coefficient. Therefore, according to Hair, et al. (2006), decisions regarding the reliability of a measure with single item can be determined based on researcher's best judgment. Overall, it was assumed that each measurement model indicated an acceptable level of construct validity.

The discriminant validity was examined by fitting all the observed items to a single-factor model in which they were loaded on the same factor. The results showed that this single-factor model produced poor fit, $\chi^2(2484) = 9500.27, p < .001$; CFI = 0.36, while more than 40% of the factor loadings were not statistically significant. The poor fit of the single factor model could be viewed as an evidence of the discriminant validity of the constructs given that the observed variables and the corresponding constructs were not only conceptually but also statistically different from each other. Therefore, we proceeded to conduct the next step in the analysis, which was testing the structural model.

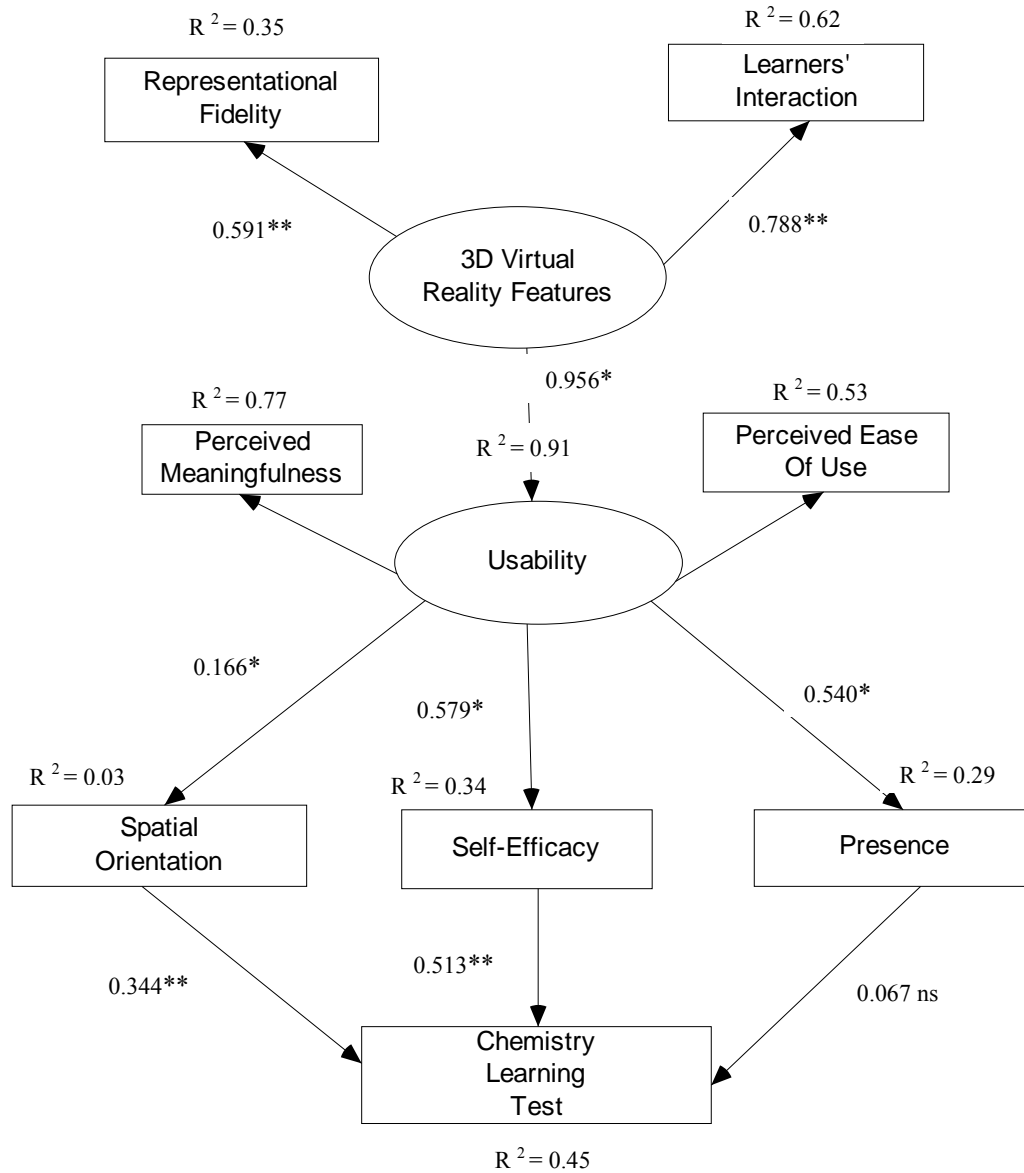
Structural Model

Figure 18 shows the results of the hypothesized structural model. We limited our analysis to testing only the hypothesized model because we developed this model based

on the literature review and theoretical underpinnings. The overall goodness of fit indicates an acceptable fit (CFI = 0.953, TLI = 0.931, RMSEA = 0.06, SRMR = 0.04). All the model estimates were statistically significant and in the hypothesized direction.

The hypotheses of direct relationships H1, H2, H3, H4, H5, and H6 were supported. The only hypothesis that was not supported in this model was H7. Overall the model explained 45% of the variance ($R^2 = 0.45$) in the chemistry learning test, 34 % variance ($R^2 = 0.34$) in the self-efficacy, 29% ($R^2 = 0.29$) in presence, and 3% ($R^2 = 0.03$) in the spatial orientation. The 3D virtual reality features strongly and positively influenced the usability ($\beta = 0.956, p < 0.001$). Usability was strongly related to 3D virtual reality features and spatial orientation ($\beta = 0.166, p < 0.05$), self-efficacy ($\beta = 0.579, p < 0.001$), and presence ($\beta = 0.540, p < 0.001$). The perceptual variable of spatial orientation ($\beta = 0.344, p < 0.001$) and the psychological variable of self-efficacy ($\beta = 0.513, p < 0.001$) was strongly related to the chemistry learning test. The only relationship that was non-significant was between presence and the chemistry learning test ($\beta = 0.069, p = 0.367$). All the hypotheses of indirect relationships H₀₁, H₀₂, H₀₃ were supported. Usability mediated the relationship between 3D virtual reality features and spatial orientation ($\beta_{3D \text{ Virtual features} \rightarrow \text{Usability} \rightarrow \text{spatial orientation}} = 0.16, p < 0.05$), self-efficacy ($\beta_{3D \text{ Virtual features} \rightarrow \text{Usability} \rightarrow \text{self-efficacy}} = 0.55, p < 0.001$), and presence ($\beta_{3D \text{ Virtual features} \rightarrow \text{Usability} \rightarrow \text{presence}} = 0.52, p < 0.001$).

Figure 18:
Results of Structural Model Analysis



Chi-square = 58.796 df = 31, $p = 0.001$
 Normed chi-square = 1.825
 CFI = 0.953
 TFI = 0.931
 RMSEA = 0.06
 SRMR = 0.04

*Co-efficient is significant at the 0.05 level (2-tailed).
 ** Co-efficient is significant at the 0.01 level (2-tailed).
 ns = non-significant

Discussion

This study explored the role of psychological and perceptual processes in the learning of chemistry concepts in a 3D virtual reality environment. A theoretical model was developed based on previous research and theory in the area and tested using structural equation modeling. The results supported the hypothesized mediational paths from 3D virtual reality features to the usability and from usability to spatial orientation, self-efficacy, and presence. This study also found statistically significant and positive relationships between spatial orientation and self-efficacy and students' performance on a chemistry learning test. However, the hypothesized relationship between presence and chemistry learning was not supported. This study's results support the model proposed by Salzman et al. (1999) that learners' characteristics and the interaction experience mediate the relationship between 3D virtual learning environment features and chemistry learning outcomes with the exception of presence variable.

Our study makes a significant contribution because it is the first to use structural equation modeling to explore mediational relationships among the constructs that influence chemistry learning in a 3D virtual reality environment. In addition, it is the first study to examine the role of self-efficacy. According to the Salzman et al. (1999) model, a gamut of factors play mediating roles when an instruction is designed using 3D virtual reality features to enhance learning achievement. In order to test the theoretical stance proposed by the Salzman et al. (1999) it was essential to develop a more fully articulated model that could then be tested using a statistical technique that allows examination of multiple relationships between concepts. Our study tested a web of

relationships between several factors that influence chemistry learning with spatial orientation as one of them.

The Chemistry Learning Test

The hypotheses of direct positive relationships between chemistry learning and spatial orientation (H5) and self-efficacy (H6) were supported. Overall, our model could explain nearly 50% of the variance in the chemistry learning test. This indicates that our model incorporated important predictors of performance on the chemistry learning test. The fact that students struggle with the learning of chemistry concepts is very well known. Our results indicated that students' spatial orientation skills and their sense of self-efficacy were strong predictors of chemistry learning in the 3D virtual reality environment we developed. There can be other predictors of students' performance such as teacher quality, physical classroom conditions, and peer influence that can explain the other variances in students' chemistry performance.

Self-efficacy

Our findings supported the hypotheses of direct relationship between usability and self-efficacy for learning chemistry (H3) and an indirect relationship between 3D virtual reality features and self-efficacy for learning the material presented in the chemistry class as mediated by usability (H₀₂). Students' interactions with 3D virtual reality features were related to their self-efficacy levels, which, in turn, predicted their performance on the chemistry learning test. The 3D virtual reality environment provided a high level of learners' interaction in the environment. This suggests that students' ability to explore, manipulate, and rotate representations of molecular structures in the

Second Life® environment may be related to their self-efficacy for learning chemistry. According to Bandura (1993), one key factor that influences individuals' self-efficacy level is their perceived ability to control the environment. The 3D virtual reality environment provided a high level of learners' interaction in the environment. Qualitative research in which students are asked to reflect on how learning in the 3D virtual reality environment enhanced their self-efficacy level might provide further insights into the underlying psychological processes related to self-efficacy occurring during the 3D virtual reality-based instruction, as might expansion of the research to include meta-cognitive variables.

Spatial Orientation

The hypotheses of a direct positive relationship between usability and spatial orientation (H2) and an indirect relationship between 3D virtual reality features and spatial orientation also were confirmed (H_{01}). Our model explained 3% of the variance in spatial orientation, indicating that 3D virtual reality features play a significant role in enhancing students' spatial orientation ability. According to Thompson (2006), even a small effect size for a critical outcome can be very important. Spatial ability plays an important role in chemistry achievement (Mohler, 2006; Newcombe, Mathason, & Terlecki, 2002), and in our model, spatial orientation explained 34% of the variance in students' performance on the chemistry learning test. This finding is consistent with the model suggested by Salzman et al. (1999) that learners' characteristics mediate the learning process. Similarly, Dalgarno and Harper (2003) through their study have also

demonstrated that 3D virtual reality features can be leveraged to design learning tasks that involve students thinking in a 3D perspective.

Usability

The latent variable of usability was highly related to the variables of perceived meaningfulness and perceived ease of use. The latent variable of usability strongly mediated the relationship between the 3D virtual reality features and the variables of spatial orientation, self-efficacy, and presence. This finding suggests that the 3D virtual reality features can support the development of learners' spatial orientation ability, self-efficacy, and presence only when the learners' perceive the experience as meaningful and the system easy to use. This finding is consistent with the model proposed by Salzman et al. (1999) where learners' usability is another significant mediator in the learning process. This finding also resonates with the finding of other studies that have demonstrated the importance of considering task meaningfulness and ease to use computer interface (Davis, 1989).

Presence

The results confirmed the hypothesis of an indirect relationship between the 3D virtual reality features and presence as mediated by usability (H_{03}). This indicates that students who used the Second Life® environment to complete the learning activities perceived themselves as being in the environment. This finding is consistent with the finding of other studies (Hall, Wilfred, Hilgers, Leu, Walker, & Hortenstine, 2004; Winn, Windschitl, Fruland, & Lee, 2002) that 3D virtual reality features are capable of providing higher immersion levels.

On the other hand, the results did not support the hypothesis of a direct relationship between presence and the chemistry learning test (H7). This suggests that students' sense of presence was not related to their performance on the chemistry learning test. Currently, there are mixed results on the impact of presence on learning outcomes. For example, in a studies conducted by Lee et.al (2010) and Burgess (2010) there was a positive relationship between presence and learning outcomes, but Mania and Chalmers (2001) and Moreno and Mayer (2002) did not find statistically significant differences on learning outcomes measures of students when presence was manipulated by providing instruction in either higher or lower immersion level.

There could be several explanations of why the students' sense of presence was not related to chemistry learning in the present study. First, presence is an outcome of interaction between people and technology, which is an important component of instructional media. According to the literature on media effects on learning outcomes, media in and of itself cannot improve learning (e.g., Clark, 1989). Media should be used to design learning tasks in a way that best promotes interaction and engagement with the learning materials (Dalgarno, & Lee, 2010; Kozma, 1994). On the contrary, technological features supports the design of learning tasks that engages the learners in spatial instruction which were then instrumental in enhancing learning outcomes on chemistry test. Cognitive load theory (e.g., Schmidt-Weigand & Scheiter, 2011; Sweller, 1994; Van Merriënboer, & Sweller, 2005) provides a second possible reason for the failure to find the hypothesized relationship between presence and chemistry learning. The extraneous cognitive load of navigating the Second Life® environment

employed in this study may have been so complex that students did not have sufficient cognitive resources left to take full advantage of the activities provided. Thus, students could feel present in the environment without that presence translating into knowledge gains. Finally, it is possible that the presence measure used in this study did not optimally capture students' perceptions. Instruments to measure presence are limited and have received mixed reactions on their comprehensiveness (e.g., Usoh, Catena, Arman, & Slater, 2000; Witmer & Singer 1998; Slater, 2004).

Conclusions

This study supported the hypothesized model for how students interact with a 3D virtual reality environment, which consisted of perceived usability of the features of the environment, sense of presence in the environment, spatial orientation skills, and self-efficacy provided a good account of students' performance on the chemistry test. However, all data were collected from students of Chem 101 course at the university where the research was conducted. Therefore, the results may not be generalizable to the other content or students at other academic institutions. More studies need to be conducted in different contexts to replicate and generalize this study's results.

In spite of these limitations, our study makes an important contribution to the literature because it is the most comprehensive multivariate analysis of psychological and perceptual processes involved in learning chemistry in a 3D virtual learning environment and the first to test a model of chemistry learning in 3D environments to employ SEM. This study's results seem highly promising in designing learning environments using 3D virtual reality technologies such as Second Life® to enhance

student performance on the chemistry learning test. In addition, the findings have important implications for chemistry instructors. Many educators believe that VSEPR theory is fundamental, but also one of the most challenging concepts where students struggle to attain better understanding. Given the importance and complexity of VSEPR theory, the study results suggest an instructional strategy that chemistry educators can use to improve their students' chemistry achievements. Many 3D virtual reality environments such as Second Life® have features that can support the design of learning tasks that can enhance students' spatial ability and improve learning outcomes. Therefore, chemistry educators and other science educators would be well advised to embed spatial training into the curriculum when teaching concepts that involve three-dimensional thinking.

Understanding spatial relationships is imperative for improving performance on many other science-related concepts. Our model is highly applicable to all the science-related instruction that involves understanding spatial relationships. The findings of this study inform us of the potential of a 3D virtual reality environment like Second Life's to enhance undergraduate student performance on VSEPR theory. In addition, this model could be applied to design instruction to science-related topic that involves imparting spatial instruction. It should be noted, however, that direct experimental tests of these implications are needed.

CHAPTER IV
EXPLORING 3-D VIRTUAL REALITY TECHNOLOGY FOR SPATIAL ABILITY,
SELF-EFFICACY, AND CHEMICAL ACHIEVEMENT

Introduction

Freshman chemistry courses have goals to build the students' foundational knowledge of thinking as a chemist. Instructors use 2-D images and 3-D physical balls and sticks as tools to visually represent molecular structures and geometry. Then, students must mentally translate those visual representations of molecular structures to interpret complex processes and spatial relationships. Spatial abilities are used to translate chemical formulae into molecular structures, visualize possible 3-D configurations, and compare these configurations across different molecular structures. Therefore, the ability to comprehend and mentally manipulate molecular structures is critical for students to understand fundamental concepts and conduct advanced scientific research (Wu & Shah, 2004). Mathewson (1999, p. 36) stated that "A spatial image preserves relationships among a complex set of ideas as a single chunk in working memory, increasing the amount of information that can be maintained in consciousness at a given moment." It is this integration of information that is critical in understanding complex molecular structures and bond angles. To facilitate student understanding of many chemistry related concepts, it is important to enhance students' spatial abilities.

Recent reviews allude that students with low spatial ability find learning chemistry highly challenging, which in turn, adversely affects their achievement (Gilbert & Boutler, 2000). Students' difficulty in learning chemistry concepts may also influence

their self-efficacy (Oliver & Simpson, 1988; House, 1993). Research reports suggest that psychological factors such as self-efficacy act as catalysts in expediting the learning process (Lapan, Shaughnessy & Boggs, 1996; Tymms, 1997). Therefore, for students with low spatial ability, their self-efficacy may decrease, which in turn may further deteriorate their chemistry achievement. Consequently, educators must consider embedding spatial training in their instruction which may impact their self-efficacy, and academic achievement.

One of the most vital and promising affordances of the virtual reality technologies is to provide spatial instruction. According to Moore (1995) "...by teaching the students to think in 3-D using visualization techniques, their spatial cognition can be enhanced" (p. 5). Similarly, Hedberg and Alexander (1994) who emphasized the benefit of using 3-D virtual reality environment stated, "As ideas are represented in a three dimensional world, three dimensional thinking can be enhanced, and the mental transformation of information from two to three dimensions can be facilitated" (p. 216). Dalgarno, Hedberg, and Harper (2002) propose that "If 3-D environment is a metaphorical representation of abstract ideas, it may be that by developing an integrated database of two dimensional views of a three dimensional model of the concepts, we are better able to make sense of the concepts than through other instructional approaches" (p. 8). As espoused by these scholars, one of the critical features of 3-D virtual reality environments is the ability to visually depict and interact with spatial representations of abstract concepts. Therefore, this feature of 3-D virtual environments can be useful in providing instruction for developing spatial ability.

Significance of Spatial Ability in Chemistry Achievement

Researchers have understood spatial ability as a complex and multifaceted skill. Lohman (1988) has differentiated spatial ability into ten components; perhaps his categorization is the most extreme division of the spatial ability's components. More commonly, researchers have isolated the components in three major areas: spatial visualization, spatial orientation, and spatial relation (Ekstrom, French, Hartman, & Dermen, 1976; Robichaux, & Guarino, 2000; Pellegrino & Hunt, 1991; Pellegrino & Kail, 1982). However, there is a considerable overlap in the definitions of spatial orientation and spatial visualization, leading the researchers to consider only two major components of spatial ability: spatial relation and spatial orientation (Harle, & Towns, 2011; Coleman & Gotch, 1998; Mohler, 2008; Piburn, Reynolds, McAuliffe, Leedy, Birk, & Johnson, 2002).

Spatial relation is the ability to mentally rotate an object on its axes (Shepard & Cooper, 1982). Spatial orientation is the ability to mentally manipulate or transform an object into another arrangement (Ekstrom et. al, 1976). Studies in the literature have found positive correlation between the components of spatial ability measures and academic performance. Carter, La Russa and Bodner (1987) in their study found that undergraduate students who scored high on spatial ability tests also scored high on the chemistry performance test. Bodner and Guay (1997) and Tuckey, Selvaratnam, and Bradley (1991) in separate studies found statistically significant relationship between the measure of spatial relation and the chemistry tests. Therefore, it can be concluded that

both the component of spatial ability: spatial relation and spatial orientation play a significant role in chemistry performance.

Upon recognizing the importance of spatial ability in chemistry, researchers have designed studies to examine whether instruction can enhance spatial ability. Barnea and Dori (1999) used computer molecular modeling (CMM) virtual reality software with a group of 10th grade students to embed spatial instruction in teaching structure and bonding of molecules, while the other group was given traditional instruction using plastic ball and stick models. They found that the group who was given CMM-based instruction outperformed the control group on the spatial ability and the chemistry performance tests. Another study with 11th grade high school students in an organic chemistry class, Copolo and Hounshell (1995) used the computer program, Molecule Editor, to impart spatial training. They compared the impact of their instruction with three control groups using: 2-D textbook representations, 3-D ball and stick models, and a combination of 3-D ball and stick and computer models. Their study's results indicated that students receiving a combination of the instructional approaches scored higher on the isomeric identification test, but on a 2-D version of the same test, the group receiving training with 2-D textbook representations had the highest mean score. Ferik Savec, Vrtacnik, and Gilbert (2005) also investigated the impact of spatial training on secondary school students and found that the training with 3-D representations was more superior in improving students' performance on the molecular visualization test. Moreover Ozmen (2008), in a quasi-experimental study with 11th grade students found statistically

significant differences in the performance of the students with the results favoring the experimental group.

More recently, Urhane, Nick, and Schanze (2009) used CHEMnet to embed spatial training while teaching a module on the modification of carbon to a freshman class. They compared the effects of 3-D simulations against 2-D images and found no difference in the knowledge gains of both groups. Limniou, Roberts, and Papadopoulos (2008) used 3-D molecular representations with college students to teach the reactive properties of solutions and compounds. However, they provided two kinds of instruction to the same group of 14 students. This instruction included 2-D images and 3-D interactive representations of molecular structures. During the exploration of 3-D interactive virtual reality training session, students used many peripheral devices such as a glass cubicle, shutter glasses, and joystick. Their study found that students comprehended the process of reaction better after receiving training in 3-D virtual reality environment.

Current research literature on the impact of 3-D virtual reality environment use for spatial training seems inconclusive. The studies discussed above were mostly conducted with high school students and very few with college undergraduate students. In addition, these studies demonstrated that the 3-D environment is superior to the traditional approach, but the instructional advantage of 3-D environment over 2-D images is still ambiguous. Therefore we raise the following questions to be answered in our study.

Purpose

The purpose of this study is to explore the effectiveness of a Second Life virtual environment to enhance undergraduate chemistry students' spatial ability, self-efficacy, and chemistry achievement. The VSEPR theory is a foundational concept in the field of chemistry that gives an explanation of the 3-D nature of molecules, which is critical for understanding the physical and chemical properties of chemicals. It was hypothesized that the 3-D virtual learning environment would enhance students' learning and self-efficacy.

Method

The data collected from the Second Life group, along with other data that were only available for that group, were used in an article by Authors, (2012) in which a theoretical model of learning in 3-D virtual learning environments was evaluated using structural equation modeling.

Design and Participants

This study used a pretest/posttest control group quasi-experimental design, where the morning section of the course was randomly assigned to the experimental condition of 3-D virtual environment-based instruction, and the afternoon section to the 2-D images-based instruction. The same instructor presented the class lectures to both groups. The treatment condition consisted of the experimental group completing three assignments in Second Life and the control group completed the same assignments using 2-D images.

The study's participants were 403 undergraduates enrolled in two sections of the Chemistry 101 course at a large Southwestern university. Of the 403 students enrolled in the course, 2 choose not to participate in the study and another 6 dropped the class. Further, 11 students were dropped from the study because they completed the set of tasks out of order. The final sample consisted of 384 participants of whom 64% were female and 36% were male. Most of the participants' (91%) age ranged between 18-21 years. They were mostly Caucasians (73%) or Hispanic (15%). A total of 23% identified themselves as proficient gamers, and 3% of the students had some prior experience with Second Life. More descriptive statistics can be found in Table 6. Chi square analyses revealed that students who were not included in the study did not differ from students who were included on the demographic variables.

Table 6
Demographic statistics study's participants included in the ANCOVA analysis

Variable	Groups	Experimental	Control	Total
		N	N	N
Gender	Male	68	70	138
	Female	136	108	244
Age	< 18	4	4	8
	18 – 21	188	163	351
	22 -25	9	9	18
	26 – 30	3	3	6
	>30	0	1	1
Race/ Ethnicity	Caucasian	146	136	282
	Hispanic	34	24	58

Table 6: Continued

		Experimental	Control	Total
Variable	Groups	N	N	N
	Asia/Pacific Islander	15	12	27
	African American	3	6	9
	American Indian/Native Alaskan	2	0	2
	Others	4	2	6
SL experience	I have never heard of Second Life.	151	102	253
	I have heard about it, but had never entered that virtual world.	42	73	115
	I am familiar with the Second Life Environment and had created an avatar, but I consider myself a beginner in Second Life.	7	5	12
	I have spent a lot of time exploring the Second Life environment.	2	0	2
Gaming experience	Yes	43	44	87
	No	161	136	297
Years of gaming experience	0-1 year	90	98	188
	2-5 year	29	17	46
	More than 5 years	67	59	126

Measures

The three measures of learning outcomes were administered twice, before and after the intervention. A self-report instrument measuring students' self-efficacy levels was administered only after the intervention. These measures were the VSEPR Theory test, the Card Rotations Test (CRT), and the Purdue Visualization of Rotations test (PVRT).

The VSEPR test consisted of 11 knowledge-based multiple-choice questions of students' knowledge of VSEPR theory. Answering the questions required the students to mentally rotate 3-D molecular structures using 2-D perspective drawings (See Appendix A). This test covered three components of VSEPR theory. The Molecule Angles section consisted of three questions on identifying 2-D line/wedge drawings of 3-D molecules. In the Molecular Geometry section, students had to answer four questions covering the topic of molecular geometry from 2-D pictures of 3-D molecules. The Species Identification section entailed four questions encompassing the concept of species determination from 2-D pictures of 3-D molecules. Participants obtained one point for every question answered correctly.

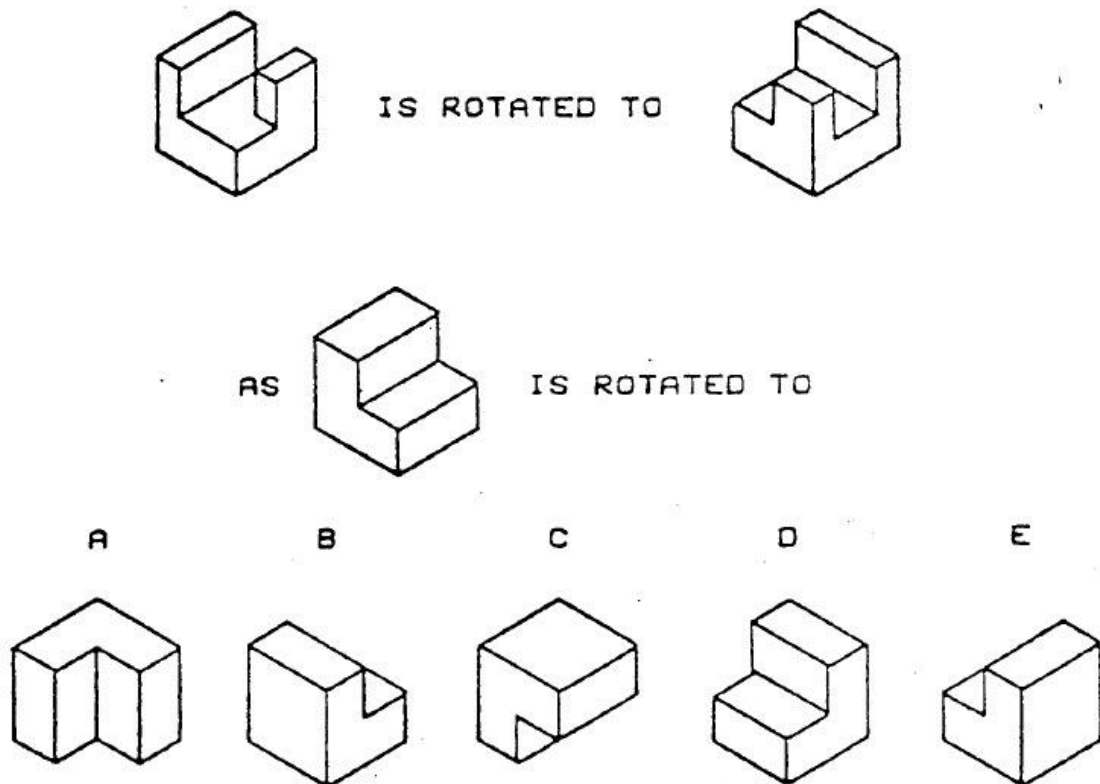
The VSEPR test was developed by the instructor. Three chemistry professors reviewed this test to ensure its content validity. A pilot study was conducted with 53 students who had previously taken Chem102 from the same instructor. The coefficient alpha reliability for the score of the pilot study was 0.87.

The Card Rotations Test (CRT) is a 2-D mental rotation test in which participants see a 2-D target object with 8 other objects and respond whether each of those 8 were

either rotated or a mirror image (Ekstrom et. al, 1976). This is a paper-based test with 20 items that must be completed in 6 minutes. Its coefficient alpha for in the present study was 0.80. This test was administered before and after the intervention.

The Purdue Visualization of Rotations test (PVRT), a 20 question test developed by Bodner and Guay (1997), is a widely used measure of spatial ability in chemical education. PVRT items are analogy problems in which students are asked to perform the rotation that is shown at the top of the item, choosing from the five options shown at the bottom. Thus in the problem shown in Figure 19, option D is the correct answer. It has consistently demonstrated a good reliability (KR20) index in many contexts ranging from 0.78 – 0.80. The Cronbach alpha reliability coefficient for the present study was 0.77. Participants are asked to select the correct rotated version of a given 3-D object from five alternatives. Participants are allotted ten minutes to complete 20 questions. This study's participants completed the test before and after the intervention.

Figure: 19:
An example of test question from Purdue Visualization of Rotation test



The self-efficacy measure (see Appendix A) consisted of 15 items adapted from the instrument developed by Witt-Rose (2004). The instrument was considered the most comprehensive and appropriate to measure learners' self-efficacy level in the context of this study. Items for all the above measures were based on the Likert scale of "Strongly Disagree" (1) to "Strongly Agree" (5). The only modification made to this instrument was to reflect the concepts being learned. For example, "I am confident I can understand the material taught in anatomy and physiology (A&P)" was revised to "I am confident I

can understand the material taught about VSEPR theory.” More details for each measure are provided in Appendix A. The Cronbach’s alpha reliability coefficient for the present study was 0.91.

Instructional software

Second Life®, an innovative 3-D technology, launched by Linden Labs in 2003 was used to provide spatial instruction to this study’s participants. This internet-based immersive virtual environment allows its users, who are called residents, to interact within this environment by creating their digital self-representation, called an “avatar” (Second Life.com). Second Life also has the ability to build 3-D virtual objects (molecules in this instance). Other interactive features include the ability to interact with the object by zooming in and out, rotating the object, and programming the objects to behave in a certain manner. Currently, there are two spaces in Second Life that exhibit fundamental chemistry concepts: Drexel University’s simulation on chemical solubility testing and Texas A&M University’s Dr K’s Chemistry Corner on molecular structures.

Texas A&M University’s Dr K’s Chemistry Corner

Dr. Wendy Keeney-Kennicutt from the Chemistry department has built a corner in SL (<http://slurl.com/secondlife/12thMan/213/239/26>). Students were familiarized with the environment of SL and its features, using seven introductory videos specifically developed for this study. Later students completed three assignments in Second Life using the simulations called Molecule Game, The Chemist as an Artist, and The Tower of VSEPR Theory.

The Molecule Game was designed for students to develop Second Life skills and see molecules in 3-D from multiple perspectives. Students had to “rez” (i.e., make an object appear in the Second Life environment) a molecule and answer a question at five different stations to complete this activity. Finally, students emailed their avatar’s picture to the instructor doing the activity.

The Chemist as an Artist was a simulation designed to develop more Second Life skills and further develop students’ ability to see molecules in 3-D perspective by copying, linking, and rotating molecules. The students then had to translate the molecules into 2-D perspective drawings. The students were given three molecules to manipulate in Second Life. For each molecule, they were required to provide a photograph of themselves with two orientations of their molecule, and a 2-D drawing of each orientation using solid lines, wedges, and dashed lines.

The Tower of VSEPR simulation was designed to deepen students’ understanding of VSEPR Theory. During this activity students rezzed 11 different molecules to measure bond angles, determine geometry, and Lewis dot structures. At the end of the activity students completed a VSEPR report on their 11 molecules.

Procedure

The study began in the fifth week of the semester. The instructor informed both the sections of Chemistry 101 class about the study as a special project to be conducted during the semester. Both the sections students received handout respective to their group membership, containing all the details of this project (i.e. activities to be performed, assignments, credit assigned for the completion of the activities). During the

first week participants completed the Purdue Visualization of Rotations Test and the Card Rotations Test. In the following two weeks participants completed the instructional activity of the Molecule Game. During the seventh week participants completed the VSEPR Theory test. In the ninth week of the class participant completed the activity of The Chemist as an Artist. In the tenth week the participants began the instructional activity of The Tower of VSEPR Theory, which continued for three weeks. In the 13th week participant took the two posttest of spatial ability: Purdue Visualization of Rotations Test and the Card Rotation Test, complete the survey, and the long report on VSEPR theory. In the 14th and the final week of this study students will completed the VSEPR Theory posttest.

Three doctoral students observed the instructor to judge instructors' consistency on various factors in teaching both the sections. The observers were from civil engineering, entomology, and computer science majors with 1 to 3 years of teaching experience. They observed the instructor for four consecutive classes on the VSEPR theory. The inter rater reliability of the observers' ratings ranged between 75% - 100%.

Results

Means and standard deviations for the pretest scores are shown in Table 6. Independent-sample *t* tests were conducted to examine preexisting differences between the 3-D virtual reality (experimental) group and the 2-D images (control) group on the three components of the VSEPR learning test (i.e. VSEPR- Molecule Angles, VSEPR- Molecular Geometry, VSEPR-Molecular Geometry) and the PVRT and CRT, which

measured spatial learning . The results depicted in Table 7 show that there were no statistically significant differences in the pretest scores of any of the measures.

The posttest scores of the 3-D virtual environment group and the 2-D images group on the three VSEPR subtests, PVRT, and CRT are also presented in Table 6 along with the results of one-way ANCOVAs with pretest and self-efficacy as a covariate. As shown in the table 6, there were no statistically differences between the groups for any of the measures when pretest or self-efficacy scores were included as a covariate.

Table 7
Pretest and posttest scores analysis
Pretest scores on measures of learning outcomes

Variables	<u>Experimental</u>		<u>Control</u>		<i>t</i>	<i>df</i>	<i>p</i>
	Mean	<i>SD</i>	Mean	<i>SD</i>			
VSEPR-Molecule Angles	0.15	0.39	0.19	0.50	-1.20	288	0.23
VSEPR-Molecular Geometry	2.21	1.07	2.21	1.06	-2.21	288	0.27
VSEPR-Species Identification	0.90	0.81	0.99	0.86	1.04	288	0.29
CRT Pretest	103.93	27.90	107.92	30.40	1.34	288	0.18
PVRT Pretest	11.71	3.78	12.01	3.48	-0.65	288	0.51

ANCOVA results of pre-test as a covariate.

	<u>Experimental</u>		<u>Control</u>		<i>F</i>	<i>p</i>	Adjusted <i>R</i> ²
	Mean	<i>SD</i>	Mean	<i>SD</i>			
VSEPR- Molecule Angles	0.92	1.12	0.78	1.08	2.41	0.12	0.08
VSEPR-Molecular Geometry	3.53	1.27	3.59	1.23	0.19	0.66	0.06

Table 6. Continued

	<u>Experimental</u>		<u>Control</u>		F	p-value	Adjusted R square
	Mean	SD	Mean	SD			
VSEPR-Species Identification	1.27	1.04	1.16	0.98	1.01	0.31	0.09
CRT Post test	127.28	29.18	127.34	29.03	0.03	0.86	0.51
PVRT Post test	11.71	4.00	11.71	4.00	0.00	0.97	0.24

ANCOVA results of self-efficacy as a covariate.

	<u>Experimental</u>		<u>Control</u>		F	p-value	Adjusted R square
	Mean	SD	Mean	SD			
VSEPR- Molecule Angles	0.92	1.12	0.78	1.08	3.05	0.08	0.19
VSEPR-Molecular Geometry	3.53	1.27	3.59	1.23	0.01	0.90	0.14
VSEPR-Species Identification	1.27	1.04	1.16	0.98	1.31	0.25	0.06
CRT Post test	127.28	29.18	127.34	29.03	0.76	0.38	0.01
PVRT Post test	11.71	4.00	11.71	4.00	0.01	0.91	0.04

Discussion

The current study used the 3-D virtual environment of Second Life to enhance freshmen students' spatial ability and chemistry-related achievements. Many chemistry concepts such as the VSEPR theory are abstract and complex to understand. The virtual environment like Second Life has the affordances to represent the molecule structures in 3D space. This can allow students to visual the concept and interact with these structures to deepen the understanding of the concept.

This study failed to support the hypotheses that chemistry instruction presented in a 3-D virtual environment provided by Second Life® would enhance spatial ability as measured by CRT and PVRT compared to 2-D images-based instruction as well as self-efficacy. There are several possible explanations for this finding. First it is likely that extraneous cognitive load navigating the 3-D virtual environment of Second Life may have been so complex that students did not have sufficient cognitive resources left to take full advantage of the activities. This may have interfered in enhancing learning gains derived from students' interaction with 3-D virtual environment. Thus espoused by scholars who proposed the cognitive load theory, it is essential that researcher must take into account the technological load the learners will be facing before interacting with the actual learning materials (Schmidt-Weigand & Scheiter, 2011; Sweller, 1994; Van Merriënboer & Sweller, 2005).

The first reason may feed into the second possible explanation of this finding. Because students who completing the Second Life activities devoted their time to familiarizing themselves with the navigation of this environment, they probably needed more time to focus on the instructional activity compared to the group who working completing paper-based assignment. Researchers have discussed the importance of considering the instructional time for learning benefits (Vincent & Braman, 2010). Therefore, it is likely that the instructional time provided in the study could have been longer in order to find differences in students learning achievements.

Importance of this study

Improving science academic achievements has been a great concern for educators. Our study contributed by highlighting the importance of considering students prior experience with the technology to be used for instruction. Sophisticated technology such as Second Life can pose extraneous cognitive load on the students and this can interfere in their learning. Additionally, it is importance that chemical educators can carefully determine instructional time when imparting instruction.

Future studies must be conducted to examine the unique impact of 3-D virtual environment-based instruction compared to the other forms of instruction with more extensive treatment time. Also, in future result could be analyzed controlling the impact of classroom instruction to examine the impact of 3-D virtual environment-based instruction.

CHAPTER V

SUMMARY AND CONCLUSION

The use of 3-D virtual reality-based instruction such as virtual worlds, games, and simulations in K-12 and higher education is rapidly increasing. These forms of learning environments seem to be promising in enhancing the instructional effectiveness, but they are still in their infancy stage. It is imperative that educational technology researchers focus more attention on the design of 3-D virtual environments because technology in itself does not promote learning effectiveness; it is the affordances of environment that lends itself to the design of the learning environment which in turn supports students' learning.

Three manuscripts employing three different quantitative approaches to the study of learning in 3-D virtual reality-based were presented in this dissertation: a meta-analysis of instructional effectiveness of 3-D virtual reality-based instruction in promoting learning in K-12 and higher education, a test of a theoretical model of the impact of a 3-D desktop virtual reality environment on the learner characteristics (i.e. perceptual and psychological variables) that can enhance chemistry-related learning achievements in an introductory college chemistry class using structural equation modeling, and a quasi-experimental study of the effectiveness of an implementation of a 3-D virtual reality environment in the learning of a major concept in college chemistry. The results of each of these studies are informative, but they did not converge, illustrating the complexity of the learning process in the 3-D virtual environment.

Chapter II presents a meta-analysis of the studies conducted to test the instructional effectiveness of the virtual reality-based instruction on learning outcome measures in K-12 or higher education settings. It also discusses the effect of design features that moderates the effect of instruction on learning achievement. Often there is a tendency to focus on the technological features without understanding the instructional need. As an instructional designer of the virtual environment it is imperative that one must understand how the technological features available within the virtual environment can lend itself to learning needs. Therefore, the main purpose of this section was to identify design features by which instructional designers can embed in virtual reality-based instruction to enhance learning effectiveness.

This study found that virtual worlds and simulation are equally effective and more effective than games. Key finding included that students performance did not differ based on type of learning outcome measures. This indicates that virtual reality technology is suitable to improve students learning outcomes that can be assessed using knowledge, skill or abilities-based measures. Further, elaborate explanation was the most effective form of feedback. This highlights the importance designing feedback system in a virtual reality-based instruction that provide students sufficient information about the reasons of correct/incorrect responses. In addition, virtual reality-based instruction was most effective when delivered as stand-alone instruction. This result suggests instructional designer must consider using virtual reality incorporating a unit or a course rather than an activity. Finally, students performed better in a collaborative environment compared to individualized learning environment. This result suggest that as informs the

instructional designer that collaborative environment such as multi-user virtual environment allows students to interact with other students to exchange ideas, resolves dissonance, and conceptualize understanding.

Chapter III presents a study that examined a theoretical model of relationships among the features of 3-D desktop virtual reality environment, learner characteristics (i.e., perceptual and psychological variables, and chemistry-related learning achievements in an introductory college chemistry class. Structural equation modeling analysis was used to test the model.

The model was designed to explain how features of a 3-D virtual reality environment and of learners' experiences in the environment

The findings emphasize that instructional designers can utilize 3-D virtual reality features to design spatial instruction which is significantly related to the academic achievement in many STEM related concepts.

This research found support for the predictions that 3-D virtual environment such as Second Life can provide learning environment wherein students' can enhance their spatial ability and self-efficacy levels. This study also found that students' spatial ability and self-efficacy can support students chemistry related achievements.

Chapter IV reports the result of the investigation of the potential of Second Life® (SL), a 3-D virtual world, to enhance undergraduate students' learning of a major chemistry concept. A quasi-experimental research design was used to examine whether there was a difference between the academic achievements of students who were given 3-D virtual reality-based intervention vs. those given 2-D images. The study found that

both the groups performed equally well on the learning outcome measures of the VSEPR theory test, PVRT, and CRT. There was no difference in the self-efficacy levels based on the type of intervention. The findings suggest that 3-D virtual environment was equally effective to enhance students' spatial ability levels, chemistry performance, and self-efficacy levels.

The three approaches to studying the effectiveness of 3-D virtual environment-based learning employed in this dissertation provide complementary perspectives on the issue, each with the potential to their findings are not easily reconciled. Nevertheless, each contributes to our understanding of learning processes and outcomes using these technologies. The quest for a better understanding of the complexities of how learners and instructors use such technology demands that we use every weapon in the researchers' arsenal. The methodologies of the three studies reported in this dissertation are by no means exhaustive of the ways researchers can approach the issue, but they do provide a road map of how these technologies can be best utilized to support students learning needs.

The meta-analysis provides a combined estimate of the overall effect sizes of the studies that examined the relationship between 3-D virtual environment features and learning outcome measures. Based on the meta-analysis study of the current research implications for instructional designers were addressed. This meta-analysis built on the previous meta-analysis conducted on this topic. In addition, there were several variables such as feedback, design quality, kinds of instrument, modes of instruction, and time of administration that not analyzed in previous meta-analysis. Therefore, this meta-analysis

sheds light on the effectiveness of selected design principles on the learning effectiveness. However, within the outcome there was a need to further explore the underlying learning processes that occur during 3-D virtual reality-based instruction so that design implications can be deciphered. The second manuscript analyzed the data from a freshman chemistry who instructed in 3-D virtual environment of Second Life for spatial and chemistry instruction using structural equation modeling analysis. The third manuscript investigated the achievement differences between those students who were given 3-D virtual reality based instruction and those who were given 2-D images based intervention.

Several limitations should be kept in mind when interpreting these results. With regards to the meta-analysis, studies that might have altered results may not have been included because they were not found during the search process, despite the elaborate search procedures used to ensure that most of the studies were included in the analysis. In terms of the second and third study, with regards to external validity, generalizability of the results is limited because the sample was taken from a single large southern university, and learning outcomes were restricted to a single concept in college chemistry. In addition, the SEM study used self-report measures that were based on subjective experiences and personal judgment. Future research is encouraged to gain a more thorough understanding of the complexity of how 3-D virtual reality affordances can be utilized to enhance instructional effectiveness and learning achievements. Researchers should report more details about the learning environment features for further meta-analysis purposes.

This dissertation contributes findings to the body of research analyzing the effectiveness of 3-D virtual reality-based instruction for promoting learning outcomes. Useful information was presented related to the relationship between different design features and its relationship with the learning outcome measures. Based on this result certain design features were used to test its effectiveness in enhancing chemistry related achievements. This study also determined if 3-D virtual reality-based features were effective compared the 2-D images based instruction. These findings should be further validated and explored in the future studies.

These studies highlight the importance for designers of 3-D virtual environment to carefully consider various design features. A vigilant and conscience selection of design features is imperative to enhance instructional effectiveness. It is highly recommended that designers of 3-D virtual environment consider specific design features based on the instructional need.

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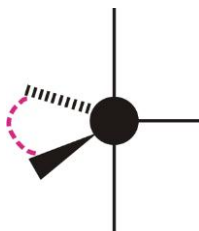
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APPENDIX A

ITEMIZED DESCRIPTION OF EACH INSTRUMENT

Variables	Items	Source
Chemistry Learning Test	<p>1. A typical 3-dimensional representation of a molecule in 2-dimensional space uses wedges for bonds coming toward the viewer, dotted lines for bonds going away from the viewer and lines for bonds in the plane of the paper. What is the bond angle (rounded to the nearest whole number) expressed by the red dotted line in this molecule?</p>	Self-developed

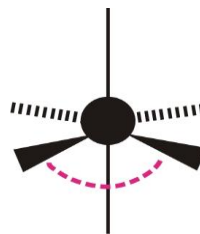


- a) 30° b) 45° c) 60° d) 90° e) 109° f) 120° g) 150° h) 180°

Correct Response: 120°

2. A typical 3-dimensional representation of a molecule in 2-dimensional space uses wedges for bonds coming toward the viewer, dotted lines for bonds going away from the viewer and lines for bonds in the plane of the paper. What is the bond angle (rounded to the nearest whole number) expressed by the red dotted line in

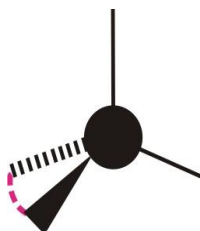
this molecule?



- a) 30° b) 45° c) 60° d) 90° e) 109° f) 120°
g) 150° h) 180°

Correct Response: 90°

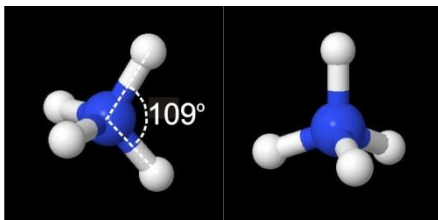
3. A typical 3-dimensional representation of a molecule in 2-dimensional space uses wedges for bonds coming toward the viewer, dotted lines for bonds going away from the viewer and lines for bonds in the plane of the paper. What is the bond angle (rounded to the nearest whole number) expressed by the red dotted line in this molecule?



- a) 30° b) 45° c) 60° d) 90° e) 109° f) 120°
g) 150° h) 180°

Correct Response: 109°

4.

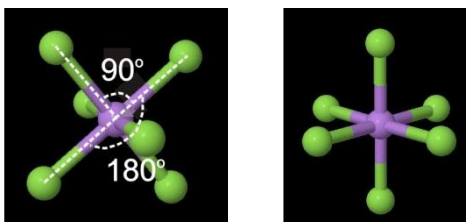


You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

- a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: tetrahedral

5.



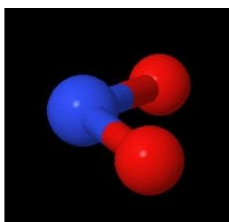
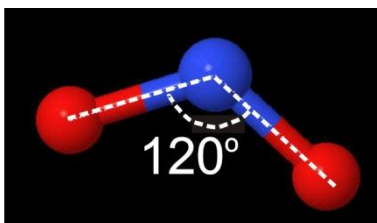
You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

- a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g)

square pyramidal h) trigonal pyramidal i)
pentagonal j) tetrahedral h) T-shaped

Correct Response: octahedral

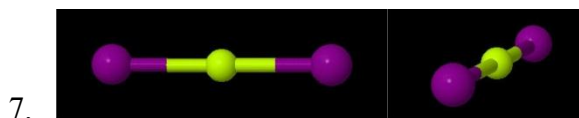
6.



You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

- a) bent or angular b) quadrangular c) triangular
- d) hexagonal e) see-saw f) trigonal bipyramidal
- e) linear g) square planar h) trigonal planar
- i) octahedral g) square pyramidal
- h) trigonal pyramidal i) pentagonal
- j) tetrahedral h) T-shaped

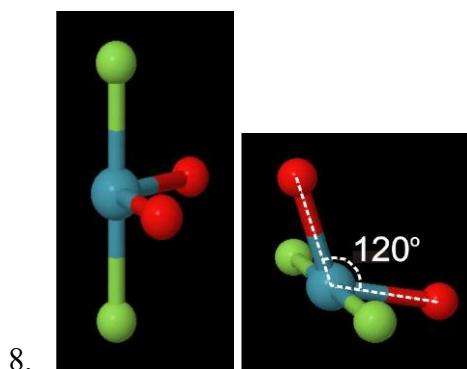
Correct Response: bent or angular



You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

- a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: linear



You are given two 3-dimensional views of the same species. Pick the correct molecular geometry.

- a) bent or angular b) quadrangular c) triangular d) hexagonal e) see-saw f) trigonal bipyramidal e) linear g) square planar h) trigonal planar i) octahedral g) square pyramidal h) trigonal pyramidal i) pentagonal j) tetrahedral h) T-shaped

Correct Response: see-saw

9.

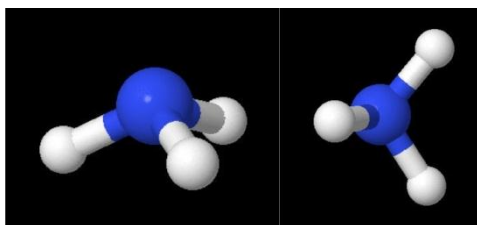


You are given two 3-dimensional views of the same species. Ignore the atom colors. Pick ALL the species that has/have that shape. There may be more than one.

a) H_2S b) SO_2 c) BeF_2 d) CO_2 e) BrF_2^- d) H_2O e) CaCl_2

Correct Response: BeF_2 , CO_2 , BrF_2^-

10.

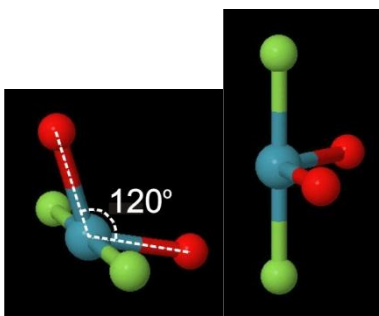


You are given two 3-dimensional views of the same species. Ignore the atom colors. Pick ALL the species that has/have that shape. There may be more than one.

a) BF_3 b) PBr_3 c) CO_3^{2-} d) BrF_3 e) NH_3 f) FeCl_3
g) H_3O^+

Correct Response: PBr_3 , NH_3 , H_3O^+

11.



You are given two 3-dimensional views of the same

species. Ignore the atom colors. Pick ALL the species that has/have that shape. There may be more than one.

a)CF₄ b) SCl₄ c) NH₄⁺ d) SnCl₄ e) AsF₄⁻ f) SiH₄ g) BrF₄⁺

Correct Response: SF₄, BrF₄⁺

Representational Fidelity	<ol style="list-style-type: none">1. When I was doing my class assignments on VSEPR theory, there was a direct close connection between my actions/key strokes/mouse clicks and expected changes of the molecular structures. (realism factor)2. The visual display quality of the molecular structures distracted me from performing the assigned tasks on VSEPR theory. (realism factor)3. There were times when the molecules became more real and present for me compared to the real world (realism factor).4. The molecules seemed like the real molecules to me (realism factor).	Witmer & Singer 1998
Learners' interaction	<ol style="list-style-type: none">1. I was able to examine the molecular structures closely (Control Factor).2. I was easily able to examine the molecular structures from multiple viewpoints (Control Factor).3. I was easily able to move and manipulate the molecular structures very easily (Control Factor).	Witmer & Singer 1998
Perceived Ease of Use	<ol style="list-style-type: none">1. I found the molecules cumbersome and awkward to use.2. Learning to interact with the molecules was easy for me.3. Interacting with the molecules is often frustrating.4. I found it easy to get the molecules to do what I wanted them to do.5. The molecular structures were rigid and inflexible to interact with.	Davis 1989

	<ol style="list-style-type: none"> 6. It is easy for me to remember how to perform tasks. 7. Interacting with molecular structures requires a lot of mental effort. 8. My interaction with the molecular structures was intuitive and easy to figure out. 	
Perceived Meaningfulness	<ol style="list-style-type: none"> 1. Using the molecular structures improved the quality of my understanding of VSEPR theory. 2. I felt that I was in control of my own learning about VSEPR theory using the molecular structures. 3. The molecules enabled me to accomplish the task of learning about VSEPR theory easily. 4. The molecules helped me learn about a very important topic, VSEPR theory. 5. Using the molecules as an effective way to learn about VSEPR theory. 6. Using the molecules improved my class performance on VSEPR theory. 7. Using the molecules allowed me to learn more about VSEPR theory than would otherwise be possible. 8. Using the molecules enhanced my effectiveness in learning about VSEPR theory. 9. Using the molecules makes it easier to do my school work on VSEPR theory. 10. Overall I found the molecules useful in my school work on VSEPR theory. 	Davis 1989
Self-efficacy	<ol style="list-style-type: none"> 1. I am confident I have the ability to learn the material taught about VSEPR theory. 2. I am confident I can do well on exam questions about VSEPR theory. 3. I think I will do as well or better than other students on exam questions about VSEPR theory. 4. I don't think I will be successful on exam questions about VSEPR theory. 5. I am confident that I can understand the topics taught about VSEPR theory. 6. I believe that if I exert enough effort, I will be successful on the exam questions about VSEPR theory. 	Witt-Rose (2004)

7. I can characterize a molecule or ion as obeying or disobeying the octet rule.
8. I feel like I don't know a lot about VSEPR theory compared to other students.
9. Compared with other students in this class, I think I have good study habits.
10. Compared with other students in this class, I don't feel like I'm a good student.
11. I am confident I can do well on the exam questions about VSEPR theory.
12. I am confident I can do well on the lab experiment dealing with VSEPR theory.
13. I think I will receive a B or better in Chem 101.
14. I don't think I will get a good grade the exam questions dealing with VSEPR theory.
15. I am confident that I could explain concepts on VSEPR theory learned in this class to another person.

Presence

1. I had a sense of being there when I explored the molecular structures.

Slater &
Usuh,1994
