12-1-2017

Using Two Simulation Tools to Teach Concepts in Introductory Astronomy: A Design-Based Research Approach

Pamela A. Maher
University of Nevada, Las Vegas

USING TWO SIMULATION TOOLS TO TEACH CONCEPTS IN INTRODUCTORY ASTRONOMY: A DESIGN-BASED RESEARCH APPROACH

by

Pamela A. Maher

Bachelor of Arts in Art Education
Oregon State University, Corvallis, Oregon
May 1977

Master of Arts in Teaching, Art Education
Lewis and Clark College, Portland, Oregon
May 1984

A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy - Curriculum and Instruction

Department of Teaching and Learning
College of Education
The Graduate College

University of Nevada, Las Vegas
December 2017

UNLV | GRADUATE COLLEGE

Dissertation Approval

The Graduate College
The University of Nevada, Las Vegas

September 22, 2017

This dissertation prepared by

Pamela A. Maher

entitled

Using Two Simulation Tools to Teach Concepts in Introductory Astronomy: A Design-Based Research Approach

is approved in partial fulfillment of the requirements for the degree of

Doctor of Philosophy - Curriculum and Instruction
Department of Teaching and Learning

Janelle M. Bailey, Ph.D.
Examination Committee Co-Chair

Hasan Deniz, Ph.D.
Examination Committee Co-Chair

P.G. Schrader, Ph.D.
Examination Committee Member

Dale Etheridge, Ed.D.
Examination Committee Member

Doris Watson, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Dean

ABSTRACT

Technology in college classrooms has gone from being an enhancement to the learning experience to being something expected by both instructors and students. This design-based research investigation takes technology one step further, putting the tools used to teach directly in the hands of students. The study examined the affordances and constraints of two simulation tools for use in introductory astronomy courses. The variety of experiences participants had using two tools; a virtual reality headset and fulldome immersive planetarium simulation, to manipulate a lunar surface flyby were identified using a multi-method research approach with *N* = 67 participants. Participants were recruited from classes of students taking astronomy over one academic year at a two-year college. Participants manipulated a lunar flyby using a virtual reality headset and a motion sensor device in the college fulldome planetarium. Data were collected in the form of two post-treatment questionnaires using Likert-type scales and one small group interview. The small group interview was intended to elicit various experiences participants had using the tools. Responses were analyzed quantitatively for optimal flyby speed and qualitatively for salient themes using data reduction informed by a methodological framework of phenomenography to identify the variety of experiences participants had using the tools. Findings for optimal flyby speed of the Moon based on analysis of data for both the Immersion Questionnaire and the Simulator Sickness Questionnaire done using SPSS software determine that the optimal flyby speed for college students to manipulate the Moon was calculated to be .04 x the radius of the Earth (3,959 miles) or 160 miles per second. A variety of different participant experiences were revealed using MAXQDA software to code positive and negative remarks participants had when engaged in the use of each tool. Both tools offer potential to actively engage students with astronomy content in college lecture and laboratory courses.

ACKNOWLEDGEMENTS

An undertaking of this magnitude is not achieved in isolation. I received help and support along the way from many people. Thank you to Dr. Dale Etheridge who started me on this journey eleven years ago when I began working at the planetarium. I appreciate your patience and encouragement, and for allowing me to explore a topic that was professionally and personally meaningful to me. This dissertation would not be as thorough without the guidance of Dr. Janelle Bailey. Thank you for keeping me on as a doctoral student when your career path took you to Temple University. You taught me to be a careful researcher and guided my steps through those first conference presentations and publications. You showed me the importance of leaving no stone unturned and that when doing research, no detail was too small to investigate. I am very thankful to Dr. Kraig Knapp for his continued support and advice through all of the major milestones in this process and for Dr. Tom Gill and Dr. Harold Nations who were available to listen to my ideas and help me prepare my presentation. Special thanks to Dr. Andrew Kerr and Nick Juliano, they supported my research by sharing the planetarium and by proofreading my dissertation with a critical eye. I want to acknowledge Allan Tucka for his steadfast and consistent help with operation of the VR headset; my research would not have progressed without this assistance. Christa Speights, Coordinator of the Haile Digital Planetarium at Northern Kentucky University generously shared her knowledge and scripts of lunar and planetary flybys with me and allowed me to manipulate her scripts for use in my research; for this I am very grateful. And finally, to the members of my dissertation committee: Dr. Janelle Bailey and Dr. Hasan Deniz the co-chairs of my committee, and Dr. P. G. Schrader, Dr. Doris Watson, and Dr. Dale Etheridge for your continued energy and vision, many thanks for you made this scholarly journey possible.

DEDICATION

For Florence and Helen

and

In Loving Memory of my Husband

Jack Maher
(1952-2013)

TABLE OF CONTENTS

ABSTRACT……………………………………….………………………………………….....iii

TABLE OF CONTENTS…………………………………………………………………….…vi

LIST OF TABLES………..………………………………………….…...……...................xi

LIST OF FIGURES………..…………………………………….……...…..…..............xii

CHAPTER 1: INTRODUCTION…………………………………………………………..…1

Two Simulation Tools for Teaching Science……………………..………………………..1

Using the Planetarium as a Simulation Tool………………………………………..…2

Using a Virtual Reality Headset as a Simulation Tool…………………………….…9

The Problem Addressed in the Study……………………………………………….....…13

Justification of the Problem as One Worthy of Study………………...……………..…14

Identification of Gaps and Silences…………………………………………………….....15

Operational Definitions………………………………………….……………..…16

Intended Audience for Whom the Study is Directed…………………………………..18

Scope of the Study………………………………………………………………………..19

CHAPTER 2: LITERATURE REVIEW……………………………………………….…...23

Introduction…………………………………………………………………………….23

Simulations……………………………………………………………………………….24

Planetaria……………………………………………………………………………30

Virtual Reality and Virtual Reality Headsets……………………………………….34

Multimedia Learning………………………………………………………………..37

Learner Engagement……………………………………………………………………..38

Purpose and Research Questions……………..…………………………...……..39

CHAPTER 3: METHOD………………………………………………………..….41

Introduction…………………………………………………………………………41

Intentional Choice of Multimedia Design Principles……………………………………41

Design-based Research, the Method Used to Answer Research Question One……...…41

Salient Aspects of Design-based Research……………………………………….…42

Iteration……………………………………………………………………..…..43

The Feedback Loop…………………………………………………….…...44

Relationship………………………………………………………...……..…45

Immersion……………………………………………………………..…..…46

Retrospective Analysis as a Stance…………………………………………….…48

Rationale for Using Design-based Research………………………………..................48

Phenomenology and Coding as an Approach to Answer Research Question Two……...49

Setting and Participant Selection…………………………………………...……..…51

Design of the Treatments……………………………………………………….…...56

Data Sources…………………………………………………………………….…..59

Simulator Sickness Questionnaire……………………………………………..60

Immersion Questionnaire……………………………………………………...61

Small Group Interviews……………………………………………………….62

Data Sources Used to Answer Research Question One…………………………65

Data Sources Used to Answer Research Question Two…………………………66

Data Collection…………………………………………………………….……….66

Data Analysis……………………………………………………………………………74

The Researcher's Role in the Study………..………..…………………………………...78

Study Timeline and Summary…………………………………………………..…..…....80

CHAPTER 4: RESULTS…………………………………………………………...……..……..81

Introduction and the Two Research Questions……………………………………….81

Research Question One–Results…….…………………….……………………….….81

Use of the Motion Sensor Device….………………….……………………..…….82

Use of the Virtual Reality Headset……………………….……………...……..…..98

General Understandings from the Two Devices….………………….……..…..101

Research Question Two–Results……..……………………………………...…...….102

Affordances Experienced using the Motion Sensor Device……………..….......103

Constraints Experienced using the Motion Sensor Device……………………..106

Affordances Experienced using the Virtual Reality Headset………..………115

Constraints Experienced using the Virtual Reality Headset……………...…….122

What was Learned from the Data about these Two Devices?……………………….…126

CHAPTER 5: DISCUSSION AND CONCLUSIONS………………………………....……130

Summary of Findings as they Relate to the Two Research Questions………………....130

Discussion of Research Question One Results………………………………………130

Discussion of Research Question Two Results………………………………………...132

Comparison of Commonalities and Differences………………………………………134

The Limitations of the Study……………………………………………….……..135

Practical Significance for Instructors, Designers, and Researchers……………………139

Practical Significance for Instructors……………………………………………..140

Practical Significance for Designers……………………………………………141

Practical Significance for Researchers……………………………..………..142

Further Research to Extend these Findings……………………………………….143

Conclusions……………………...………………144

APPENDIX A: SOCIAL/BEHAVIORAL IRB APPROVAL…………………………..…..146

APPENDIX B: DATA COLLECTION PROTOCOLS ……………….……….....……...…..147

APPENDIX C: PERMISSION TO USE FIGURES 150

APPENDIX D: EXAMPLE OF CODING USING MAXQDA SOFTWARE………………...156

REFERENCES…………………………………………………………………………………158

CURRICULUM VITAE……………………..…………………………….………..…175

LIST OF TABLES

Table		Page
1	Participants by Pseudonym in the Tuesday and Wednesday Evening Fall Semester Classes…………………………………………………………	54
2	Participants by Pseudonym in the Monday Morning and Tuesday Evening Spring Semester Classes……………………………………………………...	55
3	Participants in the Monday Morning Course Small Group Interviews During Spring Semester………………………………………………………………….	64
4	Participants in the Tuesday Evening Course Small Group Interviews During Spring Semester………………………………………………………………	65
5	Codes Created from Transcribed Data………………………………………….	78
6	Timeline Used to Implement and Complete the Study…………………………..	80
7	Number of Participants that Experienced each Speed from Slowest to Fastest using the MSD……………………………………………………………….	84
8	Lunar Flyby Speeds and Comfort Levels Tested for Simulator Sickness and Immersion (MSD)……………………………………………………………….	87
9	Percentage of Participants Reporting Levels of Immersion using the MSD……..	92
10	Data used to Create Figure 16……………………………………...…………	96
11	Percentage of Simulator Sickness Symptoms When Using the VR Headset…….	98
12	Percentages of Key Symptoms from Results of the VR/MSD Simulator Sickness Questionnaire………………………………………………………...	127
13	Percentage of Participants Reporting Immersion Levels of each Condition using the MSD/VR………………………………………………..………………….	128
14	MSD and VR Headset Affordance Table for Instructors, Designers, and Researchers…………………………………………………………………….	139
15	MSD and VR Headset Constraint Table for Instructors, Designers, and Researchers…………………………………………………………………….	140

LIST OF FIGURES

Figure		Page
1.	Zeiss Model II star ball projector during a show…………………..	3
2.	An Asteroids-like video game configured in X-Y mode…………..	5
3.	Number of digital fulldome systems and facilities opening by year, 2014…………………………………………………………...	8
4.	Rear view and control box of the Oculus Rift DK1 VR headset………………………………………………………...	9
5.	Five-component simulation model with factors designed for teaching nursing students………………………………………..	26
6.	The four quadrants of planetarium research.…………….….…..	32
7.	The dark figure represents the participant………………..……...	56
8.	Astronaut Bruce McCandless on a spacewalk using the manned maneuvering unit…………………………………………………...	58
9.	Participants experiencing a preliminary virtual reality headset simulation using their smart phone. ………………………………	68
10.	The data collection chart used in the pilot study…….………….…	69
11.	Data collection flowchart for the final study…………………..…	70
12.	Expected conditions of simulator sickness and immersion as speed increases…………………………………………………………	75
13.	Simulator sickness and immersion over two semesters using the MSD ……………………………………………………….……	89
14.	Lunar flyby speeds and discomfort levels for MSD simulator sickness.………………………………………………………	90
15.	Lunar flyby speeds and comfort levels for MSD immersion………	91
16.	Simulator sickness and immersion over Fall semester using the MSD……………………………………………………………..	94
17.	Simulator sickness and immersion over Spring semester using the MSD……………………………………………………………..	95

18. Immersion and simulator sickness results when participants used the MSD…………………………………………………………… 97

19. Using the DK 3 VR headset and computer set-up………………… 124

CHAPTER 1: INTRODUCTION

Two Simulation Tools for Teaching Science

Teaching and learning have always depended upon tools to aid in the process of knowledge acquisition (Putnam & Borko, 2000; Winarno, Muthu, & Ling, 2016; Wu, Hwang, Yang, & Chen, 2017). From the earliest instruction where man drew pictures in the dirt with a stick to chalkboards, whiteboards, smart boards, and digital slides, education has been aided by tools to help explain the content. Advances in technology stretch the boundaries of traditional college lecture halls and invite the world into the classroom through multimedia instruction (Mayer, 2003; Vazquez, & Chiang, 2016; Zhou, 2016). Two quite different tools that have striking similarities are the object of this study for their implications in teaching and learning. The tools just mentioned are the motion sensor device used in a fulldome planetarium and the virtual reality headset.

Planetaria are structures and devices used to project images into a domed ceiling theater to a group of participants. A virtual reality headset is worn by an individual viewer and simulates an experience in a non-group setting. Planetaria have been in use since 1923 to simulate the night sky (Chartrand, 1973); virtual reality headsets for consumer use have emerged in the past 20 years. These tools offer benefits to learning introductory astronomy by simulating the night sky and deep sky objects in a way that is difficult with a textbook (Plummer, 2009). Each tool offers different affordances for teaching and conversely, offers different constraints that limit what they can do. Information on how to quicken understandings using teaching best practices can be gained by studying the phenomenon of student learning using multimedia tools to deliver content (Berger, Lu, Belzer, & Voss, 1994). For teaching introductory college astronomy curriculum, information gained can inform the practice of teaching both face-to-face classes and classes taught online (Fokides, Mastrokoukou, & Atsikpasi, 2017).

Using the Planetarium as a Simulation Tool

For decades planetaria have been used to simulate the celestial sphere supplementing observation by conventional methods that use wavelengths on the electromagnetic spectrum (i.e., light) to gather information about the heavens (Plait, Silva, Graves, Reed, & Cominsky, 2006). The planetarium dome theater came into existence in 1923 when Walther Bauersfeld, of Jena, Germany, projected stars and planets inside the optical white surface hemisphere of a planetarium dome using a Model 1 Zeiss projector (Chartrand, 1973; Hagar, 1960; Norton, 1968). Since then, planetaria were built worldwide and are used to simulate the night sky and the movement of celestial bodies.

Early planetaria used *star balls* to simulate the night sky. These were mounted to move as a whole and simulate the rotation of Earth. Not all of the star balls made use pinhole projection. The pinhole projection technique was developed by Armand Spitz in 1947 to enable the production of inexpensive planetarium projectors to be used in schools. All other star ball designed projectors use optical techniques to project all stars. Early star balls were limited as they were incapable of proper occultation. Occultation is when one celestial body passes in front of another thereby hiding one (Elliot, Person, & Qu, 2003). Star ball projectors have two main constraints that limit their usefulness. First, the function of the planetarium as a simulation device using star balls is constrained by the inability to move beyond an Earth-bound view of the heavens. Second, planetarium content began to shift from simulations of the celestial sphere to more diverse content as edge-blended *all sky* slide projectors were introduced. Later star ball or opto-mechanical projectors were supplanted when all sky projectors became popular.

Edge blending is a technique where the video signal from one projector is gradually faded out through a banded zone. The adjacent projection or pixels are faded up. The appearance of banding is eliminated and a single image is created across the screen. *All sky* slide projectors expanded the ability to provide content in a planetarium dome theater making the star ball an accessory projector. After the introduction of *all sky* slide projectors, many star ball projectors fell into disuse and were abandoned.

Figure 1. Zeiss Model II, star ball projector during a show. Berlin Planetarium, 1938. From “B 145 Bild-P018935,” by A. Frankl, 1938, Bundesarchiv, Berlin, Germany. Copyright 2008, German National Archives.

When the Soviet Union launched Sputnik, the world’s first artificial satellite, in October 1957, America entered the Space Race and attention was focused on planetaria as a way to inspire and engage students in science. “President Eisenhower’s advisory council deemed the planetarium to be one of six outstanding innovative educational projects to emerge during his term” (Lantz, 2011, p. 295). Funded by federal National Defense Education Act matching monies to promote post-secondary education and Title III grants for technology and equipment aimed at Historically Black Colleges and Universities, planetaria were built across the country. Many recipients of these funds and grants were two-year colleges because they were undergoing a growth curve with the rise of baby boomers going to college and many were built during that decade. During the 1960s many two-year colleges were in the planning phases and planetaria were written into the architectural drawings and into construction budgets. As planetaria proliferated, content continued to diversify. A planetarium became not only a simulation theater for the night sky but afforded a general-purpose group immersive visualization experience capable of supporting a wide range of programming.

Planetarium science entered the digital age when David C. Evans and Ivan Sutherland introduced the first vector-based, calligraphic star projector at the University of Utah research park in 1983 (Lantz, 2011). This star projector used a single hyper-brilliant cathode ray tube and a fisheye lens as its projection equipment. This new use of computer systems expanded planetarium content because it went beyond the limitations of the star ball. One of the first examples of this expanded use of planetaria used vector calligraphic color displays to visualize large molecules such as enzymes and polynucleotides in the study of chemistry (Husain, Sancar, Holbrook, & Sancar, 1987; Pearl & Honegger, 1983).

Vector calligraphic displays offer improvements over *all sky* slide projectors. Vector calligraphic displays have depth cueing and allow content creators to draw large wire-frame type models. Depth cueing is similar to atmospheric perspective artists use to render distance. Objects farther from the viewer become more faded. Depth cueing enables water, smoke or atmospheric conditions to be rendered and projected onto the dome (Cheng, Li, Tsai, & Chen, 2009).

Vector calligraphic models are manipulated in real-time with controls to rotate, shift and zoom the image during its creation. These displays use mathematical points and paths to describe an image (Crow, 1978), and this makes these adjustments possible. Vector display systems were used for astronomical simulations and training systems like the game Space Rocks. Space Rocks is a 2013 Atari 2600 video game programmed by Darrell Spice Jr. It is a blending of the classic arcade game Asteroids with graphics, animations, and sound developed for the Atari 2600.

Figure 2. An Asteroids-like video game configured in X-Y mode. Brooklyn, New York, 2013. Adapted from: Hudson, T. (2013, June). *Space Rocks (game)*. Brooklyn, New York: NYC Resister. Copyright 2013, Trammell Hudson.

In this game, you are on a routine stellar cartography mission when your space ship experiences a malfunction and you are warped into an asteroid field. You must destroy asteroids and warships intent on your destruction. If your ship passes too closely to one of the asteroids (space rocks), the ship is destroyed and the simulation restarts. As the pilot of your ship you must maneuver quickly, rotating left and right to avoid asteroids. Once the ship runs out of (simulated) fuel, it is stranded and unable to complete its mission.

Vector graphics based systems in planetaria were introduced in the late 1970s with the Digistar I system created by Evans and Sutherland (E&S). Digistar I was the prototype system for using vector graphics in a planetarium dome and was a major technological breakthrough from digital slide systems. A decade later Digistar I gave way to a more complete vector graphics based system containing program enhancements to surpass the current system. The new system, introduced in the early 1990s, was called Digistar II. This system was the basic platform that began the fulldome era and Digistar II was such a proven and serviceable system that many are still in use in planetaria today.

In the late 1980s vector calligraphic displays gave way to raster displays in planetaria. Raster display projection systems break up an image into grids of pixels. These grids give more details and options for further rendering of objects in the dome theater. Content variety increased after the release of the first digital raster display system in the late 1980s. By 1996 multi-projector, raster-scan, electronically edge-blended projection systems became the new standard for fulldome equipment used in planetaria.

When E&S introduced the Digistar 3 (D3) digital system in July of 2002 fulldome video playback was enhanced, real-time computer graphics were improved, and a complete three-dimensional digital astronomy package was integrated into a single theater system, bringing full immersion with operator flexibility into the fulldome hemisphere (Sutherland & Hodgman, 1974). Patrons were now able to interact with the content images in a way not possible before D3 introduction. D3 was well received by end users leading to an increase of dome theater use and construction because content for raster digital systems were easier to render and create. The change from Digistar I & II to D3 was significant because of ease of operation. It gave the operator tools to create content. Raster display projections systems afford use of the planetarium dome as an immersive medium. Patrons are able to experience content in a way that was not possible using vector display due to the enhanced digital graphics images. Because of raster-scan, digital dome theater projection systems began to be used as a way to simulate content and concepts. These simulation capabilities are used across a range of disciplines including art and potential for using fulldome for teaching and learning.

To further disseminate this knowledge and the new ideas coming from raster, alliances to promote fulldome immersion proliferated. The annual IMERSA summit is a growing gathering. This group began in 2008 to spread advances in the art and technology of immersive digital expression. The 2014 ix Symposium in Montreal, Canada was an international symposium on immersion and experience. These kinds of alliances encourage research and development in raster projection for dome hemispheres. Since the inception of the fulldome digital theater more planetaria have been built than other large format theaters, increasing the presence of immersive experience that goes beyond exploration of the celestial sphere.

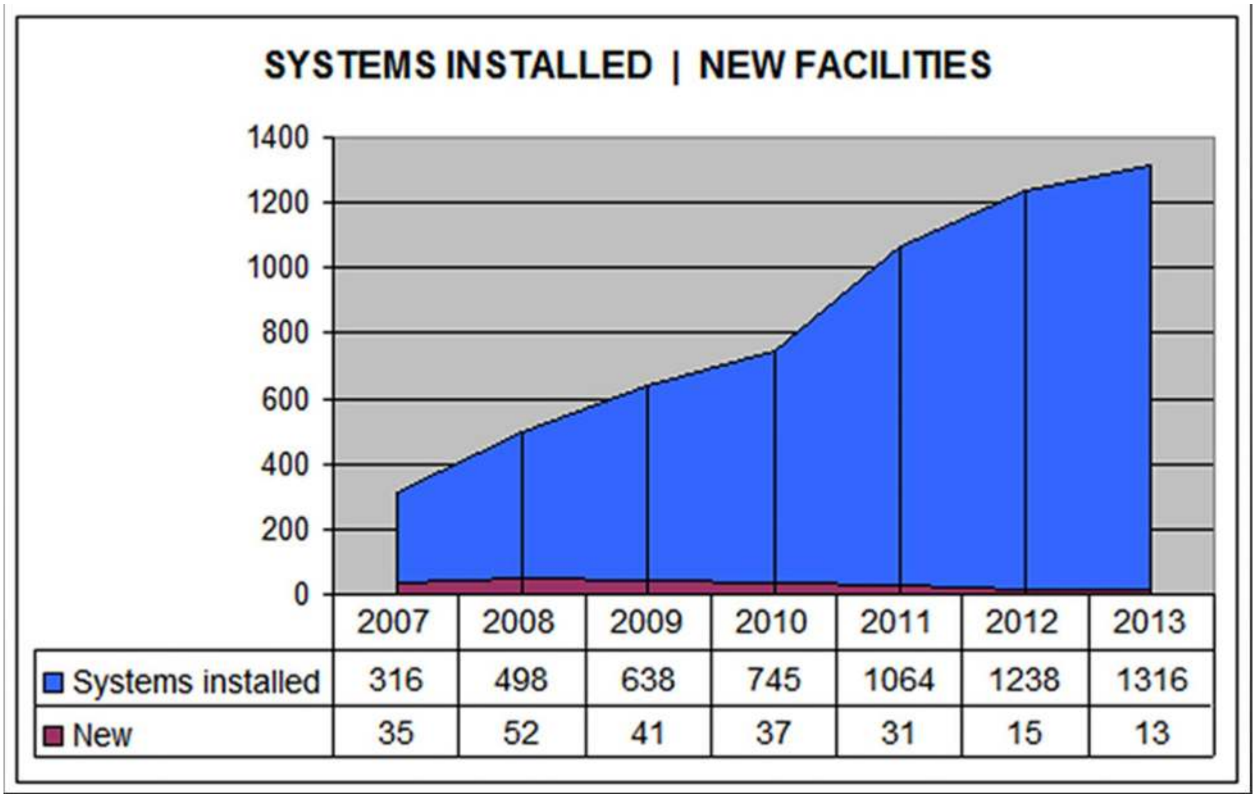


Figure 3. Number of digital fulldome systems and facilities opening by year, 2014. Adapted from: Petersen, M. C. (2014, March). *Systems Installed/New Facilities*. Denver, Colorado. Loch Ness Productions Copyright 2013, Mark C. Petersen.

Motion sensing devices used with planetarium software. Accelerometers, the tiny mechanical motion sensors used for motion capture in computers came into the consumer market in 2007 with the rollout of the Nintendo Wii. With the advent of Digistar 4 in 2011 the Microsoft Kinect motion sensor device add-on gave rise to the interactive planetarium. In an interactive planetarium a user's gestures and body positioning made controlling a planetary or lunar flyby possible. Developed to provide a keyboard-free way to interact with patrons in a dome theater planetarium an astronomy presenter can manipulate a planet or moon using their body position and arms. Presenters direct the flyby using an avatar on-dome interface. This study uses the fulldome planetarium with a Microsoft Kinect motion sensor device add-on that uses the planetarium software to project an interactive image of the Moon on the dome. This image can be manipulated by an instructor, a presenter, or by students and patrons. (Boulos, Blanchard, Walker, Montero, Tripathy, Gutierrez-Osuna, 2011).

Using a Virtual Reality Headset as a Simulation Tool

The advent of multimedia tools has potential to inform the practice of higher education teaching and learning. Since their inception in the early 1920s planetaria were used to teach concepts in astronomy. Currently there is emerging research on using a new tool, the virtual reality headset, as a classroom device for use in teaching.

A virtual reality headset is an immersive computer experience in three dimensions occurring in real-time (Reid, 2002). A virtual reality headset is a device worn on the head that allows a user to experience a virtual reality as opposed to their actual reality. An example of a modern headset is shown in Figure 4, as you can see the device is worn like a pair of goggles.

Figure 4. Rear view and control box of the Oculus Rift DK1 virtual reality headset. Adapted from: Stabinger, S. (2013, December). *Back and Control Box*. Tirol, Austria. Paethon. Copyright 2013, Sebastian Stabinger.

Two very early prototypes are worth mentioning. The first tool follows the definition given by Reid (2002) but involved a machine that simulated the experience of riding a motorcycle. This virtual reality machine was called the Sensorama. Developed by Morton Heilig in 1962, the Sensorama used 3D visual, audio, haptic, olfactory and atmospheric stimuli to provide a virtual reality experience. The Sensorama was more like an arcade video game than a headset but it is regarded as one of the first examples of virtual reality (Boas, 2013). The next early prototype was more like the virtual reality headset shown above but was developed decades before this definition was defined in the literature. In 1968 Ivan Sutherland created a device that was worn by stepping into the headset. Called the Sword of Damocles this was a very bulky virtual reality headset that was hung by the ceiling of his laboratory. The Sword of Damocles was able to track the user's position accordingly creating an immersive environment that was sensitive to the user's body position.

The first commercially available virtual reality headset was presented at the 1994 Las Vegas, Nevada, Consumer Electronics Show. This head mounted device aimed to give the user an immersive virtual reality experience for the purpose of interaction with computer games and 3-D simulations. Aspects of the virtual reality headset include a stereoscopic head mounted display providing separate images for each eye and head tracking. Head motion tracking sensors provide the user a deep sense of immersion (Travers & Yee, 1994) and use edge blending.

Edge blending was developed in the late 1930s and early 1940s. At that time lantern slide projectors, also called Magic Lanterns, were used in combination to produce panoramas around the horizon line in planetaria. Edge blending was implemented in the panorama using metal blades to soften the light path or shaded overlays on the slide. Edge techniques improved with the introduction of 35mm slides in the 1950s and 1960s. They adapted with the advent of video and digital technologies.

Virtual reality headsets use two lenses, one for each eye and uses edge blending software giving the viewer one image. This is similar to fulldome because both tools blend the image and the similarity between two lenses or two or more projectors to achieve the immersive viewer experience is reached. In fulldome two or more projectors display content onto the dome and edge blending creates one image.

A virtual reality headset affords the user a simulation experience that is portable and transferable to other venues and users. It is constrained by the single user experience unless multiple headsets, linked through software, are available for participants to use simultaneously. This idea is similar to the use of a computer lab where an instructor takes over the class screens to show content. Like ocular lens telescopes, use of a virtual reality headset is a one-at-a time experience. This differs from the group experience in a planetarium where patrons in a planetarium share the immersive experience and can see their bodies and each other as well as the content. Use of a virtual reality headset restricts the user to a truly isolated world. First time users often look down when engaged in content the content they are viewing through the headset, and are startled to not see their own feet the experience is so real.

Participants wear the virtual reality headset like a pair of large goggles and are able to interact with, and to some degree control, the experience they consume through the computer software providing content. The ability to experience learning using the senses of seeing, touching, and hearing is a primary observational method in science where input to the brain uses visualization and sound as stimulus. Simulation tools improve the ability to take in information using the senses similar to the way Galileo used the first telescope as a tool to enhance his observation of the night sky. In Cobb and Fraser (2010) the definition is more extensive:

> Virtual reality describes the combination of systems comprising computer processing (PC-based or higher), a building platform for creating three-dimensional environments, and peripherals such as visual display and interaction devices that are used to create and maintain virtual environments. Virtual environments refer to the three-dimensional environments created. The simulation may be of real or imaginary environments. The first defining feature of virtual

> environments is that they can be explored in real-time with similar freedom to real-world exploration. The second defining feature is that the user may interact with objects and events in the simulation. (p. 525)

Using simulations to teach allows students to be immersed in an environment in a way that is difficult to do in the real-time environment of an observatory. The virtual reality headset as a tool can extend observation to a level where the student is immersed in, and able to control and interact with content images in a way that is challenging to achieve if using a textbook.

Aspects present in a virtual reality headset include sensory perception, physical manipulability, and interaction quality (Crosier, Cobb, & Wilson, 2002; Lee, 2004). According to Cobb et al. (2010) some of the attributes that could enhance learning in the virtual reality headset environment include:

> …visualization and manipulation of invisible phenomena, the ability to take on different perspectives, the exploration of dangerous situations, reality and altered reality, and three-dimensional representation of abstract concepts. (p. 530)

Attributes afforded by virtual reality headset technology include presence, real-time interaction, learning style, flexibility as a teaching tool, and possibly increased motivation for the learner (Crosier et al., 2002). Of these factors, those that could be included as social factors are learning style, flexibility, motivation, and real-time interaction. Cognitive factors include reality and altered reality as well as presence.

The affordances and constraints of these tools differ, but also have many similarities. Both VR and fulldome afford presence. Presence is the ability to lose yourself in a simulation; you are comfortable in the environment and you know it is not real, but you think it is (Iribe, 2014). Lee (2004) describes presence as a "psychological state in which the virtuality of experience is unnoticed" (p. 32). Presence can be described as the feeling of being there, in the place, or in another world other than the one where the body is located (McLellan, 1996;

Rheingold, 1991; Schloerb, 1995; Slater & Usoh, 1993). Another attribute for both the virtual reality headset and fulldome is persistence. Persistence influences real-time interaction and is referred to in degrees of motion blur or judder. Judder is defined as an artifact that occurs when content is shown with a high refresh rate. This artifact shows a moving image that is not smooth. Similar to cartoon figures made with a flip-book paper motion picture of childhood pastimes, the characters move in a jerky fashion. Standard frame rate for film is 24 frames per second (fps). fulldome programming runs at 60 fps. When watching content at 60 fps the player detects the incoming signal and fills in missing frames that the eye has already seen. To ensure 60 fps the first frame is displayed three times and the second frame 2 times. This 3:2 pull-down occurs because alternating frames are not repeated in a consistent manner and can, under certain technical circumstances, cause judder. Judder influences the sense of presence and the ability to interact with the content in real-time because the eye and brain are constantly reminded that this is a projection (Zielinski, Rao, Sommer, & Kopper, 2015). It is a technical problem that hardware creators work to solve and it is this similarity that initiated the questions that started this study. The affordances and constraints of these multimedia tools for studying the lunar surface via flybys in the dome theater and using the virtual reality headset is the subject of this inquiry.

The Problem Addressed in the Study

What affordances and constraints do these two simulation tools offer for teaching, learning, and research in science? A simulation is defined as a form of experiential learning (van Joolingen & de Jong, 1993). In the simulated environment of the planetarium or a virtual reality headset participants can experience phenomena difficult to duplicate in a traditional classroom or laboratory. Unlike a text, the simulated planetarium using a motion sensor device add-on and the virtual reality headset environments afford manipulation of content. The parameters of the environments represent a reality within which students interact to promote learning of a particular concept (El-Mounayri, Rogers, Fernandez, & Satterwhite, 2016; Plummer, 2009; Weigel, & Moraitis, 2017). The simulation looks and sounds real and leads to a different understanding by the learner. Thus a simulated learning experience impacts the teaching and learning of science and facilitates differentiated instruction to meet the needs of diverse populations (Smetana & Bell, 2012), giving all students an opportunity to learn in an environment different from a lecture and note-taking based experience.

Previous research on planetaria and virtual reality headsets focused on limited topics and few studies looked at motion sensor devices used in planetaria. Several studies focused on conceptual change in learning Moon phases using digital computer simulations as the content delivery tool (Bell, & Trundle, 2008; Plummer, 2009). Other studies focus on the computer game and gaming industry (Day, 2015; Zhao, Chowdhery, Kapoor, & Bahl, 2015). Some investigations about virtual reality headsets address medicine and medical training and practice (Juanes, Gómez, Peguero, Lagándara, & Ruisoto, 2015; McCloy & Stone, 2001) or compare live experience in a laboratory to a virtual experience using a computer-generated laboratory (Winn, Stahr, Sarason, Fruland, Oppenheimer, & Lee, 2005). Literature searched found emerging and preliminary studies in this field. Peer review literature examined consisted mainly of proceedings from academic conferences.

Justification of the Problem as One Worthy of Study

The question of virtual reality headsets and fulldome immersive planetarium content presentation comes up in planetarium literature as a topic of discussion, particularly with respect to whether one can supplant the other (Aguilera, 2016). This study examined both tools and looked at how virtual reality headsets and fulldome immersive planetarium content can supplement curriculum. The results of the study are directed for use in the practice of astronomy to inform teaching and learning. The question posited here concerns the affordances and constraints of these tools for teaching and learning about the Moon using a lunar flyby to study astronomy in introductory courses at a two-year college.

Minimal research focused on the two tools as technology to inform teaching and learning in introductory astronomy courses at the two-year college level. As these technologies evolve educators are looking to their possibilities for teaching and learning in the lecture hall and laboratory. According to Aguilera (2016), the content of these media experiences are rapidly evolving and the experience of immersion is more and more accessible today through mobile and gaming devices. Because of this accessibility, immersion is being integrated with natural experiences taken in through the senses as another tool that can be used for scientific visualization. Possibilities for lunar visualizations with manipulative ability offer an interactive method of instruction for learners.

Identification of Gaps and Silences

The majority of papers that discussed virtual reality headsets were review papers (Desai, Desai, Ajmera, & Mehta, 2014; Goradia, Doshi, & Kurup, 2014) or descriptive studies. Papers investigating fulldome planetaria are mainly quantitative studies dealing with the technical aspects of the tool (Ju, Pollock, & Junkins, 2000; Mortari & Angelucci, 1999), descriptive and historic papers, and qualitative studies where planetaria are used as a vehicle to study an aspect of learning, such as conceptual change (Plummer, 2009). Only in the past year were preliminary studies emerging in the literature where these tools were examined under the lens of astronomy teaching and learning. Of the studies and papers published there were no publications examined using a design-based research approach to study these tools.

The simulation field is dynamic and emerging. From this discussion of gaps and silences in the literature the proposal continues with a discussion of intended audiences for this research and the scope of the study. But first it is helpful to examine a list of key terms that were used throughout the document and that are important to understand for this study.

Operational Definitions

Below is a list of key terms and their operational definitions used throughout this dissertation.

accelerometer – An instrument for measuring the acceleration or vibration of a machine, in this case, the visual persistence seen in virtual images.

biophilia effect – Biophilia suggests that there is an instinctive bond between human beings and the natural environment; participants in this study would comment on factors in the Immersion Questionnaire to rank the effects of biophilia.

cathedral effect – The influence of the perceived height of a ceiling and human thinking. High ceilings encourage abstract and creative thinking and low ceilings encourage concrete thinking and detail oriented thinking.

Digistar I & II – The Digistar I projection system was an early attempt at fulldome video. Unlike true fulldome video, Digistar and Digistar II are vector graphics based systems.

Digistar 3 – The first true fulldome system and unlike I and II this is a raster based system providing full-color rendered effects.

electromechanical/optical projector – A hollow ball with a light inside and a pinhole for each star. Later systems used individual projectors with focusing lenses for rendering individual bright stars.

fulldome planetarium – A dome theater immersive environment filled with real-time interactive or playback pre-rendered computer animations, live capture images, or composited environments; these systems are raster based.

Google Cardboard – A virtual reality platform developed for use with a cardboard head mount for a smartphone.

horizontalization – A system of data reduction in phenomenography where the variety of meaning in data is refined by finding meaning clusters.

infrared structured light – The process of projecting an imperceptible infrared grid pattern on an object. This pattern detects deformations when striking surfaces and allows vision systems to calculate the depth and surface information of objects.

judder – An artifact that occurs when content has an incorrect refresh rate. This leads to the image being jumpy and not smooth. Persistence refers to an image that does not show judder (see persistence below).

lunar flyby – The act of sending a space probe or avatar past the Moon but close enough to record scientific data. This can be simulated using a virtual reality headset or in the simulated environment of a planetarium using a motion sensor device.

Microsoft Kinect – Kinect is a line of motion sensing input devices by Microsoft developed for Xbox 360. This tool enables users to control and interact with their console/computer without the need for a game controller through a natural user interface involving gestures.

motion sensor device – A motion sensor device or motion controller using an accelerometer to detect approximate orientation, acceleration, and serving as an image sensor. Other systems use different mechanisms for input. Microsoft Kinect combines infrared structured light and computer vision to detect motion.

persistence –An image that is smooth running when projected, it does not show judder (see judder above).

student participant – For the purposes of this study the word student and participant are used interchangeably with participant being the preferred term. When the word student is used it is for distinction and clarity.

Intended Audience for Whom the Study is Directed

By examining the two simulation tools described and using a design-based approach, researchers who study multimedia tools can better understand the affect achieved when teaching using a lunar flyby. This research is also of interest to planetarians who want to expand their programs to include interactive and live presentations. In particular, this type of research benefits instructors and academics interested in teaching and learning to inform pedagogy when working with introductory astronomy students. To understand the various experiences students' had with these tools I captured a variety of lived experiences in real time using question protocols and small group interviews conducted after the participants used both tools. Examining this captured data informed changes made to the lunar flyby speed. Participants experienced use of the motion sensor device lunar flyby at different speeds to find the optimal speed for the flyby. Instructors of introductory astronomy at colleges and universities can use information gained about the variety of participant experiences to inform their instruction. They can also deliver instruction using multimedia tools to simulate lunar or planetary flybys. This research informs the practice of both online and face-to-face teaching.

Scope of the Study

Data collection for this study proceeded over two 16-week semesters. The first data collection occurred in the Fall semester of 2016 and the second during the Spring semester of 2017. Two classes being taught on two different days each semester were visited for the purposes of data collection. Data were collected from students enrolled in introductory astronomy courses at a two-year college in the desert Southwest. The treatment's language and content were designed to target this population. The site and population was a purposeful sample and qualitative and quantitative research techniques were used. The participants and setting were selected to yield a variety of lived experiences with the phenomenon of using a motion sensor device in a fulldome planetarium and when using virtual reality headset technology to experience a lunar flyby (Palinkas, Horwitz, Green, Wisdom, Duan, & Hoagwood, 2015). Each participant experienced a five-minute treatment using the fulldome planetarium with a Microsoft Kinect motion sensor device to control a lunar flyby (Detlefsen, 2014; Zhang, 2012). Microsoft Kinect works with the Digistar 5 fulldome computer software to give participants individual control over the speed, distance, and rotation of the Moon.

Through my work at a college planetarium and during trainings I attended at Evans & Sutherland in Salt Lake City, Utah I got to know the director of the Haile Digital Planetarium at Northern Kentucky University (NKU). It was through this association that I had the contact and connections to talk to professionals at other planetaria to request and share planetary and lunar flybys created in house at these institutions. I looked at various flyby scripts and was able to secure permission form the NKU director to alter self-created planetary and lunar flyby scripts.

This director used the flyby script as part of a space camp and had students enrolled in the camp manipulate planetary and lunar flybys at the .02 (80 mps) baseline speed with no changes. Students manipulated the flyby while interpreting facts about the planet or moon making this the ideal flyby to meet the needs of this study. Lunar flyby content was created at NKR at the Haile Planetarium using a Digistar production station and data sets collected from the Moon LRO spacecraft and the Moon in Google Earth.

Participants also manipulated a lunar flyby using an Oculus Rift virtual reality headset with a hand held game controller. The Oculus Rift virtual reality headset software used a Beta form of Star Chart by Gear VR and Escapist Games LTD (Star Chart, 2016). After doing a pilot test using a small participant sample I determined using the lunar flyby fit the needs of not only this study but was a natural content choice because two weeks of the course in all four sections covered the Moon. A local planetarium was chosen because the next nearest planetarium in the state is in the North and the second closest planetarium is in a neighboring state; time and distance prohibits travel of this magnitude to conduct the research. These alternate planetaria are located in college and university settings similar to the study site chosen so there is no advantage to doing research in other settings.

Particular tools chosen were the E & S Digistar 5 fulldome planetarium software and dome theater with attached Microsoft Kinect motion sensor device and Oculus Rift Virtual reality headset, (VR headset) Developer Kit (DK) version 1, DK version 2, and the Oculus Rift commercial version. The choice of dome theater was dependent on what was available at the time. This area has a recently built dome theater in the downtown area, but since I already had a relationship with the staff at the college and the students were taking courses in the college dome theater it was a choice of convenience to use the college dome theater.

The dome theater at the college holds 68 attendees plus a presenter. This is considered by planetarians to be a medium sized theater (Faidit, 2011). The screen edge configuration is called a Prince Valiant cut (Ellis, 2014) after the comic strip protagonist of the same name. When this theater was built the cove area held slide projectors. Although the projectors are no longer used and were taken out the Prince Valient cut cove area remains today as a physical aspect of this type of built theater. This style of theater is mentioned because in the study when data is presented some participants noted that the unusual cut of the theater made using the motion sensor device a challenge during the zoom out maneuver. This planetarium suited the purpose of the study because the participants were familiar with the facility. Some participants took their lecture astronomy class or their lab astronomy class in this venue.

Information gained from the pursuit of this line of research has potential to affect teaching and learning in higher education. It has potential to inform the practice of introductory astronomy in the dome theater classroom environment where classes are taught face-to-face by the instructor. These tools have potential for online teaching using the virtual reality headset connected to a desktop computer or the more cost effective and easily made Google Cardboard and a smart phone in the online classroom platform. Use of virtual reality has potential for distance education because this technology presents opportunity to engage with a virtual classroom and students can consume content that would be difficult to present through other online media methods. Following this line of thinking brings us to a discussion of literature used to inform this proposal. Peer reviewed literature covered the historic roots of simulations, virtual reality headsets and motion sensor devices using planetaria. Literature also reviewed covered emerging and nascent break-throughs and technological advances of virtual reality hardware and software. At this writing peer reviewed literature concerning these two simulation tools continues to emerge. Colleges and universities are installing virtual reality laboratories on campus to experiment with the VR headset tool and to use and do investigations on teaching and learning using this tool.

CHAPTER 2: LITERATURE REVIEW

Introduction

With the successful six-month-long reconnaissance flyby mission to Pluto, the New Horizons spacecraft sent large amounts of data to Earth telling scientists about the dwarf planet (Ennico, 2015). Access to advanced data image processing enabled through geographical information systems and other instruments on Earth, as well as in the science payload of spacecraft like New Horizons, continue to inform planetary scientists about the surfaces of planets in our solar system. Large data sets sent from space are translated into images available for consumption using fulldome planetarium simulation and virtual reality headset software. This multimedia approach to planetary and lunar flybys opens possibilities for not only scientists, but for students to study planet surfaces in depth (Ennico, 2015; Shevchenko, Rodionova, & Michael, 2016).

As more and more datum become available for study, our knowledge of the solar system prompts changes in teaching and learning in college introductory astronomy courses. Possibilities for a dynamic presentation platform to teach content reveal themselves through use of fulldome planetarium media, or for situations where planetarium access is limited, through use of a virtual reality headset. Because there is a paucity of literature on using these multimedia tools for teaching introductory college astronomy the topic is timely and warrants investigation.

Literature for examination in this review was nascent for the virtual reality headset and for motion sensor devices. Literature on planetaria spans decades so I concentrated on fields such as engagement and simulations as well as looking at literature on the two tools. Concentrating on peer reviewed literature from the past ten years revealed papers on planetaria, simulations, engagement, and design-based research. Empirical work on virtual reality headsets and planetary data sets was emergent with scholarly works coming from NASA technical reports, conference proceedings and abstracts. This study took two semesters to complete so new literature, findings, and scholarly works informed knowledge on virtual reality headsets and motion sensor devices used within the fulldome planetarium theater. The literature review was adjusted and updated to reflect the most current research.

Simulations

According to Smetana et al. (2012) simulations are defined as "computer generated, dynamic models of the real world and its processes" (p. 1138). The model represents the real world process and the simulation is the operation of the system over time. In this section of the literature review I examine the theme of simulations, what they are, and how they are used to examine teaching and learning not only in astronomy but in other disciplines.

In this section on simulations, a book chapter, a peer reviewed paper, and one literature review are described. The book chapter discussed student-centered learning, the peer reviewed paper dealt with a framework for using simulations to teach nursing, and the literature review covered simulations and their general use as a multimedia teaching tool.

Three empirical studies on the subject of simulations were also chosen. The studies covered use of simulations for teaching oceanography, chemistry, and astronomy. These studies were relevant to this dissertation because of their use in teaching and learning. Other potential literature examined was emergent with a paucity of empirical research findings.

A book chapter by de Jong (2011) discussed computer simulations that offer instructors the opportunity to extend student-centered learning options in a guided and supportive setting afforded by scaffolding instruction using simulations. A focus of de Jong's work is the question of guided discovery and pure discovery and the role of the instructor, but the information most apropos to this research was the question of whether people learn better through simulations or with conventional instructional tools. The research investigated why learning with simulations could be better than conventional learning methods. Findings revealed that these considerations depend on the learning goal.

In comparison to face-to-face instruction, simulations offer multiple representations that lead to deeper and more abstract knowledge (Chiao, 2017; Mayer, 2009; Zotti, Wilkie, & Purgathofer, 2006). Simulations also differ from real environments because they allow students to spend more time on task and they allow the task to be manipulated, for example when a student or instructor speeded up or slowed down a task.

De Jong posits that simulations can be used for training and that the interface may even be a physical one. In the case of nursing education the physical interface is a high-fidelity (realistic) mannequin that showed physiological response. Other historical uses of simulations for training avoided risk for both operators and subjects, such as using simulators for flight training and in the military. In the case of this study the content is the lunar surface using a flyby display. Simulation tools, when used here, are appropriate because real world experience with a lunar and lunar geology is prohibitive due to distance and expense.

Finally, de Jong discussed the merit of students reflecting on their progress and knowledge integration. He examined the effects of self-monitoring and reflective support as they helped to create well-connected knowledge integration. According to this book chapter when students have a chance to do a self-reflection they activate prior knowledge, which helps them assimilate and use new knowledge.

Jeffries (2005) makes the case for using simulations in nursing. Shortage of skilled time on task experiences plus the ethics of having students practice on patients have long been topics of discussion in this field. Jeffries created a model for teaching with simulations that uses five components with associated factors (see Figure 5). Although she says that all factors may not be relevant to all situations, her model provides a context for relating the factors. This model reflects best practices in education with the caveat that success in its use depends upon three features: the instructor, the student, and the model itself. Factors may be changed to reflect the use of the model to other disciplines and with different simulation tools.

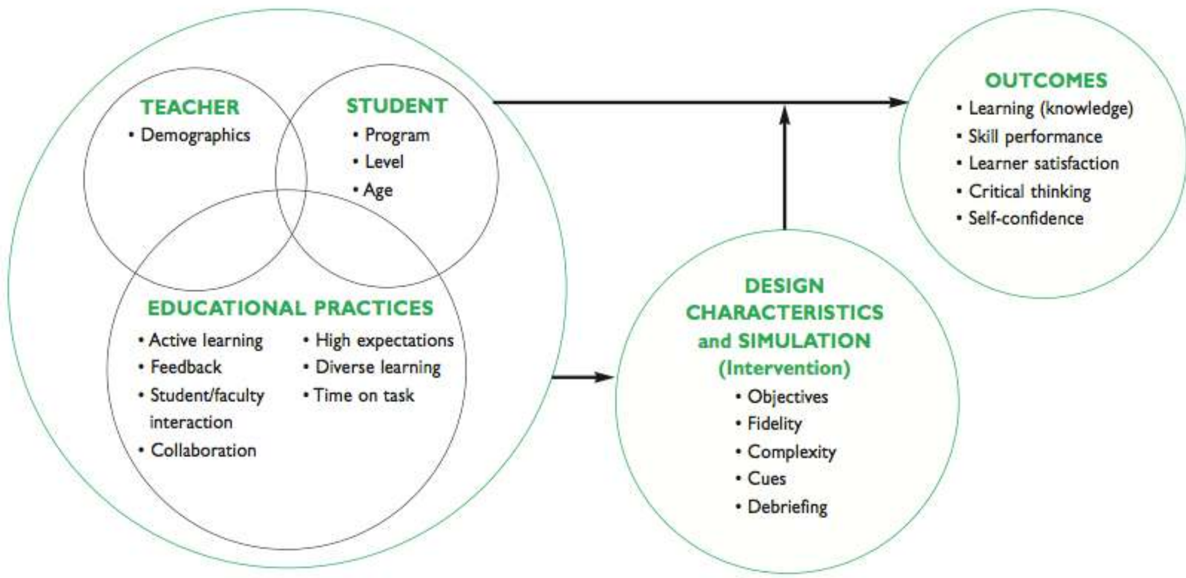


Figure 5. Five component simulation model with factors designed for teaching nursing students. Adapted from Jefferies, P. R., (2005). A framework for designing, implementing, and evaluating simulations used as teaching strategies in nursing, *Nursing education perspectives*, *26*(2), p. 97. Copyright 2005 by National League for Nursing.

Smetana et al. (2012) review literature on using computer simulations to teach science. This paper is a review of 61 empirical studies and suggests that the use of simulations to teach science content can be as or more effective than traditional lecture and textbook-based instruction. The authors forward the position that computer simulation in science instruction can be more effective than physical, hands-on, study such as in a laboratory situation. However, the authors further state that simulations are most effective when they are used to supplement rather than supplant traditional methods.

Specific research-based guidelines for best practices include use of high-fidelity support structures such as realistic content and/or models and use of student reflection (de Jong, 2011; Jeffries, 2005; Vazquez et al., 2016). Using simulations to promote cognitive dissonance is mentioned specifically. Where this was not expressed in the two previous works reviewed, cognitive dissonance is one of the factors to promote conceptual change used by Posner, Strike, Hewson, and Gertzog (1982). Previous works reviewed mention that teaching with simulations can affect conceptual change and supplant alternative conceptions and misconceptions with contemporary science knowledge when used to demonstrate concepts in astronomy that are difficult to observe in real-time.

The final three publications reviewed are empirical studies coming from the disciplines of astronomy, chemistry education, and oceanography. In these studies simulations were used to determine the benefits or liabilities of using them for problem-solving, for understanding molecular structures, and for determining the benefits of face-to-face experience versus simulated experience on learning.

In Shin, Jonassen, and McGee (2003) the simulation consisted of the "integrated multimedia program Astronomy Village" (p. 10). Astronomy Village was produced by NASA to enhance the middle school science curriculum. The interface is a village-like group of major observatories on mountaintops. Students work in teams of three to solve problems related to astronomy. Resources the students use include video clips, images from the Hubble Space Telescope, audio clips of scientists discussing their work, and computer animations and graphics. In this simulation, factors to be manipulated consisted of vignettes created by the researchers of well-structured and ill-structured problems in order to measure problem solving skills learned through the simulation software. Independent factors measured were domain knowledge, metacognition, science attitude, and justification skill.

The researchers that created Astronomy Village asked whether well-structured problem skills are sufficient for solving ill-structured problems. They also wanted to know what the relation between well-structured and ill-structured problem solving was within the same domain. Since this was a study using a simulation to examine problem solving skills it relates to the design-based research method used in this dissertation since factors in the simulation change as data were collected. Research confirmed the importance of well-organized domain knowledge when solving problems. Learners were required to justify their solutions to problems and to argue for the efficacy of their solution.

The investigation sought to engage 9^{th} grade learners in scientific inquiry as well as introduce astronomy concepts. Although the measure was for well-structured and ill-structured problems along with independent factors, this paper was included as one of the few investigations using a software interface simulation. Astronomy Village was an early CD-ROM open source software that is available through NASA Educator Resource Centers nationwide. Although simulation technology has advanced over time, Astronomy Village, developed in 1994, remains in use today.

Discussion among higher education faculty exists on the merits and drawbacks of using simulations to create online laboratory courses. De Jong (2011) talks about using simulations for virtual laboratory classes in biology and chemistry and their use in teaching distance education courses as well as face-to-face courses where content is deemed too hazardous for use in all but the most specialized of facilities or too small to be seen with the naked eye or with conventional telescopes or microscopes. The next empirical paper under review examined a series of three experimental studies used in conjunction with faculty support using simulations to aid in the understanding of chemical structures and properties.

Urhahne, Nick, and Schanze (2008) compared 3D computer simulations with two-dimensional textbook renderings of carbon in an effort to measure effect on understanding in freshman college students. According to Mayer (1997) meaningful learning is facilitated by the use of multimedia simulations because the learner is allowed to select the most important information to advance his/her own learning. This is possible because there are many modes of text, graphics, audio, animation, and visual present in a simulation. The paper by Urhahne et al. (2008) employs Mayer's generative theory of multimedia learning. This theory places the learner in the role of constructor-of-their own knowledge and puts the instructor in a facilitating role.

In this study, first year university students completed pre-tests and post-tests to determine the effectiveness of 3D simulations for learning chemistry. Computer supported learning with a 3D structural simulation was used for learning chemical facts and concepts.

Conclusions drawn from using 3D simulations to teach chemical processes tell us that unless the student has no prior knowledge of the process there is no difference between using a simulation and using a text (Urhahne et al., 2008). There was some emerging evidence for the relationship of spatial ability and learning concepts. The use of simulations was helpful for teaching introductory students these concepts rather than students with some existing knowledge of chemical structures and properties. In other words, students with low pretest scores did better in chemistry when using the simulation than students with higher pretest scores. The study had a similar participant demographic as this dissertation because participants were non-majors in the field examined.

The final paper (Winn et al., 2005) looked at the theme of simulations for learning involving the discipline of oceanography. This paper was chosen because similar to space, not all students have the ability to go out on the ocean for their coursework. This empirical study examines how students learn oceanography from an interactive computer simulation versus spending a day on a research vessel doing measurement of the ocean directly. Results showed that the field experience helped contextualize learning for students but that simulations helped them connect the information to what they learned in class. As with de Jong (2011) who asserted that use of simulations help activate students' prior knowledge, educators know that building this activation bridge between what students already know about a topic helps them to assimilate their new understandings.

Planetaria

Planetaria are considered both places and content. The place is the domed theater, and the content is software presented by computer and formulated for two projectors (Marche, 2005). As mentioned earlier, in operational definitions, this digital formulation by projectors is termed fulldome. Because a planetarium is composed of a structure and software combined this differs a bit from a virtual reality headset. A fulldome planetarium is a place; usually a building, and a virtual reality headset is a tool that can be picked up, moved, and attached to a computer for use. This gives the virtual reality headset an affordance of portability that exceeds even the most portable of planetaria, the inflatable planetarium.

Lantz (2011) as well as Plummer, Schmoll, Yu, and Ghent (2015) wrote papers to inform the practice on changes in planetaria software and hardware, and conducted educational research in planetaria respectively. In Lantz (2011) digital fulldome planetaria extend content beyond night-sky astronomy. These immersive visualization environments suggested alternatives for teaching and learning that go beyond traditional classroom lecture formats. Lantz (2011) asserted the need for a public space where participants learn in a group setting and collaborate to construct new knowledge. This group setting and the collaborative experience it creates makes the planetarium different from a virtual reality headset, a sole viewer experience.

Plummer et al. (2015) provides guidance pertaining to planetarium-based research in astronomy education. This research examined affective aspects of learning such as motivation, interest, and engagement. The team of researchers created a figure to examine the four quadrants of research; formal structured and controlled learning both in the dome and out of the dome, and informal learning that places an emphasis on social elements of an audience's visit both in and out of the dome.

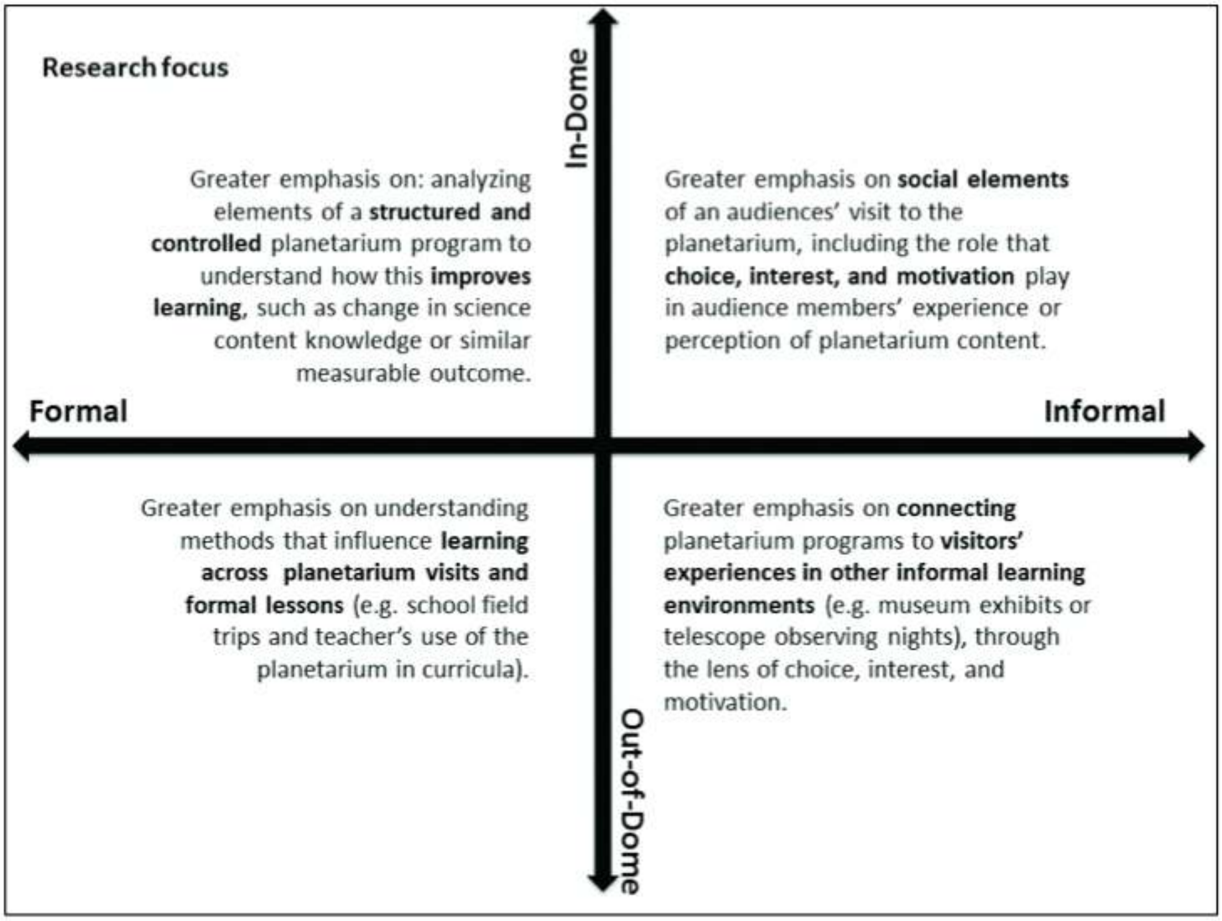


Figure 6. The four quadrants of planetarium research. Adapted from "A Guide to Conducting Educational Research in the Planetarium," by J. D. Plummer, S. Schmoll, K. C. Yu, and C. Ghent, 2015, *The Planetarian*, *44*(2), p. 11. Copyright 2015 by International Planetarium Society.

Lantz (2009) regards scientific visualization using digital domes as a successful method for teaching science content. Scientific visualization is defined as a tool for scientists to represent and investigate complex data sets. He argued that because astronomy is an observational science with distances that make it impossible at this time for human travel to its outer reaches that the universe can be known through the tools of scientific visualization. Lantz (2009) posits that the role of scientific visualization has use for teaching and learning in the classroom.

In the empirical study by Türk and Kalkan (2014), a quasi-experimental design was used to study the effect of teaching using a planetarium with 12-13 year olds for changing in their knowledge levels of the solar system. The researchers compared a group of students whose face-to-face instruction was delivered using the curriculum called “Solar System and Beyond” as a control group. Another group experienced instruction created by the researchers to cover content presented in “Solar System and Beyond” but adapted for the planetarium using the astronomy education program called Stellarium. Conclusions of this study suggest that students in the concrete operational stage of development find that the simulated environment of a planetarium helped them understand abstract concepts. In this case 3D simulation modeling of abstract concepts can be imparted through alternative methods such as the immersive environment of the planetarium.

The final paper reviewed in this section on planetaria is a technology review covering the types of planetarium software that can be used to teach standards-based lunar concepts. According to Trundle and Bell (2003) virtual planetaria, or planetarium simulations available for desktop computers, maintain good fidelity and are among some of the most realistic tools that can be used outside of a dome theater. These authors posit that software such as Starry Night have the potential to enhance astronomy instruction because they are relatively easy to learn yet are powerful enough to simulate the night sky much like the more advanced software programs in a planetarium. From here the discussion of virtual planetaria segues into the next topic of virtual reality. Trundle and Bell (2003) also investigated alternatives beyond that of portable planetaria. They investigated planetarium software that made a jump from an actual planetarium space to a single user experience. Virtual reality and virtual reality headsets take that extension one step further to a simulation experience that you wear on your head like a large pair of goggles.

Virtual Reality and Virtual Reality Headsets

Virtual reality is a computer-generated simulation of an environment or three-dimensional image. This image can be interacted with in a seemingly physical was using a VR headset. For this section on virtual reality and virtual reality headsets there is a paucity of empirical literature for review. Literature presented here consists of two review papers, a conference poster and abstract, and two scholarly papers. Both review papers deal with the Oculus Rift virtual reality headset and according to Desai et al. (2014) the headset gives the user the experience of being present in an environment. Using the factors of resolution, quality of visuals and effectiveness of visuals as well as sight, sound, touch, and movement this tool can be used without the simulator sickness and dizziness that earlier version headsets presented.

The virtual reality headset investigated by Desai et al. (2014) has advanced head tracking using a sensor that includes a gyroscope, an accelerometer, and a magnetometer. These tools collected data after a user profile is entered into the headset software. Along with data collected from the three sensor devices, the orientation of a person's head was determined. Because of individual captured participant data, these sensor devices enabled the user can look around in the virtual world the way they can in actual reality since it was a customized user experience.

In a paper by Goradia et al. (2014) a comparison study of two virtual reality headsets looked at limitations in both. These headsets were tethered to either a personal computer (Oculus Rift) or a Sony PlayStation (Project Morpheus). Each device was geared for use with different software. Oculus was compatible with open source and commercial software while Project Morpheus was limited to software developed for Sony PlayStation. The study looked at affordances and constraints of each brand of headset. Conclusions made by Goradia et al. (2014)

state that this technology was making its way to the consumer market not only for gaming but as a way to demonstrate things such as planetary or lunar flybys that could be used in teaching.

Civet and Le Mouélic (2015) used virtual reality headsets to navigate Martian landscapes rendered from large data sets gathered by NASA's Mars Global Surveyor, the European Space Agency's Mars Express, and NASA's Mars Reconnaissance Orbiter spacecraft. Instruments on each spacecraft recorded data that were rendered into Digital Elevation Models. These models were then created for use with a virtual reality headset and consumed by researchers via virtual Martian flybys.

Two scholarly papers reviewed come from different orientations on virtual reality, the first under review was an overview of the technology itself, and the second discusses the educational aspects of virtual reality. In the first work, Boas (2013) posits that using virtual reality allows consumers of the media to be able to interact with knowledge to the point of immersion. He defines immersion as the suspension of disbelief or absorption in media and describes three types of systems in virtual reality.

The first system is described was the non-immersive system similar to those outlined by Trundle and Bell (2003) in the section on planetaria. Although not very immersive for a virtual reality system, they were available and in use. Semi-immersive virtual reality systems combine high performance software with haptic feedback and stereoscopic vision. Flight simulators are an example of semi-immersive virtual reality systems. Lastly, fully immersive systems have high fidelity graphics and performance. They follow the multi-media principles of Mayer (1997) by avoiding cognitive overload through unrelated stimuli. Fully immersive systems give the consumer an awareness of their virtual surroundings through their perception of the surroundings using the physical senses.

According to Minsky (1980) fully immersive virtual reality also has telepresence. Telepresence is the feeling that you are somewhere else, but the feeling is real. Coined by Marvin Minsky in 1980 this term is connected to the concept of immersion. Minsky did work on artificial intelligence at the Massachusetts Institute of Technology and is credited with inventing the first head mounted graphical display in 1963. A head mounted graphical display was the pre-cursor to modern virtual reality headsets.

The next scholarly paper discusses the educational aspects of virtual reality. Boas (2013) talks about ScienceSpace as educational software supported by a head mounted display. This application contained three different applications to teach physics. It consists of a virtual world built by a collaborative team in 1990s. Dede, Salzman, and Loftin (2005) believe that virtual reality immersions can help students understand complex abstract material. The paper described the creation and refinement of virtual world vignettes. These virtual worlds, each of which is named after a particular scientist, relate to his field of expertise, and are branches of the immersion (Loftin, Pettitt, Su, Chuter, McCammon, Dede, & Ash, 1998). All three of these virtual reality worlds were described and assessed for usability and learnability. The intent of the paper was to develop a theory of how multisensory immersion helps with learning. Careful selection of factors used in the design can create the conditions for optimal motivation and concentration for student mastery of difficult material. Conclusions drawn indicate tools such as these exploit 3D visual and multi-sensory displays, enabling collaboration and computational steering among participants. This article informed the study because participants manipulated a flyby, similar to the computational steering described here but in this study used collaboratively. Collaboration is not studied in this dissertation but this paper presents those possibilities to explore in future research.

Multimedia Learning

When considering teaching and learning using multimedia tools it is important to discuss multimedia principles. Cognitive load theory is a multimedia principle that deals with working memory and long-term memory. When considering working memory it is first necessary to consider long-term memory. Long-term memory is where a base of knowledge is stored. Knowledge is then transferred to working memory where it is used. Working memory is where new information is processed and working memory has capacity limits. According to Sweller (2010) cognitive load theory is based on knowledge of the mind. A principle of cognitive load theory states that information being present places a load on working memory and that working memory has limited load-bearing ability. When working memory reaches cognitive overload the ability to process and remember new information becomes less effective. Because multimedia learning incorporates many factors, it is important to be cognizant of its design. Understanding multimedia principles provided the foundation for going forward with this study and were considered when structuring the questionnaires and the small group interview protocol.

Multimedia learning in advanced computer-based contexts presents special problems. In the two book chapters examined the particular points of interest necessary to avoid cognitive overload are addressed, along with factors and examples where virtual reality and simulation concepts have potential for use in teaching and learning.

Using virtual reality for education brings a unique set of factors into play. One of the methods used to measure effectiveness of virtual environments is the Simulator Sickness Questionnaire (Cobb et al., 2010; Kennedy & Fowlkes, 2009). Simulator sickness is an important factor when using a treatment involving virtual reality headsets because technology developers focus on this issue as a factor in participant comfort and take this into account when they design content.

Dealing with characteristics of simulation brings up some of the same concerns as other multimedia research. These concerns prompt questions about the role, influence, and effects of different elements of a simulation on cognitive load theory and on learning (Rieber, 2010). Similar to research by de Jong (2011), simulation research concerns the amounts and level of support and scaffolding students' need from the instructor to discover and understand the underlying simulation model. When using simulations for scientific learning students are prone to confirmation bias and alternately benefit from model progression (de Jong & van Joolingen, 1998). Confirmation bias is the tendency to design scientific inquiry with the conclusion in mind. Model progression is the theory that students develop in their understanding of the information and concept as the simulation gets progressively more difficult.

Learner Engagement

Sinatra, Heddy, and Lombardi (2015) wrote an introduction to a special issue publication dealing with engagement in the context of science learning. In this article engagement is introduced in different terms and measured on a continuum. The terms introduced in this article were behavioral; which covers persistence and effort; emotional, which covers a student's reaction to a subject; cognitive, which covers psychological investment in learning science; and agentic engagement, defined as when students are proactive with their own learning. Engagement is also measured in what the authors call grain size or degree of engagement from a micro level grain size to a macro level grain size.

The next two empirical studies examined learner engagement and student learning. The first study examined how engagement was associated with academic performance (Carini, Kuh,

& Klein, 2006). The sample size examined was large and consisted of 1,058 college students. According to Carini et al. (2006) student engagement is considered to be a predictor of learning and development. Learner engagement is defined as student interest and involvement with all aspects of education. When a student is engaged they are active in learning. In this study engagement was measured through analyzed student test scores, grades, and engagement results from the National Survey on Student Engagement. Engagement also involves the level of interest a learner has in a topic. When a student has a high level of interest in a topic of study they tend to spend more time on that topic and this is reflected in deeper understanding of the content. Results of this study indicated that lower-ability students benefit from engagement. This may or may not translate into the student demographic chosen for this study but the linkages between lower-ability and students with little preparation in the field of astronomy make this study worthy of examination.

In the second study Kuh, Cruce, Shoup, Kinzie and Gonyea (2008) link learner engagement not only to academic performance but to persistence. In this study, data were collected from a large participant sample across 18 different institutions of higher education to determine if the effects of engagement differ by student characteristics and prior academic achievement and whether engagement during the first year of college has impact on retention and grade point average. The authors conclude that the compensatory effects of engagement can sustain learners through difficult content on to understanding the targeted material.

Purpose and Research Questions

The literature reviewed in this chapter supports the purpose of the study, which seeks to examine the affordances and constraints of two simulation tools to teach lunar geographic and geologic characteristics using a lunar flyby in the context of undergraduate introductory astronomy courses at a two-year college.

Two research questions guided the study:

1. What optimal lunar flyby speed do college students report comfortably using to manipulate a flyby of the Moon using a motion sensor device in the college planetarium?
2. What variety of experiences do college students have while learning astronomy when manipulating a lunar flyby using fulldome planetarium software and virtual reality headset simulation?

CHAPTER 3: METHOD

Introduction

This chapter outlines the procedures used to collect and analyze the data. Further detail is given to describe the framework that guided the research and the method adopted for conducting the study. An overview of the quantitative design-based research method and the qualitative phenomenography research method that informed the study are presented here with rationale for their use. Design-based research and phenomenography are discussed and why these methods are appropriate for a study of this type. Time is spent discussing the context and participants of the study, followed by a description of the methods of data collection and the procedures for data analysis. Lastly, the role of the researcher, trustworthiness, and the ethical considerations in connection with this research are addressed.

Intentional Choice of Multimedia Design Principles

According to Mayer (2009) learning is quickened when words such as printed and spoken text are used in concert with graphics, such as animations, photos, charts, illustrations, graphs, or video. This multimedia form of instruction adheres to principles of multimedia design. Principles of design enhance usability, influence perception, and teach (Lidwell, Holden, & Butler, 2010; Mayer, 2001). I looked at the principles of Mayer (2009) and used the principles of Lidwell et al. (2010) when structuring this study.

Design-based Research, the Method used to Answer Research Question One

Research question one asks what optimal lunar flyby speed do college students report comfortably using to manipulate a flyby of the Moon using a motion sensor device in the college planetarium? Design-based research (Barab & Squire, 2004; Hoadley, 2004; Sandoval & Bell, 2004; Walker, 2011; Wang & Hannafin, 2005), also called design experimentation (Brown, 1992; Collins, 1992; Collins, Joseph, & Bielaczyc, 2004), was used to test lunar flyby speed. This method was chosen as a way to create a piece of curricular content that can be used to teach lunar geology using a flyby deployed with a motion sensor device in the fulldome planetarium with college students taking introductory astronomy. When looking at the history of design-based research, previous studies reviewed make design-based research a good methodological fit to answer this question.

Introduced in the early 1990s, design-based research (the term that is used to describe both design-based and design experimentation) extends existing research methods to address the issue of linking theory to practice. According to Wang et al. (2005) design-based research is defined as:

> …a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories. (p. 6)

It is the aspect of iterative analysis of design, using feedback data gathered in a real-world setting, which makes a design-based research approach appropriate for this study.

The design-based research component of the study was done using a motion sensor device (MSD). I had access and permission to use and alter the lunar flyby speed within the Digistar 5 software program by the script author, a professional colleague directing operations at the NKU planetarium. The design-based research portion of this study was done using data collected over two semesters from participants using the MSD in a college planetarium.

Salient Aspects of Design-based Research

Aspects of design-based research have a real-world context. Use of a method that includes a real-world context is appropriate for this study because the participants were taking introductory astronomy and the content applied directly to their curriculum. According to the

Design-Based Research Collective (2003), an appropriate reason to employ design-based research as a method is its use to improve instructional practice. Findings from the research done here are used to inform the practice of teaching and learning introductory college astronomy. Design-based research affords the possibility for creating and exploring novel teaching and learning environments. Teaching and learning using fulldome planetarium simulations and virtual reality headsets is timely. Design-based research is used by scholars doing experiments that involve testing new innovations in teaching. According to Brown (1992) and Collins (1992) repeated design experiments like this contribute to 'design science' in fields such as aeronautics or artificial intelligence. These types of technical fields lend themselves well to a study of simulation tools. Design-based research as a method is systematic yet flexible and uses iterative review over many weeks to analyze and develop educational designs (Reimann, 2011). The design of the Simulator Sickness Questionnaire, the Immersion Questionnaire, and the small group interviews were created using the multimedia design principles of Lidwell et al. (2010). The design principle of figure-ground relationship manifests in the Simulator Sickness Questionnaire. The design principles of biophilia effect and cathedral effect manifest in the Immersion Questionnaire and the small group interview question protocol. Iteration and the feedback loop informed the study to answer research question one and immersion was the overarching principle that informed research question two. These intentionally chosen variables provide a frame to examine both simulation tools.

Iteration

According to Lidwell et al. (2010) iteration is "a process of repeating a set of operations until a specific result is achieved" (p. 142). Iteration is a component of the feedback loop. Each loop in feedback is an iteration or repetition with changes informed by the data analysis feedback. This study was guided by the design-based research norms (Barab et al., 2004; Squire, 2011) of intervention and change. I applied the intervention—in this case, the speed of the lunar flyby, and documented the change. Then I examined the recorded data and from this and from my real time observations, I made conclusions about speeding up or slowing down the flyby speed and changed the software program script to reflect the new flyby speed. In other words the intervention was altered to reflect information gained from the change and this altered intervention was used with the next participant. I kept repeating this pattern until the same results occurred again and again.

The Feedback Loop

A feedback loop is a relationship between variables in a system (Lidwell et al., 2010). Variables examined using the MSD were performance over lunar flyby speed. Performance was examined as a factor of simulator sickness and immersion. The feedback loop was an important factor because it aided the design-based research method. This factor was considered an imbedded factor for purposes of this research because the method was informed by data collected. A feedback loop is defined as a process where input into the system affects and informs changes to the system. As an example, data collected from participants after using the simulation tool was fed back into the system as changes to the software the MSD displayed in the fulldome planetarium. This modified the next iteration of content that the participants viewed.

Data saturation, knowing when to stop taking data (Fusch & Ness, 2015; Mason, 2010; Walker, 2012) was achieved when the same results keep emerging over and over. I incorporated the principle of feedback loop into the design-based research component and used the reactions participants had to the increased speed to as well as data taken and examined these to inform changes to the flyby speed.

According to the work of Forrester (1997), there are two types of feedback. These are negative feedback and positive feedback. I analyzed the Simulator Sickness Questionnaires for negative feedback. Negative feedback dampens output (Lidwell et al., 2010) because when participants are feeling sick they are not able learn about the Moon. I made changes in the flyby speed to minimize the feelings of sickness.

Looking at the effect of immersion as a feedback loop helped me make changes to the flyby speed. A high immersion score on the questionnaire was good. It meant that the participants were more involved in the simulation. The greater the feelings of immersion in the simulation the higher the ordinal indicator on the positive side of the feedback loop. Positive indicators told me the participants were more immersed in the simulation and to keep these numbers in the positive, or immersive state I would change the flyby speed and then look at the data before making changes for the next group of participants.

Relationship

Figure-ground is a form of perception where information needed to identify an object or figure from the background comes in to the brain through the sense of sight. It is vital for basic recognition; for example children learning to read must be able to perceive the words, usually written in black type, from the white paper background that contains the words. The Simulator Sickness Questionnaire was the instrument that measured figure-ground awareness because when participants used a simulation tool they could have felt sick. This figure-ground sickness symptom is what happens to your perception when viewing op art images. Simulation content can give the viewer an impression of hidden images, swelling, warping, or vibrating patterns that could cause sickness symptoms.

Immersion

Immersion is a state of intense mental focus where the participant becomes so engrossed in the simulation that they lose track of space and time. Csikszentmihalyi (2000) describes this as the mental state in which a person performing an activity is fully involved and absorbed in what they were doing. In the context of simulation, the term immersion is used to describe the users' reaction to the virtual world in terms of emotions. When immersed the user feels as if they are actually part of a virtual world. Ryan (2001) talks about immersion as a balance between the under taxed and over taxed system. Similar to the zone of proximal development (ZPD) of Vygotsky (1978), immersion is a state of mental focus where a sense of time and the actual world are lost only to be replaced by a feeling of satisfaction. This usually happens in a balanced system where the activity is neither too difficult nor too easy.

The biophilia effect. The effect of biophilia, or preference for nature describes any number of positive experiences when interacting with living things and the natural world (Baldwin, 2012; Grinde & Palil, 2009; Gullone, 2000). Biophilia was intentionally tested for in this study because the Moon is an object in nature. The biophilia effect assumes that environments rich in views and imagery reduce stress and enhance focus and concentration (Wells, 2000). In this case the nature views would be the in-depth renderings of the lunar surface that came from the large NASA data sets sent to Earth via satellite technology. The environments tested were geologic and geographic in nature. Testing included close views of planet surfaces versus farther distant landscapes, with participant data collected after each iteration to determine optimal viewing in light of changes made to the design factors of speed. Changes in speed affected how well participants controlled the avatar during zoom in, zoom out, and rotation.

During development of this study the Immersion Questionnaire was constructed asking questions to determine the effect of biophilia. These effects were revealed through examination of the written comments and audio transcriptions of small group interviews. Participants also recorded comments on the back of their Immersion Questionnaire describing experiences with the simulation.

The cathedral effect. The cathedral effect is the relationship between the perceived height of a literal ceiling and the way it affects creativity and concentration. These perceived high ceilings promote abstract thinking and creativity. On the other hand, a perceived low ceiling promotes the ability to focus and perform detail-oriented work (Meyers-Levy & Zhu, 2007). In the case of fulldome simulation and virtual reality headsets, the overall ceiling is determined by the perception of height that the participants indicate in the simulation.

Lidwell et al. (2010) discusses the cathedral effect as coming from the perception that there is a relationship between ceiling height and the type of processing people do. High ceilings and bird's eye views induce creativity and freedom. Manipulation of an avatar in space to observe a lunar flyby in the 30-foot dome of the planetarium may be considered a bird's eye view. Low ceilings and wearing the virtual reality headset could induce a close and intense space considered a worm's eye view.

Bird's eye view. High ceilings prime creativity and freedom (Meyers-Levy et al., 2007), and a bird's eye view is an elevated view of an object from above. Part of the cathedral effect comes from the perspective of two foci, a high foci of bird's eye view as associated with creativity and the ground level view of worm's eye view associated with focus and concentration. During data analysis, both of these views are discussed under the umbrella of cathedral effect.

Worm's eye view. As said before, according to the cathedral effect of Lidwell et al. (2014), low ceilings enhance focus. If the MSD is postulated to give the impression of creativity and freedom due to its use in the 30-foot planetarium dome theater then the VR headset by its blinder-like headset apparatus could enhance focus and attention. Worm's eye view is from the vantage point of a very small being (a worm) looking up. The relationship between the VR headset and worm's eye view is that participants are wearing a device and that this closes in their field of view so they only see and hear what the simulation presents thus keeping them focused.

Retrospective Analysis as a Stance

In a design-based research study the iterations of treatment and data gathering inform changes as the design goes forward. My data were continually examined in retrospect. Earlier events opened up, constrained, and enabled the events that followed (Cobb, Confrey, Lehrer, & Schauble, 2003). The development of theory, in this case an instructional design informed by testing intentionally selected factors, and the iterative analytic nature of this method were useful tools for doing this study because I was looking to gather information on these two simulation tools in light of a variety of participant experiences.

Rationale for Using Design-based Research

The motivation for choosing design-based research as a method to understand two simulations situates the study in the context of pedagogical practice (Reimann, 2011). Using the universal principles of design promulgated by Lidwell et al. (2010), design factors were intentionally chosen and then tested with participants. The design study was an extended investigation of educational interactions over two semesters where treatment was used and the design factors were adjusted by informed feedback from the participants. The method helped capture data used to determine optimal flyby speed for manipulating the Moon using a MSD. This iterative cycle was repeated until saturation was reached as designated by a similarity in data collected. A similarity of data collected indicated that the study was complete.

Design-based research is a highly interactive method (Cobb et al., 2003). One of the salient features of this method are bringing in new forms of learning, in this case two simulation tools, in order to study their effects on the teaching of introductory astronomy. This study of the phenomenon of using the two simulation tools and the various lived experiences of the participants as their comments inform the iterations makes this method work well.

I used two methods to answer the research questions. The first research question on optimal flyby speed was answered using a design-based research method to inform to changes to lunar flyby speed when participants manipulated it in the planetarium using a MSD. Data sources used to collect information on the change were the Simulator Sickness Questionnaire, the Immersion Questionnaire, and comments analyzed from the small group interview transcripts. Phenomenography, the various experiences participants have using each tool, was the method used to answer the second research question on the variety experiences participants had using the MSD and the VR headset. Data sources used to collect information on these experiences came from comments participants wrote on the back of their Simulator Sickness Questionnaires and their Immersion Questionnaires after experiencing each simulation. I also analyzed the transcribed small group interview sessions.

Phenomenography and Coding as an Approach to Answer Research Question Two

Research question two asks what variety of experiences do college students have while learning astronomy when manipulating a lunar flyby using fulldome planetarium software and virtual reality headset simulation? Data collected from participants using the VR headset consisted of two questionnaires, written comments on the questionnaires, and transcribed small group interview data. The same data sources were taken when participants used the MSD. Data were captured in the same manner for both tools but only the MSD lunar flyby speed was altered and data was analyzed quantitatively for question one and qualitatively for question two. When participants experienced a flyby speed change only on the MSD speed was changed within the scripting of the Digistar 5 fulldome planetarium program.

The methodological approach taken in this study was phenomenography (Bodner & Orgill, 2007). Phenomenography provides a lens where decisions informing the progress of the study can were examined (Crotty, 1998). Phenomenography investigates the variety of experiences participants have when learning. Stemming from qualitative research (Patton, 2005), phenomenography supports this investigation of the different experiences each participant had when learning with the two simulation tools.

Phenomenography is the study of perceptions people have of the world around them and the variety of meanings people make from their perceived experiences. It focuses on the various meanings people make of these experiences (Orgill, 2011) and deals with the variety of experiences participants have with a phenomenon, such as the phenomenon of learning using a virtual reality headset or a fulldome planetarium simulation to experience a lunar flyby. Different than phenomenology, which are the lived experiences of a group as the group undergoes a common experience phenomenology deals with the whole of the shared experience, whereas phenomenography deals with smaller parts and variations of this shared experience.

Within the methodological approach of phenomenography there are two aspects to consider (Marton, 1981). The first approach posits research as something oriented toward the world. Statements made by participants provide information about various world experiences. The second approach, and the one chosen for this study, suggests that participants are oriented toward ideas and experiences of the world and make a variety of meanings from these experiences. These meanings may be different for each participant even when examined in light of a common experience. The experiences and ideas investigated in this study included the variety of ways college students engage with and experience the content of a lunar flyby while consuming this content using a MSD in the fulldome planetarium and a VR headset. The goal of this phenomenography study was to identify participants' various ways of experiencing the phenomenon of using the simulation tools.

Setting and Participant Selection

The study took place at a planetarium associated with a two-year college in the desert southwest. This planetarium is part of the physical science department and is used to teach astronomy lecture and laboratory courses during the week, host school field trips on weekday mornings, and offer public planetarium presentations during the weekend. It also hosts meetings of the local astronomy society. Of these types of planetarium patronage groups, participants selected were students taking an introductory astronomy course taught using traditional methods of lecture and laboratory. The courses selected were ones taught in the planetarium and were recruited from these sections. Enrollment in each course was capped at 40 students. The demographics met the study outcome and this study was supported by the college administration because results of the study were viewed as useful to inform the practice of college teaching using simulations. Recruitment from astronomy courses taught in the planetarium facilitated data collection because participants were already familiar with the planetarium thus reducing some of the novelty effect. All participants self-reported as physically and mentally healthy adults before undergoing the simulation and the sampling strategy used to select participants was a sample of convenience.

The study's participants were recruited from classes of AST 105 Introductory Astronomy Laboratory. This course was a listed in the course catalog as one of a choice of general education science requirements for graduation, and provided practical experience in observational astronomy. Participants took this course with or after AST 103 Introduction to Astronomy: The Solar System or AST 104 Introductory Astronomy: Stars and Galaxies. These were survey courses for studying nearby objects of the solar system, the formation and evolution of planetary bodies, and the exploration of space. The nature of light and gravity were also covered to help students understand the Sun, stars, and the planets. Planetary geology and physical geography were studied, as were comets, asteroids, and moons. All students were required to participate in the intervention described below as part of their normal classroom curriculum. As a caveat to this I explained that they had the option to allow me to use the data gained through their participation. It was made clear that they had control of the data given.

The first week during the recruitment and orientation phase all students in the target course spent 20 minutes completing an Informed Consent for permission to use/abstain from using the data. Each student was required to indicate consent to use data or deny use of data collected in class as part of the written paperwork requirements of the course. Participants were also allowed to deny or allow use of data at any point during the course. During the Fall 2016 semester five students either missed the opportunity to use these tools because they were absent, they dropped the course, or they recused themselves. During the Spring 2017 semester that number was four. One student in the Fall semester course when through the data collection process then changed his mind about letting the data be used for the study. This was noted on the data collection sheets and this data was not analyzed or used for any study purposes.

Student body demographic information was retrieved through the college administration (College Institutional Research, 2013) indicated that the student body had a median age of 27 years. The entire student body consisted of approximately 37,000 students enrolled with about 19,000 enrolled as full-time students. Student ages varied from under 18 to over 62 with the majority of the student population falling between 20-24 years old. Of this total enrollment number 55% identified as female and 45% male. Many students (27,000) received financial aid to support their education and 43% of financial aid applicants were considered first generation college students. First generation college student status was identified when students stated that neither parent attended college. Students at this institution represented a diverse ethnicity, with 27% of the total population Hispanic, 11% African American, 10% Asian, 4% multi-ethnic non-Hispanic, 2% Hawaiian or Pacific Islander, 1% Native American, 38% white, and 7% unknown. This college is a Minority Serving Institution and was recently designated as a Hispanic Serving Institution when enrollment rose above the U.S. Department of Education's requirement of 25% self-reported Hispanic to 27% self-reported Hispanic students. All data taken from the institution's research division concerning individual students was blinded per IRB standards to ensure that appropriate safeguards were upheld both for the participants and for reliability of the study outcome. All participant names used within this study were changed to pseudonyms and are shown in Tables 1 and 2. Individual demographic information was not collected from each participant, however, the four classes represented a general cross section of students attending this college.

Table 1
Participants by Pseudonym in the Tuesday and Wednesday Evening Fall Semester Classes

Semester	Class Section	Participant	Gender
Fall 2016	Tuesday Evening	Yuri	Male
		Christian	Male
		Shell	Female
		Maury	Male
		Walt	Male
		CeeCee	Female
		Dan	Male
		Monik	Female
		Damian	Male
		Jessica	Female
		Anna	Female
		Estephani	Female
		No	Female
		Chrystal	Female
		Josh	Male
		Jon	Male
Fall 2016	Wednesday Evening	Hristo	Male
		JiWon	Male
		Roxy	Female
		Joe	Male
		Brian	Male
		Steve	Male
		Lou	Male
		Seth	Male
		Ji	Male
		Jas	Male
		Teres	Female
		Val	Female
		Vaness	Female
		Ashlee	Female
		Juan	Male
		Yin	Male

Table 2
Participants by Pseudonym in the Monday Morning and Tuesday Evening Spring Semester Classes

Semester	Class Section	Participant	Gender
Spring 2017	Monday Morning	Dave	Male
		Aberham	Male
		Elaine	Female
		Nadia	Female
		Ash	Female
		Andrea	Female
		Yanniana	Female
		Ira	Male
		Whitnee	Female
		Prissy	Female
		Saul	Male
		Jazz	Male
		Dulce	Female
		Leo	Male
		Ed	Male
		Dan	Male
Spring 2017	Tuesday Evening	Steph	Female
		Kayla	Female
		KC	Female
		Darian	Male
		Raina	Female
		Gill	Male
		Rod	Male
		Chris	Male
		Chan	Male
		Auchmood	Male
		Corini	Female
		Alex	Male
		Edgar	Male
		Corey	Male
		Balish	Male
		Carol	Female
		Brianna	Female
		LeeLee	Female
		Will	Male

Design of the Treatments

The MSD, Microsoft Kinect was selected as the tool used for participants to manipulate a lunar flyby in the fulldome planetarium to determine the optimal flyby speed that participants could comfortably manipulate a lunar flyby. The MSD was integrated into the Digistar 5 planetarium software. Microsoft Kinect uses a red green blue camera with a depth sensor and infrared projector with a monochrome complementary metal-oxide semiconductor sensor. This sensor sees the environment as a series of dots arranged in 3D and creates an avatar on the dome that is used to experience the lunar flyby.

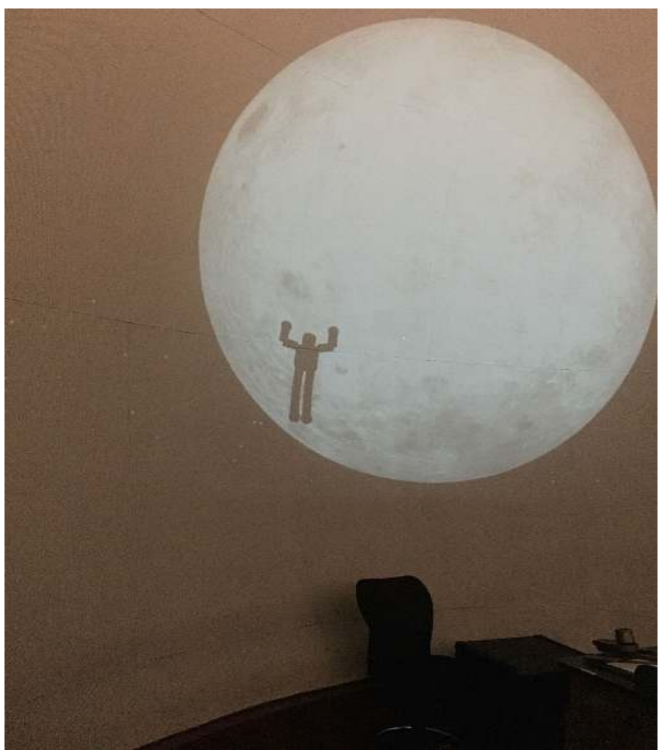


Figure 7. The dark figure represents the participant. A participant uses the Microsoft Kinect shown here as the dark figure with arms raised silhouetted in front of the Moon.

Participants experienced the MSD while standing before the device and looking at the planetarium dome to view the flyby. They manipulated the Moon by moving their outstretched arms in the manner of driving using a car steering wheel as well as using their arms and hands together to pull back and move forward similar to using a stick on an airplane.

When orienting participants to the use of the MSD I showed them NASA photo no. 84-H-71 obtained from a regional NASA Educator Resource Center as an example of how to use their avatar. This photo showed an astronaut using a manned maneuvering unit (MMU) in space. An MMU is a self-contained jet-pack that was used by NASA on three Space Shuttle missions in 1984. The MMU allowed astronauts to perform untethered spacewalks at a distance from the spacecraft. I asked participants to imagine the avatar represented them using an MMU in low lunar orbit to explore the Moon. After a brief tutorial and some experimentation each student was then instructed to manipulate their avatar towards the Moon, away from the Moon and to use the avatar to observe the surface of the Moon during the flyby.

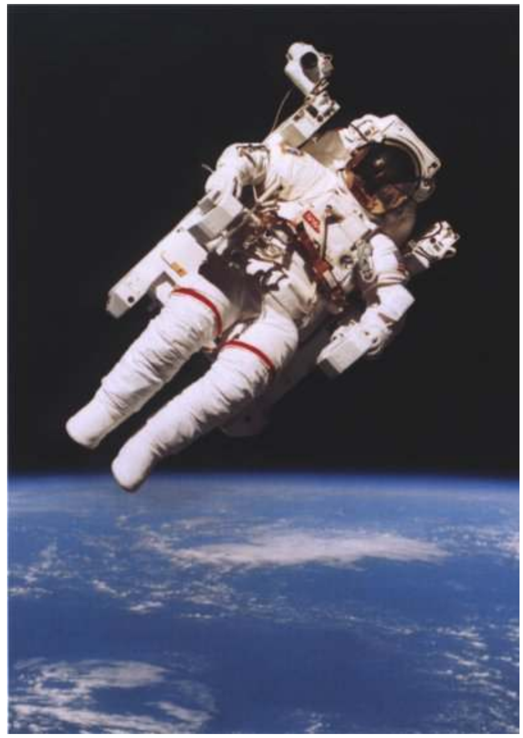


Figure 8. Astronaut Bruce McCandless on a spacewalk using the manned maneuvering unit. STS-41B, February 1984. Participants were shown this lithograph during the explanation of how to manipulate the avatar when using the MSD (NASA photo no. 84-H-71).

The VR headset used a commercial software program called Star Chart. Star Chart was developed by Chris Walley, co-founder of Escapist Games as a way to explore the universe with a VR headset and a game controller. When Oculus Rift began supporting the Gear VR controller for this system I made the intentional decision that Star Chart's lunar flyby gave the best experience comparable to the lunar flyby created at NKU. After working with other software programs for lunar flybys and working to wrap a sphere and create an original lunar flyby to use with the VR headset it was concluded that using a commercial software program gave participants the best experience with a lunar flyby and would yield appropriate data to answer research question. Access to game development coding within Star Chart for VR was not pursued due to permission, technical, and time limitations. The study was not a comparison of the tools so use of a commercial software product was not a confounding variable.

Participants experienced the VR headset in the virtual reality laboratory situated in the workroom behind the planetarium. They sat at a desk and wore the VR headset that included headphones. They used a hand held a game controller to manipulate the lunar flyby. Participants received a five-minute tutorial by a colleague on how to use the game controller to zoom in and out and investigate the Moon in low lunar orbit. After this tutorial, they had a chance to ask questions and try the device. When they were comfortable with operation of the VR headset and game controller they were instructed to use the device to zoom in towards the Moon, out away from the Moon, and investigate the lunar surface. The colleague assisting was able to see what participants saw using the headset on the computer monitor and was able to offer a re-direct or assistance if participants got off task or needed help. This colleague timed participants for five minutes of use on the VR headset then gave them the two questionnaires to complete.

Data Sources

Data sources used in this study were chosen and created to answer the research questions. Two questionnaires were used, the Simulator Sickness Questionnaire and the Immersion Questionnaire. Both questionnaires were administered to participants immediately after using the MSD during both Fall and Spring semesters. Participants were also asked to record immediate impressions of the tool on the back of one of the questionnaires using either bullet points or a short paragraph. Participants in the Spring semester also completed both questionnaires immediately after using the VR headset and were asked to record immediate impressions of that tool on the back of one of the questionnaires using either bullet points or a short paragraph. Participants in the Spring semester also engaged in a small group interview that followed a protocol consisting of six open-ended questions. This interview was recorded, transcribed, and member checked. Each of these data sources are described in greater detail below.

The Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire (Kennedy et al., 2009; Kennedy, Lane, Berbaum, & Lilienthal, 1993; Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989) is an omnibus test form that was analyzed, empirically validated, and cross validated over a twenty-year period. It was patterned after the Pensacola Motion History Questionnaire done by the Naval Aerospace Medical Institute (1968). The questionnaire was further developed for use in determining simulator sickness and uses the hierarchical factor-analysis method of Wherry (2014) and principal-factor analysis iteration followed by normalized varimax rotation to produce factors that were theoretically orthogonal.

This questionnaire was used to assess an over-taxed perceptual and cognitive system and was administered after each MSD treatment until saturation was determined by ease and comfort participants had with controlling these lunar flyby factors at the determined speed: rotation, zoom-in, and zoom-out speed, and overall ability to manipulate the Moon. The easier this manipulation was for the participant to achieve the closer the Likert-type data reached the comfort area as determined by less sickness. The instrument targeted different systems in the human body and used a list of 16 sickness symptoms such as “sweating” or “nausea”. Ranking choices were: None, Slight, Moderate, and Severe. Cronbach’s alpha was .87 (Bouchard, Robillard, & Renaud, 2007).

According to Kennedy et al. (1993) a valid index of simulator sickness was analyzed for the principal factors of oculomotor, disorientation, and nausea. Oculomotor factors were eyestrain, difficulty focusing, blurred vision, and headache. Within the category of oculomotor two separate factors indicate disturbance of visual processing (blurred vision and difficulty focusing) and symptoms caused by that disturbance (headache, eyestrain, and fatigue). Disorientation factors include dizziness and vertigo.

Factors indicating nausea were stomach awareness, increased salivation, and burping with emetic (vomiting) on the extreme end. Nausea factors reflect premonitory signs of nausea (increased salivation and burping) and advanced stages of nausea (sweating). Very advanced stages of nausea to the point of emetic were not reflected.

The Immersion Questionnaire

The Immersion Questionnaire was developed by Spielberger, Gorsuch, and Lushene (1983) and Jennett et al. (2008). The questionnaire was adapted for data collection in this study to assess the factors of biophilia and cathedral effect to determine the level of immersion participants experienced when using the tools (see Appendix B: Data Collection Protocols). The Immersion Questionnaire was administered after each participant used the MSD and the VR headset. The variables of biophilia effect and cathedral effect were tested for using this instrument. I adapted the Immersion Questionnaire to answer the following questions:

1. To what extent did the simulation imagery reduce stress?
2. To what extent did the simulation imagery enhance focus?
3. To what extent did the simulation imagery enhance concentration?
4. To what extent did the simulation imagery induce harmony?
5. To what extent was the simulation imagery comforting?

The Immersion Questionnaire was used like the Simulator Sickness Questionnaire to measure factors to determine the participant's state between an over- and under-taxed perceptual and cognitive system. For example, an under-taxed cognitive system leads to apathy and boredom, and an over-taxed perceptual and cognitive system leads to frustration and stress

(Vygotsky, 1978). This questionnaire consisted of five questions (e.g. “To what extent was the simulation imagery comforting?”) and asked participants to rate on a scale from 0 to 5 how they felt after using the simulation (where 0 equals not at all and 5 equals a lot). Cronbach’s alpha for internal consistency according to Spielberger et al. (1983) was .74 to .82.

Small Group Interviews

Eight small group interviews were conducted following the procedures of Krueger and Casey (2014) for planning, creating questions, hosting, moderating, and analyzing interviews in applied educational research. These eight small group interviews lasted from 11-17 minutes long and followed a protocol for consistency. Recorded small group interviews used six open-ended questions (see Appendix B: Small Group Interview Protocol). According to procedures for phenomenography as described by Moustakas (1994), participants were asked two broad, general questions and then more focused questions. These questions put attention to each participant’s experience using the simulation tools and the contexts that affected these experiences. These questions and the answers they provided allowed me to gather data on the variety of experiences participants had with the simulation tools and the content. The questions were open-ended and participants were encouraged to provide thick description and rich dialog. I also looked for thick description when doing transcript coding and analysis.

Small group interviews were conducted during the Spring semester Monday morning class and the Tuesday evening class. Participants were asked about their perceptions, opinions, beliefs, attitudes and experiences after using both tools. These small group interviews were recorded using Voice Memos on an iPhone 6s smart phone and were transcribed to a Microsoft Word document. Transcriptions were, then passed back to each participant for member checks. During member checks participants corrected any parts of the transcription in writing to either change the meaning or to add more detail. Member checked comments were then added to the final transcriptions and differentiated from the original transcript by being written in italics.

Of the 20 students enrolled in the Monday morning class, 16 participated in the interviews (see Table 3). The interviews occurred on January 23 (five participants, four males and one female); January 30 (three participants, two males and one female); February 6 (six participants, one male and five females); and February 13 (two participants, one male and one female). Four students did not participate in small group interviews because they were absent (two participants), refused (one participant), or had dropped the course (one participant).

Table 3

Participants in the Monday Morning Course Small Group Interviews During Spring Semester

Date	Participants	Interview Length
January 23, 2017	Dan Jazz Leo Aberham Whitnee	12 minutes 00 seconds
January 30, 2017	Ed Ira Dulce	17 minutes 08 seconds
February 6, 2017	Dave Ash Elaine Prissy Andrea Nadia	16 minutes 57 seconds
February 13, 2017	Saul Yanniana	13 minutes 35 seconds

Note. *n = 16 in the Monday morning class out of 20 enrolled students. Average interview time 14 minutes 55 seconds.*

Small group interviews were conducted during the same semester for the Tuesday evening class. Of the 20 students enrolled, all participated in the interviews (Table 4). These took place on January 17 (seven participants, four males and three females), January 24 (four participants, three males and one female), January 31 (four participants, three males and one female), and February 21 (three participants, two males and one female). According to Krueger et al. (2014) interviews are best conducted in groups of 6-8 participants but since these were the participants who had just had the MSD and VR headset experience these smaller group numbers worked well to produce insights into participants' experiences.

Table 4
Participants in the Tuesday Evening Course Small Group Interviews During Spring Semester

Date	Participants	Interview Length
January 17, 2017	Edgar	14 minutes 52 seconds
	Darian	
	Batista	
	Kayla	
	KC	
	Riana	
	Rod	
January 24, 2017	Chan	11 minutes 01 second
	Auchmood	
	Carol	
	Corini	
	Brianna	
	Chris	
January 31, 2017	Alex	14 minutes 38 seconds
	Corey	
	Steph	
	Will	
February 21, 2017	Gill	10 minutes 36 seconds
	LeeLee	

Note. *n = 20 in the Tuesday evening class out of 20 enrolled students. Average interview time 12 minutes 47 seconds.*

I acted as the moderator for the eight small groups. These were conducted with participants sitting chairs in a circle around a small table that held an audio recorder. The professional colleague that assisted each participant with the VR headset was also in the room and offered encouragement and some comment during the groups. All participant comments plus comments made by myself and the colleague that assisted were transcribed.

Data Sources Used to Answer Research Question One

To answer research question one the data sources used were the Simulator Sickness Questionnaire and the Immersion Questionnaire. These two Likert type instruments yielded numeric data. In addition to this numeric data, participants were requested to record their impressions of each tool using open-ended comments on the back on one of their questionnaires after using each tool. These impressions were recorded in the form of a brief paragraph or in bullet points. Participants from Fall and Spring semesters answered both questionnaires immediately after using the MSD. Participants from Spring semesters also answered both questionnaires immediately after using the VR headset.

When I noticed a participant talking about flyby speed being too fast or too slow it was noted. These notes and the results of the Simulator Sickness Questionnaire and Immersion Questionnaire informed changes to the scripting during data collection.

Data Sources Used to Answer Research Question Two

To answer research question two data sources used were the written comments from the backs of the Simulator Sickness and Immersion Questionnaires and transcripts from the small group interviews. I examined results from the two questionnaires but found that more informative data came from the analysis of transcripts.

All qualitative data from both member checked small group interview transcriptions and written bullet point comments or brief paragraph comments were analyzed using MAXQDA qualitative data analysis software. Coding progressed according to Bodner et al. (2007) methodological framework of phenomenography. In this framework coding is interpretive so I looked for similar themes and created codes such as, "things participants liked." These broad codes were then examined and broken down into smaller parts, for example under "things participants liked" they may have liked the visuals or they may have liked using the hand controller. Coding progressed to answer research question two the phenomenography question that addressed the variety of experiences participants had using both tools.

Data Collection

A pilot study was conducted during the Summer of 2016 to test the workability of the study logistics and to test the equipment. This was a small sample study using volunteers. Data were collected for the pilot study but not analyzed. Doing the pilot study allowed me to refine the process of data collection before working with the actual participants in the study.

Data collection with study participants was done in the Fall 2016 semester after the Summer pilot testing was finished. Data collection took place over two 16-week semesters in the Fall of 2016 and the Spring of 2017. Participants (N = 67) used the MSD to manipulate a lunar flyby. Spring 2017 semester participants (n = 36) used both the MSD and the VR headset to manipulate the lunar flyby.

I assumed the role of guest lecturer during these courses and was introduced to each class as such by the instructor of record. Before data collection began, participants were introduced to the study and invited to complete an informed consent document giving or denying my use of the data collected. After this form was circulated it was read to the students and there was an opportunity to ask questions before the forms were collected. After the paperwork was filled out each class had a preliminary experience using Google Cardboard and their smart phone to watch the Google Cardboard Video Journey through the galaxy-SPACE TRIP Video VR Video HD. Total run time was 9.65 minutes. Participants accessed this at the following URL: https://youtu.be/vOc2llE1anA. A classroom set of Google Cardboard virtual reality goggles were passed out and students were able to share smart phones in a cooperative manner until all students had a chance to view the presentation. The Google Cardboard presentation of the solar system was an anticipatory set in preparation for when they would use the Oculus Rift VR headset.

After finishing with Google Cardboard a preliminary experience with the MSD occurred when I took the class to the college planetarium and gave them a demonstration of the MSD by manipulating a lunar flyby while they watched and asked questions while seated in the dome theater. This demonstration gave them an initial experience to reduce the novelty effect (Kubota & Olstad, 1991) when it came time for them to use the MSD themselves.

Each participant's expected time involved in the total treatment was in the range of 45-65 minutes. Involvement with each simulation tool took 6-10 minutes with the remaining time for participants to complete the questionnaires. The recorded small group interviews lasted from 11 to 17 minutes.

Figure 9. Participants experiencing a preliminary virtual reality headset simulation using their smart phone.

The pilot study ran the Summer before actual data collection began during Fall classes. Data collection in the pilot study proceeded according to Figure 10. Data was collected for the pilot study but was not analyzed. Data collection with participants was done in the Fall 2016 semester after the Summer pilot testing was finished and the data collection process refined.

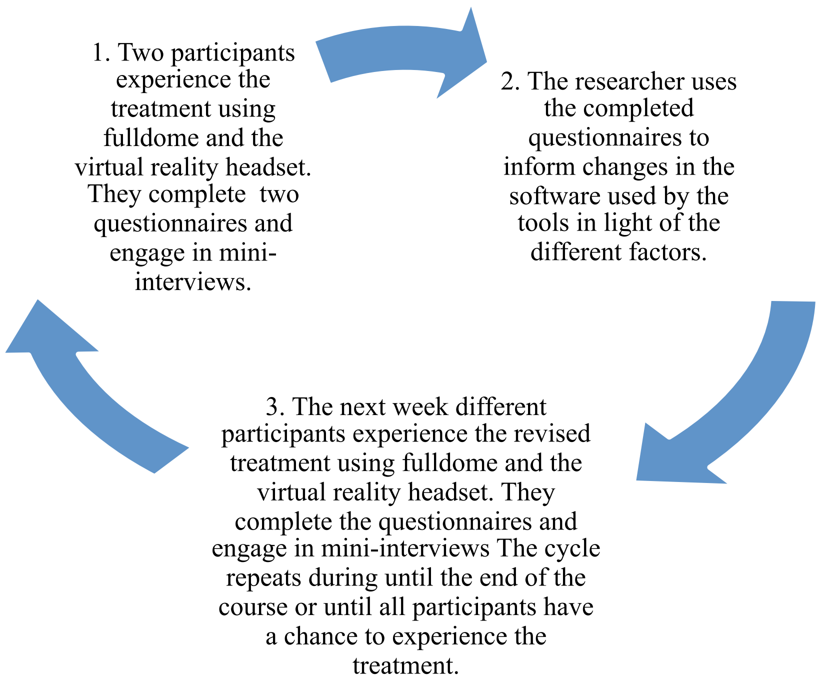


Figure 10. The data collection chart used in the pilot study.

Changes to the original data collection phase of the study were made after the pilot test. Data collection with participants then proceeded following the flowchart in Figure 11. Notice that all participants experienced the Google Cardboard VR and observed a demonstration of the MSD in the planetarium before data collection began. When all students had an opportunity to experience the simulation using Google Cardboard the instructor and I walked the students from their lab room on the second floor to the ground floor planetarium where they saw a demonstration of the MSD and a flyby of the Moon. All these procedures were part of the regular orientation to the lab that happened on the first day of class with the exception of completion of the informed consent.

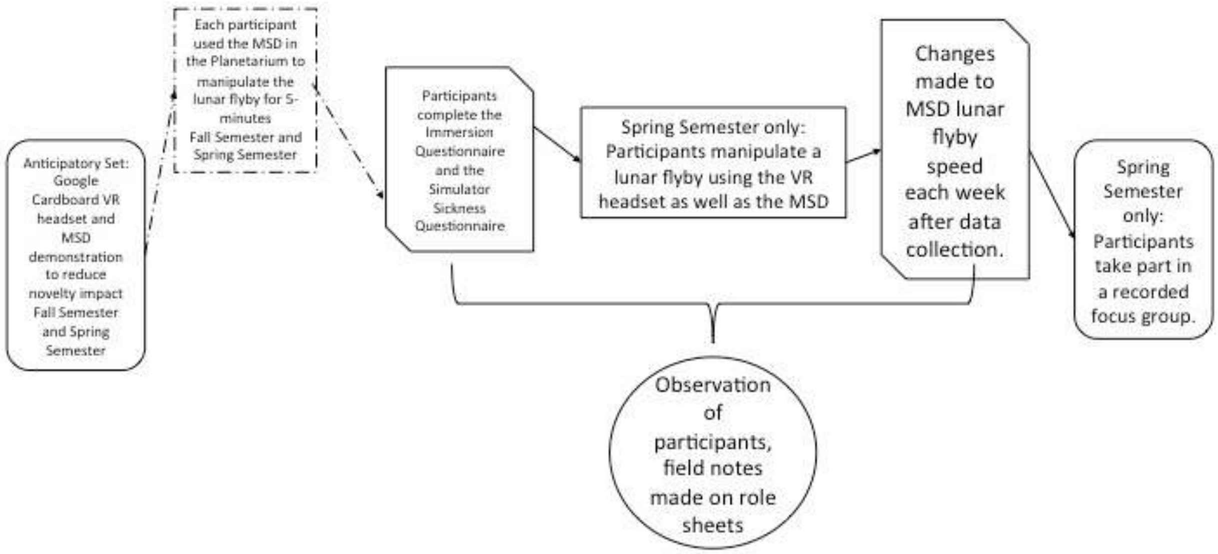


Figure 11. Data collection flowchart for the final study.

Data collection occurred during the Fall 2016 semester in two sections of Introductory Astronomy Laboratory taught by the same instructor (hereafter instructor #1). During the collection period participants in two sections of evening introductory astronomy classes (n = 31) used the MSD in the college planetarium to manipulate a lunar flyby projected on the planetarium dome theater. The MSD used the Digistar 5 computer to project a lunar flyby on the dome. By changing the speed of the flyby in the computer software script commands different flyby speeds were achieved.

A computer software script is a program written for a specific run-time environment, in this case the flyby speed of the Moon. A script automates the execution of tasks. These tasks are executed one-by-one. Scripting made the tasks repeatable and executable. Imbedded within the script was a value that determined the flyby speed used within the script. When this value is multiplied by the radius of the Earth, for example .01 x 3,959 = 39.59, the result is the flyby speed in miles per second (mps). Since participants were doing a lunar flyby the altitude used to orbit the Moon was low lunar orbit (LLO) of 62 miles above the surface of the Moon using the MSD. For the VR headset the LLO was unknown.

Participants individually experienced the MSD and completed two questionnaires with written comments on what they experienced when using the tool. I reviewed the questionnaires gathered week to week after participants manipulated the Moon using the MSD. The weekly data were examined and used to modify the MSD script to slowly increase and when informed by the data sometimes decrease the lunar flyby speed. Treatment software content targeted for change included the speed and ability to do three things with the lunar manipulation: rotate the Moon, zoom the Moon closer, and zoom the Moon away from the participant. Changes in speed were made in terms of the radius of the Earth per second. The control speed as set by the developer in the flyby was .03x the radius of the Earth, or 120 mps. I created faster flyby speeds by changing the computer script to .03+. I created slower speeds by changing the script to .03- and less. These changes were made as informed by participant feedback via questionnaires and real-time observations. As data were collected I made changes to the treatment software from the results of the week-to-week questionnaire information and out of ethics concerns for the participants from my actual observations at the time. Each group of participants experienced the new treatment speed when it was their week to use the MSD. This continued until all participants had the opportunity to experience use of the MSD during the Fall 2016 semester.

Participants used only the MSD during the Fall semester and not the VR headset. Software was no longer supported for the Oculus DK1 and DK 2, (DK means Developer Kit) VR headsets, the headsets I had available and the ones I used for the Summer pilot test. Oculus (the corporation) was preparing to introduce a new version of VR headset and was phasing out the

DK series to promote the sale of their first commercial headset the Oculus Rift. I was not able to have the Fall 2016 participants use a VR headset because the study period fell into this production gap resulting in continuation of the study to the Spring 2017 semester. Over the Winter break I acquired one commercial Oculus Rift VR headset and video card to run the software. Since I had an approved IRB in the Fall semester I began gathering data for the design-based research portion of the study and completed taking data using both tools in the Spring of 2017. Originally, I had planned to gather all data during the Fall semester and then continue in the Spring semester only if I needed more data to finish answering the two research questions. The way data collection proceeded in actuality I had plenty of data to reach saturation and run some repeat treatments on slow speeds and fast speeds of the flyby for verification.

Students tested during the Fall 2016 Tuesday evening fall class experienced flyby speeds of .01 (40 mps) on November 1, .02 (80 mps), .03 (120 mps), and .04 (160 mps), in this order on November 8, and .25 (990 mps) on November 15. The participant group (*n* = 15) for this class of students represented 89% of the total class due to participant attendance and recusal.

Students tested during the Wednesday evening Fall class experienced flyby speeds of .04 (160 mps) and .05 (200 mps) in this order on November 2, .13 (520 mps), .15 (590 mps), and .2 (790 mps) in this order on November 9, and .13 (520 mps), .35 (1,400 mps), .4 (1,600 mps), and 1.5 (5,900 mps) in this order on November 16. The participant group (*n* = 16) for this class of students represented 79% of the total class due to participant attendance, recusal, and one participant who was very tall and the MSD was unable to recognize his height as parameters for the device were set for average height and weight.

In both the Tuesday and Wednesday sections, participants completed a Simulator Sickness Questionnaire (Kennedy et al., 1993) and an Immersion Questionnaire (Jennett, Cox, Cairns, Dhoparee, Epps, Tijs, & Walton, 2008). Both of these instruments are included in this document under Appendix B. After participants completed both questionnaires they were asked to record some impressions of what they experienced when using the MSD on the back of one questionnaire. These writings consisted of a few bullet points or a paragraph or two of what they experienced when using the simulation.

Each of the Spring 2017 treatment sessions progressed with two participants at a time, one using the VR headset and one using the MSD. Data were collected and then the participants switched tools. While one participant was using the MSD the other participant used the VR headset. I had an emeritus professor from the college volunteer to show participants how to use the VR headset. Spring sessions involved different participants and progressed in this order: Treatment 1 – a participant individually manipulated the Moon using the MSD. They then completed the Simulator Sickness and Immersion Questionnaires. Treatment 2 – the participant then experienced the lunar flyby using the VR headset and completed the same questionnaires. After participants used both tools they participated in an 11 to 17 minute recorded small group interview using a question protocol.

Data collection continued during the Spring 2017 semester using two sections of Introductory Astronomy Laboratory classes taught by two different instructors for a total of three different instructors over two semesters. These courses were taught on Monday mornings by instructor #2 and on Tuesday evenings by instructor #3. Students with instructor #2 tested during the Monday morning Spring class experienced flyby speeds of .04 of the radius of the Earth or 160 mps on January 23, .05 or 200 mps, and .15 or 590 mps in this order on January 30, and .2 or 790 mps on February 6. The participant group (n = 16) for this class of students represented 80% of the total class due to participant attendance, dropped course, and recusal. Students with instructor #3 tested during the Tuesday evening Spring class experienced flyby speeds of .01 (40 mps) on January 17, .4 (1,580 mps) on January 24, .25 (990 mps) on January 31, and .3 (1,200 mps) on February 7. The participant group (*n* = 20) for this section represented 100% of the total class. The treatment stopped after all 36 students in the Spring courses had a chance to participant.

Data Analysis

Data collected during the Fall semester used the Immersion Questionnaire and the Simulator Sickness Questionnaire. Analysis of the responses both on Likert type scales, written comments made on the questionnaires and observations cued changes in the MSD flyby speed between participants and between treatment weeks. Data collected during the Spring semester included all of the above but added a small group interview using the Small group interview Protocol. Analysis of the Spring semester responses also cued changes in the flyby speed when participants used the MSD.

To answer the first research question about flyby speed numerical data from both questionnaires were analyzed for descriptors using SPSS software. Written data were examined using a MAXQDA software program. I looked for anything participants wrote having to do with the lunar flyby speed being reported as too fast or too slow. These passages were then coded according to Bodner et al. (2007). Codes were examined in light of the design-based research question that addressed changes in flyby speed. Three codes were added to investigate the design-based research portion of the study. These codes were as follows: a) comments talking about flyby speed; b) comments talking about flyby speed being too fast; c) comments talking about flyby speed being too slow. Figure 12 shows the expected optimal speed as the intersection of simulator sickness and immersion.

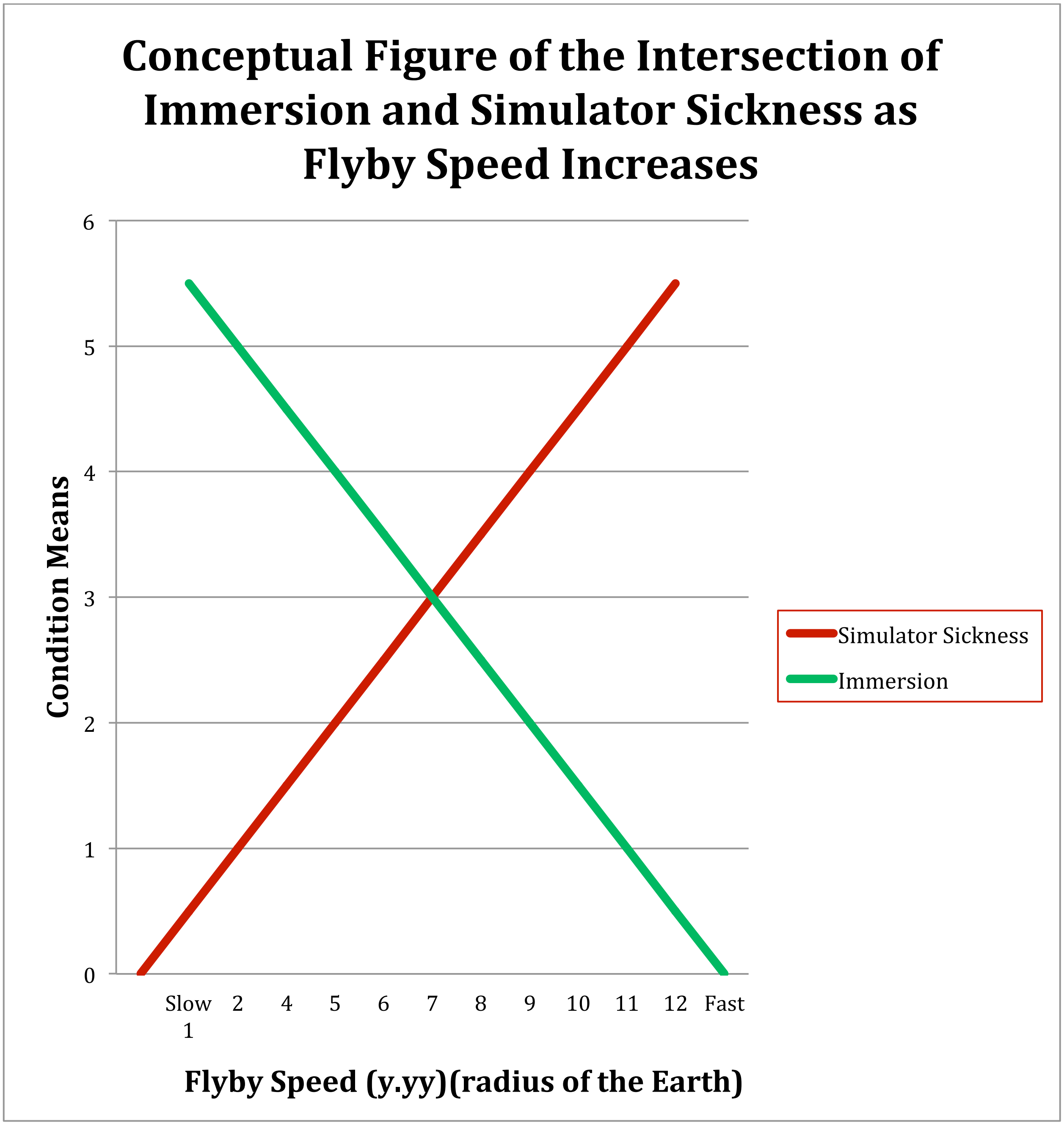


Figure 12. Expected conditions of simulator sickness and immersion as speed increases.

As flyby speed increased from the slowest speed of .01 (40 mps) to fast at .4 (1,600 mps) Figure 12 shows that the line of simulator sickness condition means increases. In plain language, as the speed increases the participants experience more symptoms of sickness. Notice that the opposite occurs with immersion. A slow speed increases the immersion participants experience while engaged in the simulation. In plain language, as the speed increases participants experience less immersion. The point where the simulator sickness and immersions lines cross is optimal speed.

The goal for the Simulator Sickness Questionnaire was to reach as many participants trending towards the *slight to none* end of the scale. Variables manipulated to test this were flyby speed and participants ability to control lunar rotation speed, zoom-in speed, and zoom-out speed. Some weeks of trial and error with speed changes were made until a trajectory that improved responses to the desired slight to none edge was achieved. The treatment was informed by changes made after data taken in the design-based research portion of the study were analyzed.

To answer the second research question small group interview data was analyzed according to Orgill's (2011) procedures for conducting phenomenography. I transcribed the data from eight recorded interviews to written transcripts. Each interview took about 1.5 hours to transcribe and I included text as heard including laughter and utterances such as *um*'s and *ah'*s. All participant quotations are presented verbatim as written or transcribed from audio.

After these data were transcribed from audio to written form I took the written transcripts back to each class and gave the blinded transcripts to each participant organized by small group interview group. Instructions to participants were to read over the transcript and identify their comments then change or correct anything they wrote having to do with either the intent or clarification to any part of their transcript. Some participants made many changes, some made very few changes. Some participants made changes to speech disfluency (the ums, ahs, and other speech fillers) and some participants clarified technical parts of their transcript or clarified meanings. The participants then gave back their corrected transcripts and I added these changes to the original digital transcripts. These member checks ensured the written form was verified by the participant giving an extra measure of data validity and reliability to this part of the study.

After the data were transcribed they were horizontalized and reduced. This was done using the MAXQDA software program designed for computer-assisted qualitative and mixed methods data, text and multimedia analysis. This program helped me organize and retrieve portions of the text making interpretation less arduous. Being able to interpret a text meant being able to fuse the horizons of what was known in the historical tradition of language as a medium for understanding. The ability to interpret a transcribed text involved a *Horizontverschmelzung*, or fusion of horizons where both the text and the I found themselves within a particular historical tradition (Gadamer & Fantel, 1975). When I sought to understand a text, a common horizon emerged. The result of this horizontalization was a deeper understanding of the variety of interpretations participants had with the subject matter. According to Moustakas (1994) every statement was treated with equal value. During horizontalization statements, sentences, or quotes were highlighted and statements irrelevant to the topic and also overlapping or repetitive statements were deleted. The highlighted portions that were left are identified as parts of the dialog that detailed the variety of ways participants experienced the phenomenon of using the MSD in a fulldome planetarium and the VR headset to explore the lunar surface.

Data for answering research question two were also collected from participants when they used the MSD and the VR headset. Five codes were created during and after data reduction to organize the data around experiences that the participants reported when using the tools. These codes can be seen in Table 5.

Table 5

Codes Created from Transcribed Data

Code	Example(s)
a) Potential Additions	a) Control of speed, more/different audio, a task or goal, more labels, a Hit Box, the ability to stop, audible control
b) Details of Use	b) Liked the ability to relate to the vastness of space, liked the ability to experience a spacewalk, good perspective of flight
c) Ease of Use	c) Very immersive, controls took some practice, zooming out was more of a problem then zooming in.
d) Overall Experience	d) Very realistic feeling of being in space, of being able to touch things in space, VR headset a little heavy, relaxing

Note. Codes were created after data was transcribed.

The codes were as follows: a) potential additions, things participants mentioned that they would like to see added to the experience or to the software to enhance their learning and their experience; b) details about the experience of using the MSD or the VR headset; c) things participants liked about using the MSD and the VR headset; d) things that participants thought were easy or hard about manipulating the MSD and the VR headset; and e) how the participants felt about the experience or use of the MSD and the VR headset.

After data was reduced and examined for clusters of meaning and themes I used these themes to gather transcript passages associated with them. The final step was where data were read and considered by two professional colleagues for input as a third and final check. This achieved triangulation and acted as a reliability measure for the meaning clusters before the variety of experiences were analyzed for eventual findings.

The Researcher's Role in the Study

As part of this study I assumed the position of guest lecturer in these classes. Each instructor of record granted me permission to enter their classes with this status (during the Fall 2016 semester the same instructor of record taught both labs, and during the Spring 2017 semester there were two different instructors). Further approval came from the department chairperson in physical science before the study proceeded. Positioning myself as guest lecturer allowed me to work with the classes as a whole and required participation of all class members. Even so, there was one student in the Fall semester that recused and three from the Spring semester that recused themselves from participation. As the researcher, I was mindful of the potential for coercion and did not press students to participate respecting their right of refusal.

The role of the researcher in this phenomenographical investigation must include some discussion on bracketing. Bracketing is the position the researcher must take to sort out and put aside qualities that belong to their own personal experience with the phenomenon (Drew, 2004; Gearing, 2004; Tufford & Newman, 2010). Bracketing is important because it lends trustworthiness to the study. For me, the experience of working in a planetarium for the past eleven years could bias the research. It was important to be vigilant about pre-existing thoughts and beliefs when collecting and analyzing data so as not to bias the results of the study (Davies & Harré, 1990). It was important to bracket or suspend, but not abandon, researcher biases (Creswell, 2012; Creswell & Miller, 2000) as the study proceeded.

Using design-based research methods reinforced the importance of bracketing. Design-based research by its very nature is an emic approach. An emic approach investigates how people think (Kottak, 1996). Since this was a phenomenography the objects of the study were the various lived experiences of the group of people undergoing the phenomenon of using a fulldome planetarium and a VR headset to learn about a lunar surface through flybys. The use of bracketing to suspend, but not abandon, researcher biases while investigating how participants think and experience the two simulation tools made it important to be mindful of the researcher position in the study throughout the progression of data collection, data analysis, and throughout the final writing of the results.

Study Timeline and Summary

Timeline for this research proceeded according to Table 6.

Table 6
Timeline Used to Implement and Complete the Study

Semester	Tasks
Summer 2016	• Obtained Social/Behavioral Institutional Research Board approval • Pilot Tested the study to refine the method
Fall 2016	• 16 weeks of iterative cycles of treatments using the MSD • Changes made to flyby speed informed by weekly data
Spring 2017	• 16 weeks of iterative cycles of treatments using both tools • Changes made to MSD flyby speed informed by weekly data • Transcribed small group interview recordings and did member checks on transcriptions • Used SPSS to find descriptives for qualitative data and MAXQDA software to code qualitative data
Summer 2017	• Analyzed data and presented findings

This chapter outlined the method of research that was conducted in this design-based study. It focused on a design-based research approach for participants who used the MSD tool during the Fall and Spring semesters as they experienced a lunar flyby at various speeds to determine the best speed for manipulating the tool. During the Spring semester students also experienced the use of a VR headset to manipulate a lunar flyby. Information on the variety of experiences students had while using both tools were gathered using questionnaires and small group interviews.

CHAPTER 4: RESULTS

Introduction and the Two Research Questions

The purpose of this study was twofold and revolved around two research questions, what optimal lunar flyby speed do college students report comfortably using to manipulate the Moon using a motion sensor device in the college planetarium and what variety of experiences do college students have while learning astronomy when manipulating a lunar flyby using fulldome planetarium software and virtual reality headset simulation? To examine the results, it is helpful to first unpack each research question. A design-based research approach was used to answer the first research question and collected data was quantitative. These data were examined using quantitative research techniques (Wang et al., 2005), gathered using questionnaires but also direct observations and examination of textual data to find the optimal flyby speed comfortable to the majority of study participants. Phenomenography was used to answer the second research question and a qualitative approach was taken to discover the different experiences students had learning about the Moon when using the MSD and a VR headset. Research question one was answered quantitatively using Likert scale type data. Research question two was interpretive and explored different ways in which a group of participants experienced something or thought about something when the group had the same treatment (Töytäri, Tynjälä, Piirainen, & Ilves, 2017).

Research Question One – Results

Research question one asked what optimal lunar flyby speed do college students report comfortably using to manipulate a flyby of the Moon using a motion sensor device in the college planetarium? Data collected in the form of questionnaires are presented below and the following discusses how participants interfaced with the MSD, in what groups, on what days, and at what flyby speeds.

Before looking at the data I calculated the reliability of the two survey instruments. In the case of the Simulator Sickness Questionnaire, Cronbach's alpha was .851. The Immersion Questionnaire had a reliability of .855. Both of these values are well above the acceptable threshold of .7 (George & Mallery, 2009; Tavakol & Dennick, 2011). Because of this the conclusion was that these two instruments were sufficiently reliable for this study.

Use of the Motion Sensor Device

The motion sensor device was used by participants in both the Fall and Spring semesters. Each participant cohort began with a slow speed. These opening slow speeds were; Fall semester, Tuesday .01 (40 mps), Fall semester Wednesday .05 (200 mps), Spring semester Monday .04 (160 mps), and Spring semester Tuesday .01 (40 mps). Likewise, each cohort ended with a high speed, Fall semester, Tuesday .25 (990 mps), Fall semester Wednesday, 1.5 (5,940 mps – the fastest speed tested), Spring semester Monday, .2 (790 mps), and Spring semester Tuesday .3 (1,200 mps). Speed was increased after data analysis of the questionnaires and also in real time after observing participant behavior while they experienced the flyby.

Group # 1: Fall 2016 Tuesday evening class. This course was taught by instructor #1, who had many years of teaching experience and set the tone of the class professionally and competently. Total students enrolled in this course at the beginning of the semester was $n = 18$. All students had the opportunity to participate in the simulation but some students were absent or recused from the activity.

During the following weeks of the semester participants took turns using the MSD on November 1 ($n = 6$), November 8 ($n = 7$), and November 15 ($n = 2$). Speeds used were .01, .02, .03, .04 and .25 of the radius of the Earth or 40 mps, 80 mps, 120 mps, 160 mps, and 990 mps, respectively. Speed changes took place in that order over the weeks with week one at speed .01

(40 mps) and week three at speed .25 (990 mps). Flyby speed changes were informed by participant feedback on data sheets and by live observation as participants manipulated the flyby.

Group #2: Fall 2016 Wednesday evening class. This course was also taught by instructor #1 and proceeded in the same manner as the Tuesday evening class. Total students enrolled in this course at the beginning of the semester were n = 19. All students had the opportunity to participate in the simulation but some participants recused and others were absent and unable to make up the time.

Participants took turns using the MSD on November 2 (n = 7), November 9 (n = 4), and November 16 (n = 4). Flyby speeds, in chronological order, used were .05, .04, .2, .13, .35, and 1.5 of the radius of the Earth or 200 mps, 160 mps, 790 mps, 520 mps, 1,400 mps, and 5,900 mps, respectively. These speeds took place in that order with .05 during week one and .13, .35, and 1.5 during week three. One participant was unable to use the MSD because of his height. Ranges of the equipment were set within average height parameters and even when having the participant sit on a chair the MSD was not able to recognize him to create a usable avatar. Data taken for the speed of 1.5 (5,900 mps) was removed as an outlier. This removal, noted on Table 7, shows the breakdown of number of participants who experienced each speed.

Table 7
Number of Participants that Experienced Each Speed from Slowest to Fastest using the MSD

Velocity	Speed Value (Speed in miles per second or mps)	Participants
Slowest	.01 (40 mps)	12
Pre-set script speed	.02 (80 mps)	1
Slower	.03 (120 mps)	5
Slow	.04 (160 mps)	10
Medium Slow	.05 (200 mps)	8
Medium	.13 (520 mps)	2
Medium Fast	.15 (590 mps)	5
Medium Faster	.2 (790 mps)	8
Medium Fastest	.25 (990 mps)	6
Fast	.3 (1,200 mps)	4
Faster	.35 (1,400 mps)	1
Very Fast	.4 (1,600 mps)	8
Extremely Fast (removed as an outlier)	1.5 (5,900 mps)	1

Note. *N = 67 total across two semesters using four classes and three different instructors, some students participated twice. Some participants used the MSD twice and at different speeds.*

Group #3: Spring 2017 Monday morning class. This course was taught by instructor #2, a new instructor to the department. Introduction to the study proceeded in the same manner as in the courses taught by instructor #1. Total students enrolled in this course were *n* = 19 at the beginning of the semester.

Students took turns using the MSD on January 23 (*n* = 5), January 30 (*n* = 5), and February 6 (*n* = 6). Flyby speeds for this group were .04, .05, .15, and .2 of the radius of the Earth or 160 mps, 200 mps, 590 mps, and 790 mps, respectively, in that order with week one speed of .04 and week three speed of .2. All Spring participant used both the MSD and the VR headset and the flyby speed was changed only on the MSD as that device was used to determine the quantitative design-based portion of the study.

Participants used the VR headset one at a time under the supervision of a colleague in the Department of Physical Sciences who volunteered to assist with data collection. The volunteer helped participants individually with the VR headset orientation and explanation of the task while I helped participants individually using the MSD.

During Spring semester, all students participated in small group interviews. The interviews were recorded and transcribed. Member checks insured participants could make corrections to the transcription.

Group # 4: Spring 2017 Tuesday evening class. This course was taught by instructor #3, a young instructor teaching for the first time. The instructor was hesitant to allow data collection in class and revealed that because he was close in age to many of the students he was concerned that students would not take him seriously and my presence would be a distraction. We had three meetings before the semester began and his concerns were ameliorated. Total students enrolled in this class $n = 20$ at the beginning of the semester.

Data collection proceeded the same as in the Monday morning class. Participants took turns using the MSD and the VR headset with small group interviews on January 17 ($n = 9$), January 24 ($n = 6$), January 31 ($n = 4$), and February 7 ($n = 3$). Small group interviews were done after participants used both tools. Flyby speeds for this group were .01, .4, .25, and .3 of the radius of the Earth or 40 mps, 1,580 mps, 990 mps, and 1,200 mps, respectively, in that order with .01 (40 mps) given to the first week's group, .4 (1,600 mps) the second week's group, .25 (990 mps) the third week's group, and .3 (1,200 mps) the fourth week's group.

Data were collected from the Simulator Sickness Questionnaire and the Immersion Questionnaire and were analyzed to determine optimal speed (y.yy times the radius of Earth or y.yy × 3,959 = x,xxx mps) for both comfort and immersion when participants used the MSD to manipulate the lunar flyby. Miles per second values are represented using significant figure scientific notation. As noted earlier attainment of the targeted ZPD development was determined by ease and comfort with rotation, zoom-in, and zoom-out speed and the ability to manipulate the Moon when using the device. The total number of student participants in the design-based portion of the study was $N = 67$.

Simulator sickness is examined first because if a participant is struggling with adverse physical impacts from using the simulation immersion is difficult to achieve. The Simulator Sickness Questionnaire condition responses were averaged across questions about degrees of general discomfort, fatigue, headache, eyestrain, difficulty focusing (the eyes), increased salivation, sweating, nausea, difficulty concentrating, fullness of the head, blurred vision, dizziness with eyes open, dizziness with eyes closed, vertigo, stomach awareness, and burping. Participants chose from these condition responses on the questionnaire: None, Slight, Moderate, and Severe. These responses were supplied to questions about degree of stress. The responses were changed to numbers using the values of: 1 equals none or no sickness symptoms, 2 equals slight sickness symptoms, 3 equals moderate sickness symptoms, and 4 equals severe sickness symptoms. Using these numeric values data were analyzed for condition means and standard deviation. The Simulator Sickness Questionnaire favorable values were the inverse of the Immersion Questionnaire values. Higher values for the Simulator Sickness Questionnaire indicated that participants are feeling discomfort so lower values are more favorable. Figure 12 shows the amount of simulator sickness as speed increased. Speeds were from slow (.01) ×

(radius of the Earth) or 40 mps to fast (.4) × (radius of the Earth) or 1,600 mps. There was one Simulator Sickness Questionnaire from the Tuesday night, Fall semester class on November 1 that had a speed of 1.5 (5,900 mps). That was speed was much faster than the other speeds and was determined to be an outlier and not used in the final analysis. Table 8 shows all data averages for Likert type data collected using questionnaires for simulator sickness and immersion.

Table 8
Lunar Flyby Speeds and Comfort Levels Tested for Simulator Sickness and Immersion (MSD)

Pace (flyby speed) condition means (and standard deviations)		
(.yy) × (radius of Earth)/ miles per second (mps)	Simulator Sickness Questionnaire	Immersion Questionnaire
.01 (40 mps)	1.20 (.40)	4.09 (.72)
.02 (80 mps)	1.19 (.66)	3.00 (.00)
.03 (120 mps)	1.25 (.45)	3.45 (.51)
.04 (160 mps)	1.31 (.48)	3.30 (1.06)
.05 (200 mps)	1.25 (.45)	4.25 (.71)
.13 (520 mps)	1.25 (.45)	3.00 (.00)
.15 (590 mps)	1.25 (.45)	3.60 (.55)
.2 (790 mps)	1.44 (.45)	3.89 (1.13)
.3 (1,200 mps)	1.44 (.51)	2.50 (.58)
.35 (1,400 mps)	1.44 (.51)	3.00 (.00)
.4 (1,600 mps)	1.44 (.51)	2.88 (1.64)

Note. *Data collected after students used the Motion Sensor Device. Higher values for the Immersion Questionnaire are favorable and lower values for the Simulator Sickness Questionnaire are favorable.*

In the Immersion Questionnaire, each condition response was averaged. These condition responses were supplied to the questions about degree of stress reduction, focus, concentration, harmony, and comfort across anchors of Not at all, 1, 2, 3, 4, 5, and A lot with Not at all in the same rank as 1 and A lot in the same rank as 5. Higher values indicate a greater level of immersion in the simulation and are considered favorable.

I looked at the data for simulator sickness and Immersion graphing this over time (Figure 13). This graph shows simulator sickness and immersion as the flyby speeds changed. In this graph, degree of symptoms from 0 symptoms (no symptomatic impacts) to 5 (severe symptomatic impacts) are shown on the y-axis. The anchor is shown on the y-axis but was not a choice on the Immersion or Simulator Sickness Questionnaire. Treatment days are shown on the x-axis. Notice that treatment begins at a slow speed and is adjusted depending on the reaction of participants during the first semester. During the second semester shown beginning on treatment day 40, treatment speed again begins at a slow speed. Speed was adjusted as seen by the plateau during days 53 to 59 and then levels off up to week 70 as face validity determines adjustments. The variability of green line of immersion is more pronounced. Notice the red line indicating simulator sickness is dependent on speed as seen by the comparison to weeks of speed change and the vertical line that separates the Fall semester and the Spring semester. This is a lot of information so it is helpful to unpack this by looking at the components.

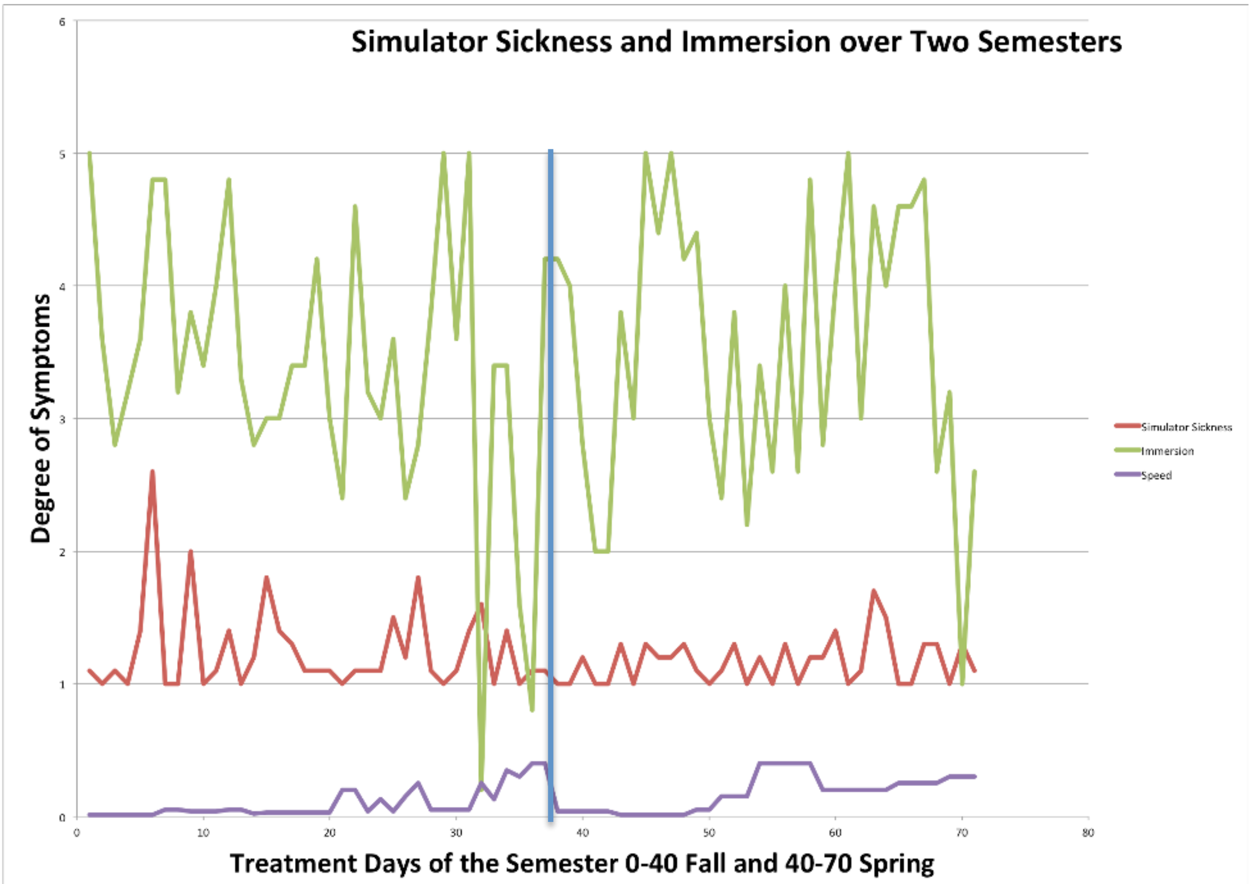


Figure 13. Simulator sickness and immersion over two semesters using the MSD; the blue vertical line indicates the change from Fall to Spring semester.

The first step in unpacking the data for simulator sickness and immersion using the MSD over both semesters is to look at the amount of simulator sickness because if participants are feeling sick they will not be able to concentrate on the task now become immersed in the task. Figure 14 below indicates the speeds starting at the slowest speed represented on the x-axis and reading to the right showing increased lunar flyby speed. Amount of simulator sickness is indicated on the y-axis by the red bar. Notice that there is consistency in elevated simulator sickness as the lunar flyby speed increased.

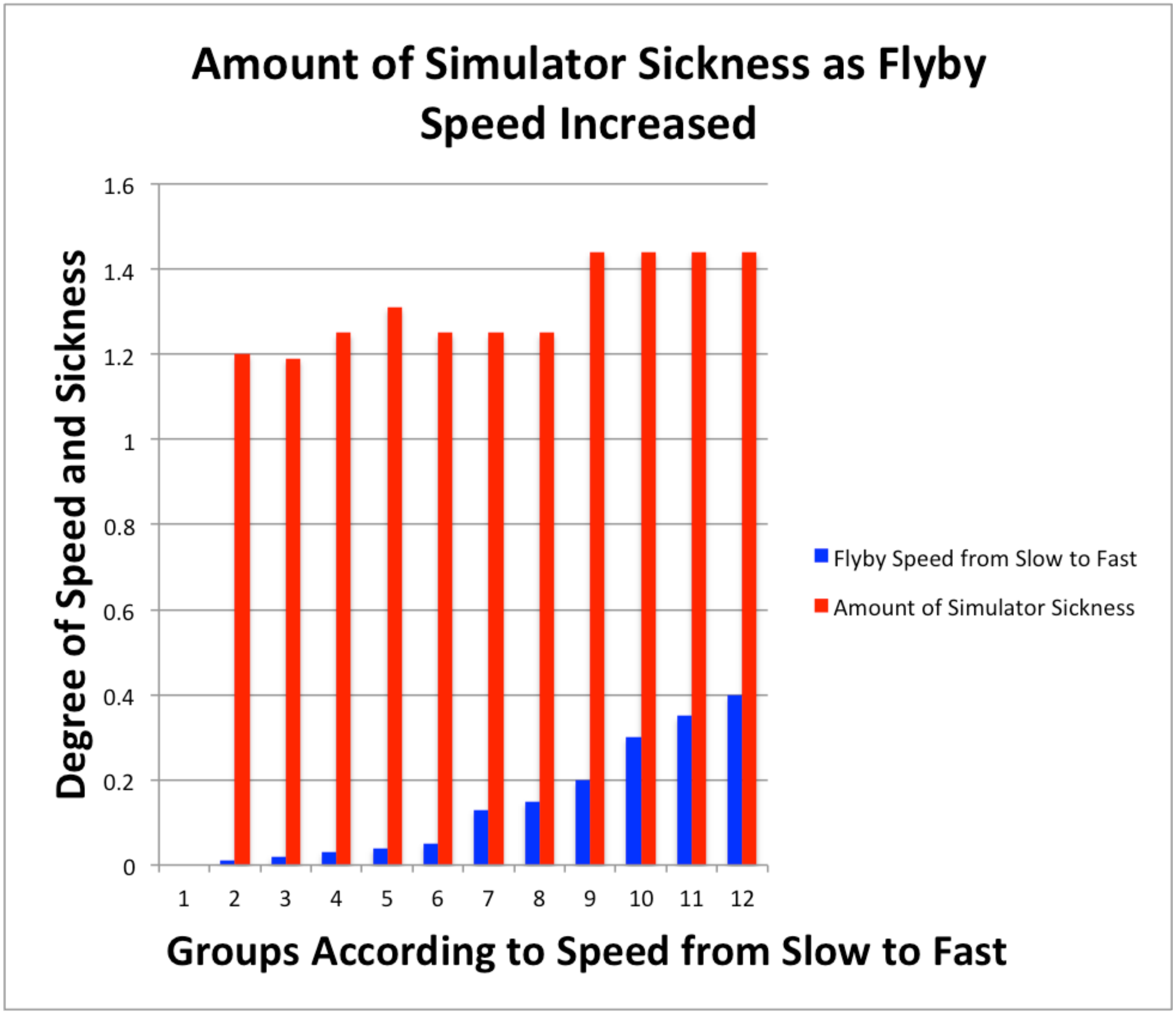


Figure 14. Lunar flyby speeds (shown in blue) and discomfort levels (shown in red) for MSD simulator sickness. Simulator sickness is the same at speeds .03 (120 mps), .05 (200 mps), .13 (520 mps), and .15 (590 mps); (red bars 4, 6, 7, and 8 on the X axis). Simulator sickness is the same at faster speeds of .2 (790 mps), .3 (1,200 mps), .35 (1,400 mps), and .4 (1,600 mps); (red bars 9, 10, 11, and 12).

Figure 15 shows flyby speeds and comfort levels for MSD immersion with the higher values showing the participants were more involved in the simulation. This involvement includes the effects of biophilia, immersion, and cathedral. These data were used to answer the design-based research question in the study with greater values on the y-axis of the graph indicating more immersion.

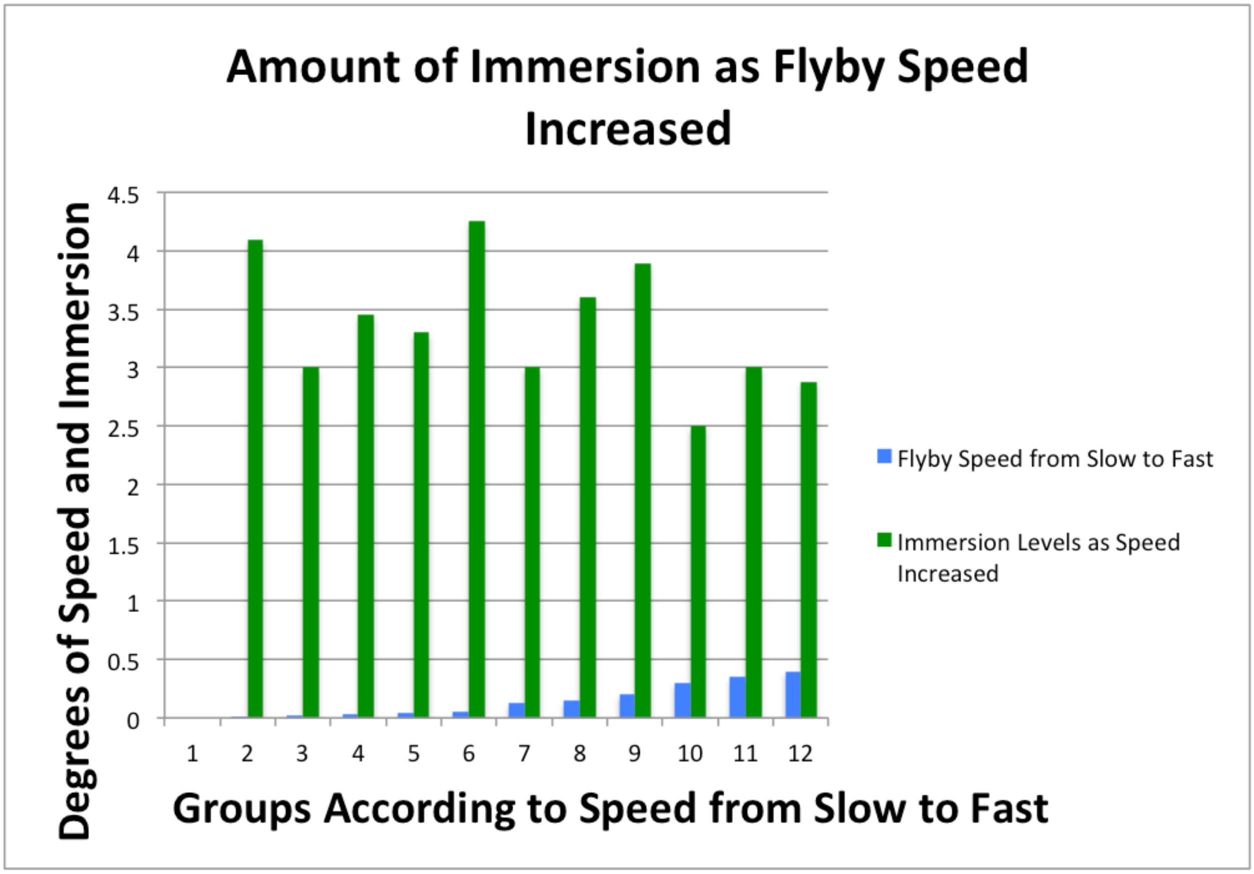


Figure 15. Lunar flyby speeds and comfort levels for MSD immersion. Higher levels of immersion (shown in green) mean participants are more involved in the simulation.

The input of speed was used to modify the event of the future along with real time observations while the MSD was in use and examination of all written transcripts and comments participants made on their questionnaires immediately after they used the device. For example, looking at this comment from a participant called Chrystal (all participant names were changed to protect their identity), her desire to control the lunar flyby as speed increased was problematic. It was difficult to observe lunar detail and there was a desire to stop the flyby, or at least slow it down:

> During my experience the speed slowed down which made it better to actually see the detail of the Moon. At the moment I had stopped [still during session] it was nice to see [as] opposed to zooming by so fast. Going slow did induce a bit of harmony.

At .04 (160 mps), Whitnee reported being able to maintain control of the flyby with this comment, “It was a fun way to explore space freely while still remaining in control.” At .05 (200 mps), Saul reported stress with the faster speed as evidenced by this comment, “It was stressful to control the mechanism. The simulation applies laws of physics. Even though I wanted to stop, the simulation kept on going as if momentum was built.”

Table 9 below represents immersion intensity across the variables of biophilia and cathedral effect. Percentages represent the participants that answered each question across the five intensity levels from “not at all” to “a lot.”

Table 9

Percentage of Participants Reporting Levels of Immersion Using the MSD

Immersion Intensity Across Five Variables *N* = 67					
	Not at All	Somewhat	Neutral	Very Much	A Lot
1. Reduce stress	10.8%	5.4%	21.6%	24.3%	35.1%
2. Focus	5.4%	5.4%	5.4%	21.6%	59.5%
3.Concentration	5.4%	5.4%	13.5%	10.8%	59.5%
4. Harmony	8.1%	5.4%	5.4%	24.3%	51.4%
5. Comfort	2.7%	5.4%	2.7%	13.5%	70.3%

Note. Numerals above correspond to these questions: 1. To what extent did the simulation imagery reduce stress? 2. To what extent did the simulation imagery enhance focus? 3. To what extent did the simulation imagery enhance concentration? 4. To what extent did the simulation imagery induce harmony? 5. To what extent was the simulation imagery comforting?

In some cases, participants requested to use the MSD simulation a second time at a different speed. When time permitted, this option was offered to participants who were finished with their regular lab work and wanted another chance to experience the tool. A male participant called Jas used the MSD at the .13 (520 mps) speed and reported, “Both speeds were fantastic, but my favorite was the slower one. It felt like I had more control and I could appreciate the view a little more." As speed increased more participants reported difficulty manipulating the flyby as evidenced by Dulce's comments when manipulating the lunar flyby at the .15 (590 mps) speed: "It was a little bit difficult to navigate. I found myself having to concentrate fully. There were times when it became a little frustrating. Either way, it was a bit difficult…" A female participant called Teres reported that for the same speed, "The traveling speed was a little faster but I had less control."

As the speed increased to .2 (790 mps) participants reported loss of control when trying to manipulate the lunar flyby, Elaine noted that, "Control is somewhat difficult/getting the hang of things." At .25 (990 mps) Alex reported, "[I] found it difficult to control speed of movement." And at .3 (1,200 mps) a female participant called LeeLee wrote, "It was difficult to control because of how fast I was traveling…" These comments were used as event feedback to adjust the speed of the flyby in real-time. At .4 (1,600 mps), the fastest speed where data were analyzed, the script was no longer modified to have the Moon flyby faster as evidenced by the quantitative data and this written comment, "This is very fast."

Taking a look at both immersion and simulator sickness helped visualize the relationship between these two variables and speed. Figure 14 combined immersion and simulator sickness into one graph. The green line of immersion shows less of a connection to changes in speed than the red line of simulator sickness. Simulator sickness increased as speed increased. The Immersion Questionnaire tested for biophilia and cathedral effect when using the MSD. The green line of immersion has a greater variation of higher scores that show more immersion and lower scores, showing the participant is less immersed in the simulation.

I continued to unpack the data shown on Figure 12 (discussed previously) by doing a breakdown of Fall and Spring semesters shown on Figures 16 and 17. As you can see in Figure

16, the red simulator sickness line follows speed except at the beginning spike. The green line of immersion has larger spikes and dips and follows a similar pattern with the red line of simulator sickness.

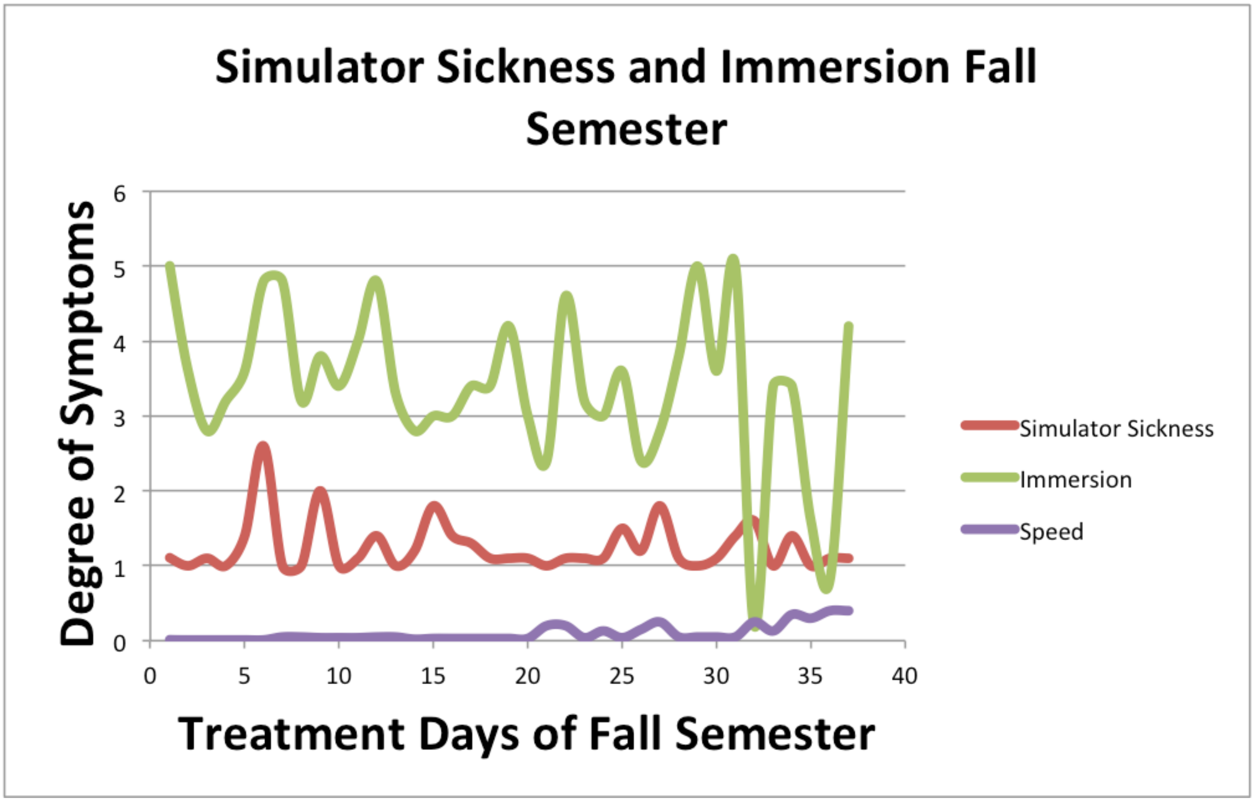


Figure 16. Simulator sickness and immersion over Fall semester using the MSD

Figure 17 below, shows a breakdown of the same data but showing only Spring semester results. As you can see the green immersion line is erratic in two places. I looked at the data for these dates and did not see any outliers to reject. The green immersion line is somewhat correlated to the red line of simulator sickness except in these instances. When looking at the red simulator sickness line there is a stronger connection between this line and changes in flyby speed. In this figure, the degree of symptoms is shown on the y-axis and months of treatment on the x-axis. The red line of simulator sickness is represented as the lunar flyby speed changed. The green line of immersion is represented as the lunar flyby speed changed. Spikes in the red line of simulator sickness indicate a greater degree of sickness. Spikes in the green line of immersion show a greater degree of immersion in the simulation. The goal is to have high immersion with low sickness. The intersection of simulator sickness and immersion occur at a symptom degree of 1.25.

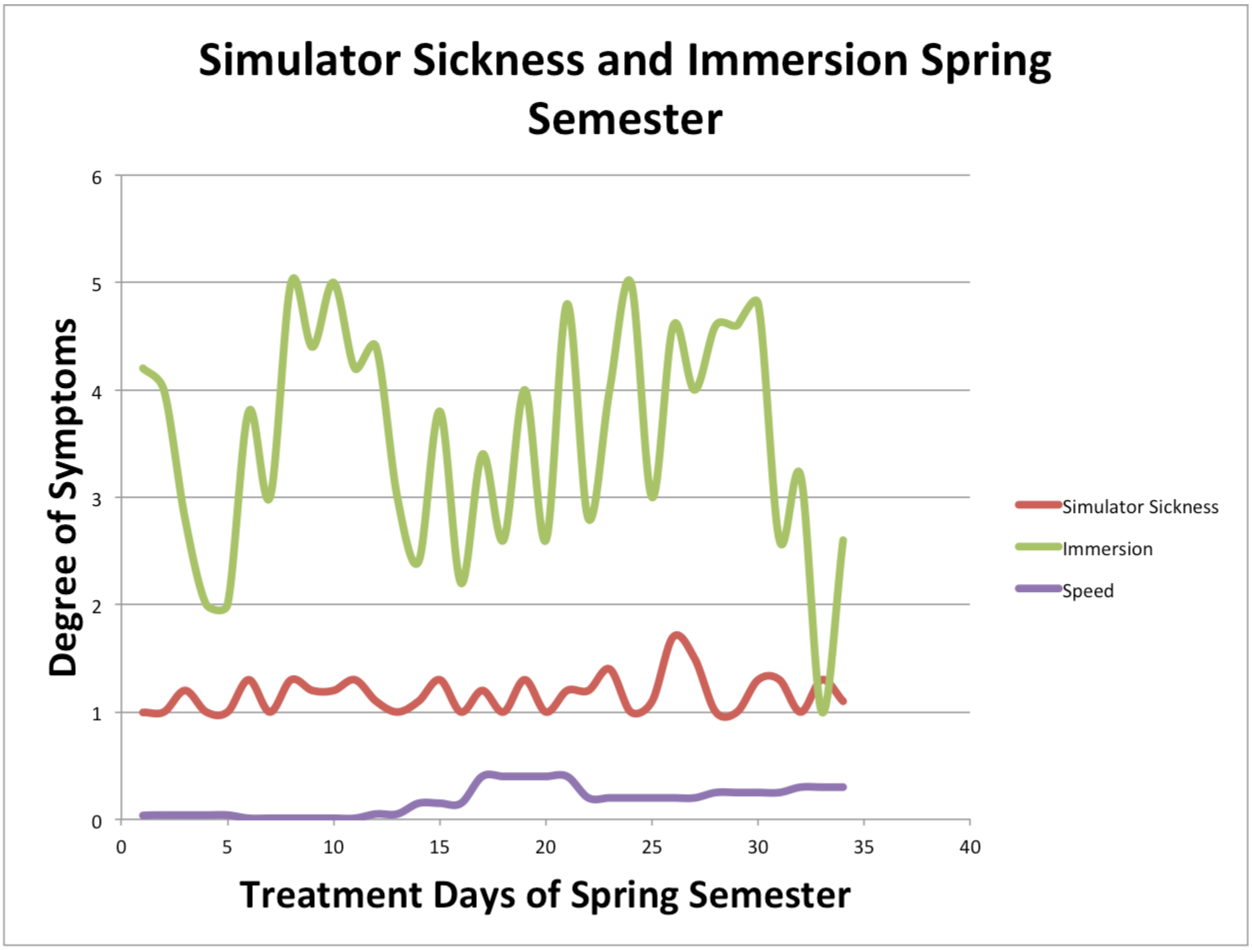


Figure 17. Simulator sickness and immersion over Spring semester using the MSD.

Table 10 shows the data used to create Figure 17. Note the degree of symptoms at 1.25 occur at the flyby speed of .04 or 160 mps. This is the same value as calculated mathematically.

Table 10
Data Used to Create Figure 16.

Lunar Flyby Speed	Degree of Symptoms	Simulator Sickness -	Immersion +
0 (0 mps)	0	0	0
.01 (40 mps)	.05	1.29	4.03
.02 (80 mps)	.75	1.2	2.8
.03 (120 mps)	1	1.3	3.33
.04 (160 mps) ←	1.25←	1.19	3.3
.05 (200 mps)	1.5	1.11	4.09
.13 (520 mps)	2	1.05	3.2
.15 (590 mps)	2.5	1.15	2.7
.2 (790 mps)	3	1.25	3.8
.25 (990 mps)	3.5	1.33	3.27
.3 (1,200 mps)	4	1.1	2.1
.35 (1,400 mps)	4.5	1.4	3.4
.4 (1,600 mps)	5	1.13	3.2

Note. Degree of symptoms at 1.25 is the intersection of simulator sickness and immersion.

I continued to look at the data for simulator sickness and immersion using different graphs because I was interested in where the lines of simulator sickness and immersion intersect. The value I calculated mathematically as shown below graphically in Figure 18. The immersion line, shown in green was greatest at the .05 (200 mps) lunar flyby speed. Simulator sickness, shown in red, remains constant with the least simulation sickness effects at the .02 (80 mps) lunar flyby speed. Results show that the lines do not intercept but are on a similar trajectory. Combined, these lines show (.05 + .02) / 2 = .04 for μ = optimal flyby speed when combining the effects of immersion and simulator sickness into one value.

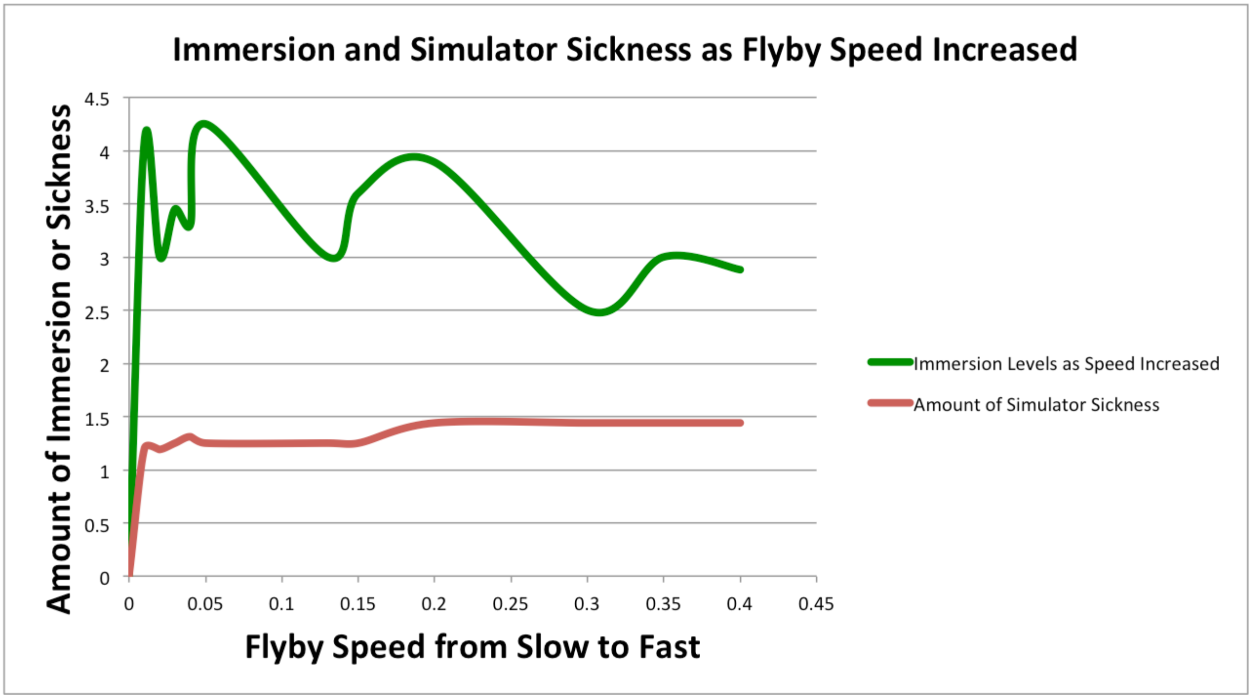


Figure 18. Immersion and simulator sickness results when participants used the MSD. Optimal flyby speed = μ of optimal simulator sickness speed (.02 or 80 mps) and immersion speed (0.05 or 200 mps)

I was able to check this by entering data for simulator sickness and immersion by speed and looking at mean difference using SPSS software. The case process summary report showed the mean for simulator sickness and immersion at each speed. I graphed this to find the intersection of simulator sickness and immersion levels as speed increased. This is shown in Figure 18 above where the lines diverge.

Use of the Virtual Reality Headset

Examination of the overall percentages of key symptomology reported in aggregate from the Simulator Sickness Questionnaire within the group *n* = 36 when participants used the VR headset were broken down into eyestrain-related as signified with the letter O, nausea related as signified with the letter N, and disorientation as signified with the letter D. The 3% result under the level of severe for the symptom "blurred vision" is an outlier since this participant did not wear his glasses while using the VR headset. Aggregate percentages of symptoms are reflected in Table 11 below, notice there were no emetic affects.

Table 11
Percentage of Simulator Sickness Symptoms When Using the VR headset

Symptom	Level: None	Slight	Moderate	Severe
General Discomfort - N	91%	9%	0%	0%
Fatigue - O	91%	6%	3%	0%
Headache - O	91%	6%	3%	0%
Eye Strain - O	74%	23%	3%	0%
Difficulty Focusing - O	86%	14%	0%	0%
Salivation - N	91%	9%	0%	0%
Sweating - N	97%	3%	0%	0%
Nausea - N	94%	6%	0%	0%
Difficulty Concentrating - O	86%	14%	0%	0%
Fullness of the Head - D	94%	6%	0%	0%
Blurred Vision - O	77%	20%	0%	3%
Dizziness w/ Eyes Open - D	80%	14%	6%	0%
Dizziness w/ Eyes Close - D	94%	3%	3%	0%
Vertigo - D	89%	9%	3%	0%
Stomach Awareness - N	89%	11%	0%	0%
Burping - N	100%	0%	0%	0%

Note. N indicates nausea symptom, O indicates oculomotor symptom, D indicates disorientation symptom. *n* = 36

While immersion was present in the MSD as suggested by the comments of this male participant called Dan, whose remarks were transcribed from a small group interview, "You could just, sort of at a particular time, like a simulation, you can zoom out as much as you want and then you could zoom back in, which I actually did" more direct immersive comments were made about use of the VR headset. In a small group interview Dulce stated, "The music really helped, it helped immerse you in the experience, it helped you forget that you were really sitting in a room in the city."

Edgar, a participant in the Tuesday evening Spring semester class wrote that using the VR headset was, "Absolutely one of the most fascinating experiences of my life. Visuals are amazing, the graphics were incredibly well detailed, my attention was enhanced." Chan reported that after using the VR headset, "The observation was amazing. I got to see [the] solar system, the Moon, the Earth, and more. I felt I was in the universe, which was impressive. It made me focused and concentrated to see the universe." Wearing a VR headset and sitting at a desk made the experience more like an enclosed space even though students had the entire universe before their eyes. Some students reported that as they explored the Moon that the cord attaching the headset to the computer processor would become twisted around them as they moved forward and backward and rotated in the rolling desk chair. This reminded them that they were in a closed headset environment.

Although 37 participants completed the Immersion Questionnaire one participant only contributed written comments and did not complete the questionnaire component. Some participants skipped questions. Possible reasons for this could be that participants lost track of the task or they did not check to see if they completed the task. Participants were able to ask questions if they did not understand the task and many did ask for clarification.

Two codes used when looking at data (see Appendix D) students recorded using the MSD concerned "The Experience," and how participants felt about the experience or use of the MSD. This code was sub-categorized and labeled "How You Felt." These codes relate to the biophilia effect, the cathedral effect and the immersion effect. Comments participants wrote that were most appropriate to the effect of biophilia concerned calmness and relaxation (Baldwin, 2012). For example, Kayla said during one of the small group interviews that this was the experience she had: “I felt like after a school day it kind of relaxed me.” This participant attended an evening astronomy lab class. All classes were held in the evening with the exception of one Spring course that was held in the morning. Whitnee wrote, “The simulation was calming.” Two male participants (Aberham and Leo) each said during small group interview group sessions, “It [the simulation] was relaxing.”

Other participants reported a stronger relation to the effect of biophilia as far as drawing conclusions from nature were concerned. A participant called Joe wrote, “[The] simulation made me feel weightless.” Gill reported during use of the motion sensor device, “to get my avatar to zoom in and out I just imagined I was swimming in a very deep pool and my arms/hands were kinda like the pointy side of an arrow.” Further comparisons to nature and the law of physics show the effect of biophilia that this tool had on yet another participant called Saul, “There’s kind of like real physical laws that apply to it and even though you stopped it [the avatar] you continue moving forward.”

A female participant (Prissy) commented during a recorded small group interview that she felt that at her eye view that she was able to achieve task easily:

> I’m quite small so I felt that the avatar did exactly what I wanted it to. Um, when I was steering around the surface of the Moon I had absolutely no trouble and I was really able to look at the depth of all the craters and all of the physical things I wanted to see. Um, and whenever I would zoom back out and turn out [ward]. I was really able to see the surface and glide as I wanted it too.

According to the experience of this participant, she was observing at the worm’s eye view because she was short and was always looking up. Prissy’s looking up to the images in the dome evoked cognition and associations with higher ceilings when she used the MSD. Yanniana (a female participant) remarked that there was more creativity allowed when using the MSD for what you wanted to do with the flyby and that the VR headset was more programed meaning that she was limited to using the affordances of the game controller as a strictly point-and-click device for zoom in and zoom out. Saul, a male participant, agreed with Yanniana when he said that the programming of the VR headset made it less creative and more restricted also but he didn't say anything about the MSD being creative. When using the MSD there was a degree of acquired skill involved in being able to manipulate the flyby to achieve the required tasks. Alex, a male participant, reported during a recorded small group interview that he recommended other students use the MSD "for the creativity" since using it in the thirty-foot dome brought out "the subtleties" of the tool. Alex came to the MSD already having skill at using the device. Saul expressed it this way: "yeah, and another thing is, um, I don't have much experience with the Wii [MSD], but it is the same thing except since we are in under the dome, like, it's much bigger…" Yanniana expresses agreement and Saul adds "you get the sense that it [the Moon] is much bigger [when manipulated under the planetarium dome]."

General Understandings from the Two Devices

Taking a look at the data in an overall way some general understandings of the two devices emerge. I looked at the MSD through the lens of design-based research to answer research question one, which dealt with changes to the flyby speed. In general, the MSD involved participants manipulating a moving flyby using their body and hands to move into the Moon's orbit, to move away from the Moon's orbit and to explore the lunar surface. This was a more public process than wearing a VR headset and involved a degree of physical activity on the part of the participant. I discovered that many participants were shy about using this device since there were sometimes other participants waiting in the planetarium theater completing questionnaires or waiting for their turn to use the MSD.

The VR headset was used in the VR laboratory, a preparation room with pass through doors behind the planetarium. When participants put on the VR headset they were aware of only their own world in the simulation and did not have the distraction of interacting with the device in an open theater the way they did with the MSD. The VR headset was a single user experience and also a solitary private experience. These were the two general understandings that I came away with from my own face validity observations and after looking at the data from both tools.

Research Question Two – Results

Data examined and discussed in this section focuses on the written comments contributed by participants after completing the Simulator Sickness Questionnaires and the Immersion Questionnaires and the transcripts from small group interviews. Research question two asks, what variety of experiences do college students have learning astronomy while manipulating a lunar flyby using fulldome planetarium software and virtual reality headset simulation? To answer this question, I looked at the data through a qualitative lens looking for meaning participants made from their experience using the tools. Data were examined using the MAXQDA coding system and through these codes all transcripts and written comments were discussed in terms of the variety of experiences students had with the tools. All coded themes offer both affordances and constraints and were grouped accordingly. Participants were drawn to compare the two tools as a natural effect of having a bilateral test situation. Effort was made to emphasize the fact that the task was not to compare and contrast the tools but to report on experience with their use. Experiences with each tool were examined in terms of what each tool afforded and allowed student participants to do. In their own words students expressed these affordances through written and transcribed comments about each tool.

Affordances Experienced using the Motion Sensor Device

Three types of documents were examined for affordances. These documents included written comments from the Simulator Sickness Questionnaire and the Immersion Questionnaire Spring and Fall semester participants completed after using the MSD plus transcripts from the eight small group interviews that the Spring semester participants took part in after they used the VR headset and the MSD. Care was taken to separate out experiences participants had with the MSD and to avoid comparisons participants made between the two tools and conclusions participants made regarding which tool was "better." Of these documents 22 coded segments were isolated using MAXQDA. They were discussed in categories labeled "what was experienced using the MSD" (10 comments), "experiences participants enjoyed" (9 comments), and "compared experiences" (3 comments). These are presented below.

What participants experienced using the MSD. Comments in this category revealed details about the tool and how participants used the MSD. These comments were reduced to three categories degree of detail experienced, light and shadow, and distance.

Degree of detail experienced. A participant called Chan commented on the ability to control the avatar in a low lunar orbit around the Moon for up close observation. Other experiences with observation included comments on lunar surface detail. Edgar observed, "[the Moon's] Craters very visible, stars moved accordingly to my movement." Prissy expressed the degree of detail experienced and noted that the simulation went beyond a three-dimensional lunar model, "The simulator allowed for a more visual representation of the moon's surface. It allowed me to understand the structures of craters more, and how a horizon on the moon would look like. The last notable thing is a lighter/darker side of the moon, how it's lit, becomes much more easier to understand in a visual 3D model like this."

Experiencing light and shadow on the Moon's surface. Participants commented on the ability to experience Moon phases and the waxing and waning of the Moon. Moon phases were defined as the shape of the illuminated portion of the Moon as seen by the participant. Moon phases change cyclically according to the changing positions of the Moon and Sun relative to Earth. Waxing and waning of the Moon is defined in simplest terms for the purposes of this study. A waxing Moon phase shows the illuminated portion of the Moon as increasing and a waning would be when the illuminated portion of the Moon is decreasing. Participant comments on Moon phases are as follows, Steph: "I like this idea and I feel like it is easy to see and get a great look of the Moon. I thought it was cool how you can see the phases of the Moon waning to waxing. You get to see the Moon really illustrated" and a female participant called Ash wrote: "I felt like this simulation is a good way to get a closer glimpse of the different Moon and phases."

Experiencing the vast distances of space. One of the topics covered at the beginning of a course in introductory college astronomy is the concept of distance. For example, distance in the solar system is measured in Astronomical Units (AUs). One AU is equal to the distance between the Sun and Earth. This distance is abstract and difficult for students to grasp. Experience using the MSD helped make these distances understandable as evidenced in this comment from Joe, "This simulation made me feel weightless. It can be great for teaching about space, you get the feel of distance and the concept of distance is very abstract until we experience it." According to the experience of this participant, the MSD helped take the abstract concept of the vast distances of space and through manipulation of the flyby enabled him/her to experience these distances.

Experiences participants enjoyed. Experiences participants enjoyed or reported as being fun were the second most reported experiences with nine comments coded. There were ranges of comments from very generalized, such as this comment from Anna, "It took a little getting used to but overall it was a fun experience" to more detailed comments having to do with manipulating the avatar and use of the body as a game controller. To use the MSD participants stood a prescribed average distance from the Microsoft Kinect hardware. The MSD hardware was permanently attached to two Christie projectors that projected the lunar flyby on the planetarium dome. The average standing distance was marked on the carpet with an X in masking tape. Participants stood with their arms at their sides until the MSD recognized them as indicated by a stable avatar. These experiences were grouped as free roam and flying and use of the avatar and are discussed in the following sections.

The experience of free roam and flying. Participants experienced the MSD through manipulation of an avatar. As mentioned previously, once the avatar was stable participants were instructed to start the simulation by raising their right arm to activate an image (the two images used were a small fire image or a concentric circle image that I called the life ring). Once this image activated, the participant was instructed to maneuver the image over the word "Go" projected on the dome to the right of a large simulation of the Moon. The participant was instructed to keep that image hovering over the word "Go" for three seconds to activate the flyby. After three seconds the Moon began to accelerate toward the participant and the participant became the avatar manipulating the lunar flyby with their body and arms. Since there is no game controller, participants used their arms outstretched with their hands about six inches apart and used the motion of their arms like driving a car. The visual image of the avatar no longer appeared as the participant became the avatar. In Anna's words, "Overall it was neat to use my body as a remote control."

Use of the avatar. Participants commented on the use of the avatar. The avatar was the participants' portal for free roam exploration of the Moon. Whitnee reported that in her mind the avatar was similar to a guide to the universe as expressed in this comment, "It was a fun way to explore space freely while still remaining in control. It's very helpful for more hands-on learners." Corey talked about the avatar using these words, "I loved how the simulation showed an human image (the avatar) as your guide around the Moon."

I just discussed the experiences participants were afforded when using the MSD in the fulldome planetarium. These affordances involved participants using their bodies as a game controller to manipulate an avatar through space to observe the lunar flyby. Next, I will report on constraining experiences through written and transcribed comments made by participants.

Constraints Experienced using the Motion Sensor Device

Constraints on the experiences participants had using the MSD came from examination of eight transcribed small group interviews and two questionnaires participants completed during the Fall and Spring semesters after using the tool. As with the previous examination of affordances, the software program MAXQDA was used to reduce the data. Constraint comments numbered 77 and were gleaned from 10 of the 12 documents examined. Comments were organized into three broad categories and were discussed in this order: problematic experiences with equipment (44 comments), physical experiences participants had using the MSD (25 comments), and experiences participants had with the overall simulation (8 comments).

Problematic experiences with equipment. Participants noted frustration with control of the flyby, in particular the tendency to "fly through the Moon" as if it were a gas planet. Other frustrations concerned recognition of participants by the active-pixel sensor in the MSD that had a difficult time recognizing light colored clothing such as white and light pink. Other constraining experiences included lack of sound effects and lack of sound when using commands such as "Go" and "Reset." Lack of visual clues for orientation were mentioned. Participants were frustrated because the lunar flyby reacted according to the laws of physics. They reported not being able to stop quickly and had difficulty zooming away from the Moon due to the forces of gravity. These are discussed under the following headings.

Flying through the Moon. The task outlined in the instructions given participants was very open ended. Participants were instructed on the use of the MSD and then instructed to investigate the surface of the Moon and manipulate the avatar to zoom towards the Moon, away from the Moon, and rotate around (orbit) the Moon. Because of the generalized way the script was written, rocky planets and moons behaved like gas planets because participants were able to penetrate the surface of these objects and continue out the other side. This aspect frustrated participants as expressed in this written comment that Shell wrote on her questionnaire, "I felt like it was too easy to travel through the Moon, which means too sensitive, plus the blend [edge blending] was off so it was looking like there was an ozone layer above the Moon" and according to Dan, "having some control of the speed would help. Even if it were automatic, like if it slowed down the closer you got to the Moon. Then exploring the surface would be more manageable, as it is, it's very easy to just clip straight through the Moon." LeeLee reported during a small group interview, "For the Kinect [MSD] simulator I had a hard time even getting myself around the Moon because I went right through it so it was really easy to get away from the Moon because that is what I kept doing." From these comments I concluded that she was able to zoom away from the Moon by going through the Moon, a somewhat alternative way to zoom out. She was unable to orbit the Moon but kept trying until the five minutes of time were up. Another female participant, Carol, reported frustration with the MSD in these words reported during a small group interview, “I was getting frustrated when we were doing the motion sensor one, because I kept getting too close to the surface and I kept going inside the Moon, because you could travel through it, um, so that part was frustrating.” Ira, a male student with some degree of technical expertise, defined the problem in this way:

> Rather than passing through it, that’s because the model doesn’t have a hitbox [programming commonly used in video games for real-time one-way collision detection]. It doesn’t have a physical box for you to stop, nor does the camera [active pixel sensor], so you pass through it. So, if it had the option to stop that could modulate that a bit so if you were to pass through the Moon you could say, ok, I could stop and back up, or I could possibly…If it does have a hit box, hit it and stop in place. Having an option like that would let me stop.

The lunar flyby software used with the MSD was programmed by a physicist to behave according to the laws of that discipline. Participants expected an experience more like a video game with specific controls and reported that in these experiences. Participants noted that they spent too much time concentrating on control at the expense of learning about the lunar surface. Students mentioned the lunar surface and their desire to explore the craters and shadows even though this was not a requirement of the task.

The active-pixel sensor. The MSD was controlled by a natural user interface, in this case body motions instead of a game controller. Using a laser and an image sensor the device recognized, or attempted to recognize the body motions of participants when they stood at a prescribed distance from the device. Participants experienced frustration with the active-pixel sensor because it was more difficult to get a strong and stable avatar if a participant was out of the average range of body norms set for the device (usually this would be a participant that was very tall), or if the wardrobe choices for a participant tended toward very light colors. When there were problems with recognition I would have the participant slowly walk closer to the MSD while watching the avatar. Usually that worked to get a read on the participant and pick up a clear avatar. A male participant named Rod describes this process, “Using the Kinect for some reason it wasn’t recognizing where I was until I started moving forward and back as I did it, it started recognizing my position, maybe my height.” Other students had problems with height recognition as the MSD was set to recognize a range of average heights and weights. Another participant, Nadia, said, “Oh yeah, with the motion sensor you know what I’m, I am getting ready to, I guess fly, or explore the Moon, my uh, I was standing still and the projector was um, I was, um, the avatar was moving its legs, uh, I dunno…” In this case the sign of an unstable avatar will signify the avatar jumping or moving its legs rapidly as the sensor tries to do a reading. A female student named No, reported on a written comment, “It was kind of difficult for the censor to read me. The avatar was still moving and I was standing still. I don’t know if it was the color I was wearing [white pants and a light pink top] or if it was the sensor.” A different female participant, Andrea, wrote about her experience trying to get the sensor to recognize her.

> Since the device did not recognize me I had to keep putting my hands on my side and then lifting them but to my sides until it recognized me. We did this about 6-8 times before it recognized me. I was wearing a pink sweater, after I removed the sweater, I had a black and white tee shirt underneath which the machine [seemed] to recognize better. When going through space I felt uncomfortable and bored.

The fatigue Andrea experienced in attempting to get the equipment to function may have contributed to her feelings of discomfort and boredom. Two tall male participants were not recognized by the sensor, one asked to be recused from the study and the other participant, Ed, had these comments about how all the attempts to gain recognition made him feel about participating in the simulation.

> It [the MSD] was difficult for me because I couldn’t get adjusted because of my height [the motion sensor device was set for an average height and weight, this student was very

large and tall] I ended up having to sit down, it, it didn't grab me as wanting to continue with that actual item. Now the one on the computer [VR Headset] there was just so much stuff the graphics and everything on that one I found just real good. That one [MSD] it could have been because I had to do so many adjustments just to get started it already it pushed me away already like [soft giggles in background] I just thought awww I gave up before I even started.

Out of the $N = 67$ participants that used the MSD, there was one female participant (Andrea) and two male participants (Ed and a participant that recused himself) who had a difficult time getting the device to recognize them. One participant gave up, Andrea reported being bored, and Ed was frustrated with the experience before it started. These experiences with recognition may have influenced their experience with use of the MSD.

Changes to multimedia features. Participants who had the opportunity to use both the MSD and the VR headset $n = 36$ reported their experience with the MSD would have been more favorable with a sound track, music, or sound effects. Music could be easily added as part of the MSD simulation but an audio track was not built into the software and I did not add one. Alex reported during a small group interview that,

> And the clicking, the clicking function is just like, it shouldn't fade to black, it should be like, [reset feature in Kinect] it should be like a noise, something to denote like [to] click the button not like fading out…

Alex noted that in order to cue the functions the clicking would not only visually act as a cue on the screen but also with a sound. Hristo, a male participant, wrote these comments, "Shouldn't have to hold [the Reset] button so long. Button should click instead of fading to darkness." I often verbally cued participants to hold their fire symbol or life ring symbol on "Go" for about three seconds because they had trouble telling when the simulation was started.

Participants noticed visual limitations that affected their experience using the MSD. Some levels of distortion were mentioned such as in this comment by Steve, "The Moon kept [me] more [interested with] interesting detail at a bit of a distance away from it, probably due to the slight distortion that occurs up close." A different participant, Damian, noticed that the Moon was somewhat elliptical due to edge blending, rather than being a sphere. This is exemplified in this statement, "The program wasn't perfect so the Moon started to become egg shaped. The speed was perfect for observing a singular object plus or minus depending on [the] student." Other visual cues that the participants mentioned were labels and markers. When using the VR headset participants could choose to turn off labels and markers. Some participants used them, others did not. This dialog between Edgar and Darian discusses the wish for some type of labels for the MSD.

> Edgar: Maybe it could tell you to go this way, or the sun is this way or…another planet is this way.
>
> Darian: yeah, I thought that too.
>
> Pam: I see
>
> Edgar: On the corner, you could have a little box that said could tell you like North South like you know anything. Because there wasn't anything really to guide you. [A participant wrote this in during member checks: *Yes, a small MP (megapixel) in the corner of the screen would have been very useful, It would tell you where in the solar system/galaxy or universe you were at.*]
>
> Darian: Because once you get away from the Moon you really can't come back without resetting. It's kind of hard to figure it out. It was a little bit difficult to navigate. I found myself having to concentrate fully. There were times when it became a little frustrating

Because this dialog occurred in a small group interview it may have been that participants were thinking of their recent experience with the VR headset labels. No comments asking for labels came from the written comments examined during the Fall semester when participants did not have access to the VR headset.

Physics and the laws of motion had effects on participant experiences. Experiences mentioned indicated the ability to control speed was desired with only "it was too fast" types of comments. No comments written or spoken requested a faster speed. Participant also wanted the ability to stop the simulation so they could examine the Moon in greater detail, especially the craters of the Moon. Because the simulation imitated physical laws participants were drawn toward the Moon using the force of gravity. Through manipulation of the avatar some were able to achieve a low orbit to observe the Moon's surface. Many had difficulty achieving escape velocity to zoom away from the Moon. Dave made these comments during a small group interview, "Ok for the Moon one for the first one it was kind of hard to control the rotation yourself so I found myself going into the Moon and going back out. I think going back around going to look at the Moon, that was really hard because that was really hard to make your movements right or if you didn't it just messed the whole thing up." Christian, a male participant, wrote that it was like having bad brakes on a car. From this discussion and presented examples of experiences participants had using the MSD hardware and software I will now focus on the physical experiences participants had while engaging in the simulation.

Physical experiences participants had using the MSD. Out of all documents, seven yielded comments on the physical experiences participants had using the device. Twenty-five comments were coded and these were broken down into three categories: dizziness, tiredness in the arms, and tiredness in the legs. They are discussed individually below.

Dizziness. Participants reported dizziness while manipulating the lunar flyby. During this simulation participants remained standing with the exception of one participant who was able to sit down to manipulate his avatar. This was one of two participants who were tall and to achieve a stable avatar he was able to sit in a chair and do the manipulation. Details on causes of dizziness include inability to control the speed of the flyby. In these cases, the Moon flyby speed was reported as too fast. Whitnee wrote, "At times I couldn't control the speed and that's what made me dizzy." Chris, a male participant, stated, "I did the YMCA with my avatar. It was harder to control than expected and the ‘driving’ controls were tough to use. Pretty cool all together but makes you a little dizzy if you don’t know what you are doing.” A different participant experienced a slight dizziness from orbiting the Moon and from turning. Some participants were skilled at manipulating their avatar into low lunar orbit; when this was achieved it appeared that the closer the avatar got to the Moon the faster the lunar rotation. This is what is meant when the participant reported “turning.”

Tiredness in the arms. After preliminary instructions and achievement of a stable avatar, participants were instructed to zoom their avatar in toward the Moon, zoom their avatar away from the Moon and put their avatar into a low orbit around the Moon. Participants used the MSD for five minutes. Participants reported their arms got a little tired and their arms got weak after five minutes. During instruction and after achieving a stable avatar, participants were instructed to raise their arms straight out in front of them with their hands about six inches apart. They were instructed to manipulate their avatar as if they were turning a small steering wheel as well as lowering and raising their arms as though they were manipulating a “stick” when flying an airplane. It was verbally suggested that if their arms got tired to put their elbows in toward their body but continue to manipulate the flyby.

Tiredness in the legs. During the Spring semester due to the word of mouth spreading of knowledge of the project coupled with better explanations of the task and comfort with the equipment participants were able to do other types of body movements to maneuver and achieve better control of the lunar flyby. Two techniques used by participants were ski jump/surfing/Superman and YMCA. Ski jump/surfing/Superman is a body position that two participants adopted to control a low lunar orbit of the Moon and sustain it when using the MSD. This body position consisted of a crouched position with arms outstretched in front of the body much like the position of a ski jumper coming down the ramp or of a surfer crouched in the curl of a wave. As you can imagine, holding this position can be a challenge as reported by the written comment of this participant, "Lactic acid build up during prolonged flight in Superman pose." This exchange, between two male participants and the moderator, was recorded in a small group interview:

> Will: Yeah, the Planetarium, yeah, my legs because I was bending down.
>
> Pam: Yeah, you were doing all those ski things.
>
> Will: Yeah, my legs were getting sort of, my thighs were getting…
>
> Pam: your quads were burning…
>
> Gill: yeah, pretty tired and stuff like that so, [clearing throat]

A sustained theme was holding the poses required for participants to manipulate the flyby and how this was tiring on the muscles. Tiredness in the arms and legs was experienced by some participants as well as dizziness.

Experiences participants had with the overall simulation. Experiences in this category were generalized to comments made about the purpose of working with the MSD and controlling the lunar flyby. Participants commented that they would have experienced more interest if the task involved locating a specific crater on the Moon rather than controlling the zoom in, zoom out, and achievement of an orbit around the Moon. Anna wrote that, "It was fun but I felt like the purpose was aimless." Chrystal wrote these comments to exemplify this point, "as of focus and concentration, without any objective to 'find' seas or craters it seemed kind of pointless. If there was an objective like find the 'sea of tranquility' then it would be a lot more challenging and thus enhance focus and concentration." Aberham wrote these suggestions on this topic, "the simulation can also add other things than just the Moon, because besides the craters, there is nothing else to look at. So after a minute and possibly seconds one will lose focus and start to wander." These students reported that there was little purpose to the activity and that the objective of the activity needed to be more specific to be engaging.

Andrea, a female participant mentioned earlier, wrote that she was uncomfortable and bored doing the simulation. She had worn light clothing and I worked with her for about five minutes to get a stable avatar so she could begin the simulation. A final comment dealing with the subject of the simulation being tiresome and boring was obtained from written bullet point notes on the back of a questionnaire. Nadia wrote that she, "I lost focus because it was kind of boring spinning around the Moon and that the motion was not as realistic [as the VR headset.]"

In this section I discussed affordances and constraints of each simulation tool in terms of participant experiences. Affordances with each tool were reported as positive experiences participants had with the tools. Constraints were reported as negative experiences and/or things participants wanted added to the tool's affordances to make their experience working with the tool better. Constraints were also the physical experiences that participants reported having while manipulating the MSD using their body as the game controller to manipulate the Moon. These were things like tiredness in the arms or legs from holding positions to manipulate the Moon using the MSD.

Affordances Experienced using the Virtual Reality Headset

Participants experienced the VR headset during the Spring 2017 semester. Affordances were grouped by four categories: first, what the VR headset offered; second, how participants controlled the experience when using the VR headset; third, observations on how use of the VR headset can help people learn or do things; and finally, categories that came up dealing with the VR headset compared to other things the participant did or knew. Each of these will be covered in order that they were just mentioned.

Affordances experienced. I examined ten documents and coded 32 segments falling into the category of what experiences or affordances that the VR headset offered participants. Some of these 32 segments were duplicated or very similar so I will cover the main categories without sacrificing the subtle experiences and distinctions that participants express in the sections below.

Realism. After reviewing the eight transcribed small group interviews and written comments the category of realism as a repeated theme was noted. By realism I mean that the quality of representing the Moon and space as accurate and in a way, that is true to the participants' textbook descriptions. The degree of realism expressed was similar to being immersed in a compelling feature film or reading a good book; Chris reported that "I could probably do VR all day. It felt like time stopped" the headset and software program used made his experience so realistic. Corey said he does not experience this form of realism very often; the simulation maintained such a high degree of fidelity. Corini, a female participant, reported that the extreme realism made her feel excited to be using the simulation. Carol, another participant, reported details of experiencing realism in observing the dark side of the Moon:

> …the VR was, um, much more realistic, and, um, not only that but just seemed the Moon, you could see on one side the darkness. The Moon was darker on one side and then it was brighter on the other. Um, and either just seeing the constellations around it and the Milky Way was pretty exciting so it looked very realistic and, um visually appealing.

Whitnee and Carol described the texture and surface of the Moon rendered in this software program (Star Chart) as accurate and detailed. Prissy described it like this, "And, what the VR did especially is added depth to the experience of learning about these craters and the surface of the Moon." She is speaking of the three-dimensional aspect of observing the Moon when wearing a VR headset. Realism is the largest category of affordances mentioned by participants as benefits the VR headset offers.

Graphics and visuals. Similar to realism, graphics and visuals were mentioned by the participants as high-quality enhancements to the simulation. Graphics refer to realistic pictorial representations of the moon and visuals refer to information taken in by the eyes as opposed to auditory or through touch. Edgar's written comments reflect this, "Visuals are amazing, the graphics were incredibly well detailed, my attention was enhanced." Pictorial representations and high-quality detail were mentioned as helping with attention span. Other written comments describe how all this detail made a participant called Carol feel,

> The view of the constellations and asterisms just make it so visually appealing. I am not afraid of heights, but I could definitely feel a bit anxious in my stomach area. It was a good thing though. The Moon was beautiful to look at. Some part of it was dark, the other side was bright.

This degree of detail enhanced a feeling of being in space and high above the Moon to simulate vertigo. Dulce reported during a small group interview, "…the graphics were great like all the light, like everywhere I looked it was I could be a part of space which I thought was awesome." The individual features were defined to the degree that this participant felt she was part of the simulation.

Music and sound effects. The VR headset had built in headphones and participants heard soft instrumental music playing that was embedded in the software program as they maneuvered themselves around the Moon. Recorded audio in the program from Apollo missions played as participants neared lunar landing sites. The audio was the historic record of astronauts speaking with Mission Control, Johnson Space Center in Houston, Texas. Edgar said that the "static and radio talking" (referring to this historic record) made him feel like he was a real astronaut. Chris reported that the music and sounds made him feel like he was in space. Ira said that the music made the experience relaxing, and the music made the experience with the VR headset more immersive. Finally, Corey said that the sound effects in the simulation made the experience intense and entertaining. No students reported the music or historic recordings annoying nor did they express interest in complete silence while wearing the headset. All reports from participants on the music or sound effects were positive.

Labels. In Star Chart, the software program used with the VR headset, labels refer to a word or words used to specify astronomical objects. These labels consist of names of planets and bright stars, names of astronomical objects, star clusters, asterisms, and Messier objects (astronomical objects catalogued by French astronomer Charles Messier that were identified as not being comets). When using Star Chart with the VR headset participants held a game controller and was able to turn labels on or off by pressing a button on the controller. Ash talked about her use of the labels this way, "All of like the things, the labels, I turned off but and then it showed all of the labels to everything and then. And, what the VR did especially is add depth to the experience and of learning about those craters and the surface of the Moon." To her experience she used the labels at will to identify and to learn more about what she was experiencing using the headset flyby. Ash wrote,

> I like it how it showed and named the constellations. I also liked how it zoomed in on the Moon so that I can see all the valleys on the surface. This is a cool device to get people to get a closer feel of the Moon and its phases due to the Sun.

Ash liked the details included in the VR headset to help her navigate the solar system and learn about Moon phases.

Experience with the game controller. The VR headset used for this study came with a small, thumb sized game controller. Participants commented that this controller enhanced their ability to control the flyby. Yanniana said during a small group interview, "Well, with the virtual reality I noticed that like once, um, like there's a red circle around whatever you want to zoom into it just, it took a second but it just zoomed you right in, you know what I mean?" Another female participant, KC, noted the advantage of the game controller when she shared this during a small group interview, “um hmm, like more opportunities, because it took forever like trying to get to the sun in the Xbox one [MSD], with the headset, you could just go there if you wanted.” Steph commented that the flyby was fluid. Using the game controller participants isolated the Moon and fluidly zoomed into orbit around it. From experiences with use and control of the VR headset tool I will next examine participant comments dealing with experiences students had with other tools that bridged the experience with VR.

Experiences with VR compared to other things the students did or knew. Twelve coded segments from six documents emerged when looking at all transcribed data and from the VR questionnaires. These segments explored connections participants made with their experiences with other tools or simulations that helped them bridge the experience with VR. These are discussed in this section.

Experiences with other simulations. Some participants transferred prior knowledge of other simulations to their experience with the VR headset as illustrated in this exchange:

> Corey: I’ve had some similar experience, like uh, like it’s, uh the difference I can say when I was doing driver’s ed. we had a simulation, you know, and you’d be, it’s like you’re driving a car and then a ball come out in the streets and some kids run and you’ve got to stop. The thing I liked about the headset situation especially the controller reminded me of a Nintendo cause they had the little cross looking controls…
>
> Alex: Had a little flashback, up down, up down, left right, left right, A B, A B.
>
> (Sounds of participants chuckling in agreement)
>
> Alex: A B star, you know, and, it was more, it was more fluid with the headset but when I got into the Planetarium I had to, had more difficulty; it was still interesting.

Corey and Alex used the experiences they had using other types of simulations to transfer that knowledge into skills that they could use to manipulate the VR headset. This ability to transfer prior knowledge was recognized as an asset and discussed during the recorded small group interviews. Walt used previous video game experience to help him learn how to manipulate the lunar flyby as exemplified by this exchange, “Yeah, it’s kind of like a video game, it’s kind of like the VR, I’ve used the VR once or twice before and really it was just like a video game I, it, I was just going through it like it was just like a video game.” In this instance, the prior knowledge of video game hardware (i.e. the game controller) was a transferable skill that was used to manipulate the Moon. Other experiences participants had that they compared to this experience were the prior experiences of manipulating drones and driving a car. Another participant speculated that children would adapt to using a VR headset easily since they have grown up with technology.

The VR experience as a way to help others. Participants related their experience using VR and the headset with prior experience using simulation tools such as operating a driver education simulation or a video game. Now they draw further connections to the device and see how VR technology can be a useful tool for teaching and learning. Aberham wrote these comments in an analysis of the tool,

> My focus was throughout most of the five minutes. This was able to provide more of a practical use when it comes to learning because multiple students can use it at the same time unlike the [MDS] simulation. [It is] easier to navigate with the buttons and it tracked my head movement very accurately. This is more of an easier way for educators to teach visually, especially in Astronomy.

As a way of understanding how VR headsets can be linked, this is done by allowing multiple VR headsets to share the same single display which can be projected on a classroom screen using a data projector and by tying the single view and head tracking to a single VR headset. All users would see the same thing that the control VR headset sees. The other option is to disable the head tracking altogether thus turning all VR headset views into a common fixed shared view (Cyril, 2014).

Elaine commented, “a great way to learn things,” and Nadia wrote, “I feel I could better understand Astronomy if it was available for me to use.” Steph noted, “like we can put it in school. We can use it in schools and not just like astronomy but with so many of the other different types of like subjects. You can use it with like, I don’t know…” Two male participants, Chris and Alex, reported, “I would recommend this to all students,” and “especially like in the high, or in elementary or middle school.” During a recorded interview Steph commented, “I mean just because now we live in a world where we, like the technology is everywhere. We might as well take advantage of it you know. So, they can learn something out of it…” Participants could see some value in the tool as a way to teach college astronomy as illustrated in this exchange:

> Edgar: Have a whole class with VR headsets and then you are like and then you look over here and then the teacher is wearing one too.
>
> Darian: And then everyone can zoom in…and then everyone zooms into the Moon.
>
> Balish: That would be really cool.
>
> Darian: I think everybody would love that class.
>
> Edgar: And then they’re like on the side and they’re they can tell you like notes and stuff like that. But like the characteristics of the planets and stuff, that would be cool.

Participants also noted that VR would engage all learners because of its multimedia aspect. Jazz, a male participant noted, “when dealing with observational sciences you really have to get in there, and then as far as astronomy is concerned, we don’t really have the resources to just jump up into space; unless we have VR” and a Leo, different male student said, “So this is fantastic especially for people who are not, like, auditory.” Dan wrote, “This will be extremely helpful in education. It is calming, immersive, exciting, engaging and fantastic for kinesthetic learners.”

In the above section I discussed affordances participants experienced using the VR headset. Affordances were discussed first in terms of the physical experience with the tool in terms of the comfort of the headset and physical environment and the ability to control the software. Second, affordances were discussed in terms of the transfer of knowledge participants were able to make when connecting prior knowledge of other simulation tools and experiences to the VR headset experience. Last, affordances were discussed in terms of expanded uses and situations where participants could see uses beyond their initial single experience, uses that could be applied to teaching and learning in both K-12 educational settings as well as higher education. In the next section I will discuss constraints plus affordances participants wanted in the VR headset.

Constraints Experienced using the Virtual Reality Headset

Ten coded segments gleaned from four different documents yielded data on constraints experienced with the VR headset. Participants had suggestions and recommendations for affordances they felt would make this tool more user friendly or would enhance the multimedia experience. The following excerpts come from written comments gleaned after analyzing the Simulator Sickness Questionnaire, the Immersion Questionnaire, and transcribed small group interviews and are discussed below.

Controlling the experience when using the VR headset. In addition to the four codes describing affordances of the VR headset, I coded responses for discussion of participants' controlling experience. Twenty-three coded segments were gleaned from nine documents under this category. They were examined next for sub-categories and in the order of number of times mentioned.

Position of the headpiece. Participants noted that fit and position of the headpiece was critical to use of the VR headset. The headset has three Velcro adjustments for comfort and fit.

One adjustment goes over the top of the head and the other two were on each side of the head. Each participant had unique adjustment needs and was encouraged to move the Velcro until they were comfortable with the fit and could get good positioning to use each eyepiece. Yanniana's written comment revealed,

> This was my first time using VR and it was an interesting experience. I notice that the headpiece has to be positioned perfectly in order for the picture to be clear. Overall, I enjoyed my experience, definitely gave me a different perspective about space and the Moon.

Brianna, another first-time user of a VR headset reported a similar experience with fit and comfort of the headset,

> It was my first time using VR. The headset fit slightly heavy on my face [pressure on the bridge of my nose] but overall it was a good experience. The controls took some practice to move the Moon to the positions I wanted to view it in but once I got it, I felt like I was flying around it with ease.

Gill, a male participant noted, "Uhhh so the only thing I can really think of is when I put on the VR headset uhh, it wasn't it was really blurry at first so after I adjusted it with the Velcro it, everything got clear" and Will confirmed, "yes, yes, you have to find the point and then adjust the Velcro." Proper fit of the headset reduced distraction and enhanced immersion so participants could concentrate on the task (see Figure 19 below to see the headset in use).

Figure 19. Using the DK3 VR headset and computer set-up. Cords coming off the front of the headset attach to computer hardware. The ability to rotate and move the chair was hindered by these tethers.

The cord, desk, and chair as distractions. Participants noted the cord, the desk, and in some instances the chair they were sitting on took them out of the simulation The VR headset was attached to the computer with a cord that came off the back of the headset and connected to the computer. Participants sat at a rolling office chair. This chair was positioned at a large office desk that housed the computer hardware and monitor. This arrangement was one of convenience because the desk was available for use and finding space to do the research was a challenge.

Brianna remarked that the desk and physical environment were, at times, intrusive with this comment, “Uh, when I was using the virtual reality goggles, uh, I kept hitting my knee on the desk and it was distracting, um, taking me out of the experience, I guess." Less control of the flyby due to distractions was also noted in the following exchange. Corey said, "with the headset on…I was getting caught up in the things"; Alex and a Steph agreed as they had the same experience. Corey continued, "then I realized my foot was getting on the cord so I realized like, I don't like that!" During this exchange Alex noted, "I kept peeking underneath [the headset] to just see where I was. Was I hitting into somebody, or was somebody hitting into me?" During a small group interview Ed found the cord inhibiting as exemplified in this statement, "The goggles was great, the only difference with the goggles was uh, the cord, like I found myself turning around and I felt the cord like tugging. And so, I didn't want to go too much further to where possibly pulling it out." Dulce had a similar comment, "Yeah, the headset one rotating was really easy, the only problem was the cord getting wrapped around, but um, other than that it was really awesome." Participants agreed that the physical hardware was a distraction. A solution was suggested that making the headset wireless would be less of a distraction.

More options. Participants talked at length about zooming into the Moon but some asked for options to zoom out farther from the Moon (the VR headset commercial Star Chart software has set parameters for zoom in and zoom out). Aberham expressed this desire in technical terms, "about the headset, it was nice, and it had nice resolution but I can't zoom in any further because it's so hi-def. that you would think that you could zoom in further. So, you could see a little bit more." Some participants expressed interest in being able to achieve a higher level of zoom in ability so that they could walk on the Moon. Participants, both male and female in one small group interview expressed agreement that it would be a more entertaining simulation if they could manipulate the avatar to walk on the Moon's surface.

Fluidity was expressed as something participants wanted to experience with the VR headset. This exchange exemplifies that desire:

> Whitnee: Yeah, I wrote on the headset part, I wrote, maybe have the movements little more fluid, like you are actually more floating in space.
>
> Jazz: Yeah
>
> Whitnee: It was a little rigid

The Star Chart software program participants used is experienced through the VR headset and controlled by the motion sensor device. Participants noted that the pause and isolation time when preparing the zoom in took them out of the immersive moment. During an early experience with the VR headset a participant wrote that the Star Chart software as experienced using the VR headset had limitations in reach as expressed by this Elaine's written comment, "Maybe make it able to move a little closer to objects to see even more details, when you reach very north or above the Moon you can't rotate left or right. You need to move down a little then it allows you to move left or right."

What was Learned from the Data about these Two Devices?

On a general level, what was learned from the overview of data about these two devices is now discussed in regard to the research questions. Research question on deals with optimal flyby speed. The answer to this question was heavily informed by analysis of the Simulator Sickness Questionnaire and the Immersion Questionnaire.

Data compiled from the Simulator Sickness Questionnaire in terms of use of the MSD and the VR headset are shown in Table 12. These data show that participants reported more eyestrain related symptoms when using the MSD (23%) than when using the VR headset (14%). Numbers are further broken down from more symptoms to less symptoms with fatigue (34%), eyestrain, blurred vision, and difficulty focusing (23%), difficulty concentrating (21%), and headache (11%). Participants using the VR headset reported these symptoms from greatest to least: eyestrain (26%), somewhat more than when they used the MSD, blurred vision (skewed at 23%), difficulty focusing (14%), headache and fatigue (9%), and difficulty concentrating (5%). The high blurred vision rate was skewed because some students removed their glasses or were unable to adjust the VR headset to fit over their glasses as reported on the small group interviews.

Table 12
Percentages of Key Symptoms from Results of the VR/MSD Simulator Sickness Questionnaire

VR Nausea-Related		MSD	
Symptoms VR	Percentage	Symptoms MSD	Percentage
Vertigo	11%	Vertigo	19%
Sweating	3%	Sweating	3%
Nausea	6%	Nausea	17%
Dizziness	11%	Dizziness	15%
Stomach Awareness	11%	Stomach Awareness	9%
Fullness of the Head	6%	Fullness of the Head	24%
Note. n = 31	Averages: 8%		15%

VR Eyestrain-Related		MSD	
Symptoms VR	Percentage	Symptoms MSD	Percentage
Eyestrain	26%	Eyestrain	23%
Blurred Vision	23%	Blurred Vision	23%
Difficulty Focusing	14%	Difficulty Focusing	23%
Diff Concentrating	5%	Diff Concentrating	21%
Headache	9%	Headache	11%
Fatigue	9%	Fatigue	34%
Note. n = 36	Averages: 14%		23%

Data compiled from the Immersion Questionnaire in terms of use of the MSD and the VR headset are shown in Table 13 below. These data show that participants reported more immersion when using the VR headset (55%) than when using the MSD (24%). Breakdowns for use of the VR headset from greatest (a lot) to least (Not at all) show that comfort was experienced by 70.3% of participants, focus and concentration was experienced by 59.5% of participants, a feeling of harmony was experienced by 51% of participants, and that 17.1% of participants experienced a reduction in stress when using the device. Breakdowns for use of the

MSD from greatest (a lot) to least (Not at all) show that concentration was experienced by 30% of participants, comfort and focus was experienced by 25.7% of participants, a feeling of harmony was experienced by 21.4% of participants, and stress reduction was experienced by 17.1% of participants. In general, participants had neutral feelings in all categories of immersion for the MSD.

Table 13

Percentage of Participants Reporting Immersion Levels of each Condition using the MSD/VR

Intensity Across Five Variables Using the MSD					
	Not at All	Somewhat	Neutral	Very Much	A Lot
1. –Reduce stress	15.7%	17.1%	24.3%	25.7%	17.1%
2. +Focus	12.9%	5.7%	27.1%	27.1%	25.7%
3.+Concentration	7.4%	1.3%	18.5%	10.8%	30%
4. +Harmony	15.7%	5.7%	30%	25.7%	21.4%
5. +Comfort	11.4%	5.4%	21.4%	24.3%	25.7%
Average	13%	7%	24%	23%	24%
Intensity Across Five Variables Using VR					
1. –Reduce stress	10.8%	5.4%	21.6%	24.3%	35.1%
2. +Focus	5.4%	5.4%	5.4%	21.6%	59.5%
3.+Concentration	5.4%	5.4%	13.5%	10.8%	59.5%
4. +Harmony	8.1%	5.4%	5.4%	24.3%	51.4%
5. +Comfort	2.7%	15.1%	2.7%	13.5%	70.3%
Average	6%	7%	10%	19%	55%

Note. – Indicates reduction and + indicates enhancement. Some participants did not complete all questions due to human error or intentional omission.

Overall the student participants were more enthusiastic about using the VR headset, they reported more favorable responses during the small group interviews and comments made on data sheets. Participants reported that they felt that using an MSD was old technology; one male student reported that the MSD was "1984 technology and that the VR headset was 21st century technology." This comment may spring from experience with technology this student achieved.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

Summary of Findings as they Relate to the Two Research Questions

The overarching questions that guided this study were first, what optimal lunar flyby speed do college students report comfortably using to manipulate a flyby of the Moon using a motion sensor device in the college planetarium and what variety of experiences do college students have while learning astronomy when manipulating a lunar flyby using fulldome planetarium software and virtual reality headset simulation?

A more quantitative method of data analysis was used to answer the first research question. This method examined data from two Likert-type questionnaires administered to participants after using both tools. This quantitative approach used design-based research (Barab & Squire, 2004; Hoadley, 2004; Sandoval et al., 2004; Walker, 2011; Wang et al., 2005) and was used to look for changes in the data over time.

A qualitative phenomenographical approach was used answer the second research question to understand the variety of experiences participants had using the two tools to manipulate a lunar flyby. A wide variety of experiences in terms of affordances and constraints were gathered from written comments and small group interviews. I examined all coded text sections for fine gradients of meaning participants made of their experience using each tool and noted which experiences participants liked, disliked and discussed the suggestions participants had for making the experience using these tools better.

Discussion of Research Question One Results

Question one concerns various *factors*, which are elements or causes that contribute to a result. When using the MSD data were analyzed looking at lunar flyby speed to determine ease and comfort with speed including rotation, zoom-in, and zoom-out speed and the ability to manipulate avatar to explore the Moon in low lunar orbit. In particular I was looking at how participant use of the MSD, in particular the comfort levels, stabilized as treatment sessions progressed. Written comments and transcripts from mini-interviews provided additional material to inform speed changes. A balance of my own face validity experience along with changes in flyby speed were examined in a quantitative way to determine optimal flyby speed of the Moon when participants used the MSD in the fulldome planetarium. When looking collectively at all the data both qualitative and quantitative with focus on research question one, the design-based study investigation analysis of Likert type data for both the Immersion Questionnaire and the Simulator Sickness Questionnaire reveal the optimal flyby speed for the Moon is .04 x the radius of the Earth (3,959 miles) or 160 mps. Quantitative data analyzed using statistical software was further verified by face validity when a colleague assisted me with timing the treatment during the Fall semester and I observed participants using the MSD during the Spring semester. Results were triangulated by examination of written and transcribed data for evidence that participants mentioned speeds were too fast. Speeds for the lunar flyby were retested during the second semester with a total of $N = 67+$ participants providing data that some participants used the MSD more than once and their experiences came out in the small group interviews).

Working with groups of participants on the first research question component of this study involved using the MSD to gather data that helped me determine the optimal flyby speed for the Moon. This was important from a design-based research point of view. If curriculum is designed involving a lunar flyby, knowing the best speed to set the script sets students up for a good learning experience. Along the way to determining optimal flyby speed using design-based research opened up ancillary findings related to the second research question and helped reveal the variety of experiences participants had using the tool. Analysis of transcripts showed me that participants liked the creative open space involved with working with the MSD in the planetarium. Knowing this can help students and instructors choose a tool depending on what they want to communicate or learn. There is not a lot known about using a MSD as a simulation for teaching and learning. Knowledge of optimal flyby speed of the Moon when learning astronomy puts down a toehold for further research into using the MSD for education.

Discussion of Research Question Two Results

Question two concerns various *ways*, which are courses of conduct, actions, manner, and methods of doing things. This question deals with qualitative data analyzed from the use of both tools to determine the variety of experiences participants had using the tools. The MSD afforded participants the opportunity to experience light and shadow on the Moon's surface and the experience of free roaming and flying using the avatar. Participants reported that the MSD made them aware of the vast distances in space but they also reported some constraints when using this tool. Examining data from the Immersion Questionnaire and from written transcripts this tool gave participants a bird's eye view of space and induced the cathedral effect of openness and freedom.

The MSD was problematic for many participants because it was more difficult to use and its use was more public. Participants used the MSD in the fulldome planetarium as opposed to the smaller space of the VR laboratory. In the theater participants were pretty much on stage, even though they were standing at the back of the planetarium their actions were projected across the 30-foot dome. This may have added to some of their critical feedback.

Participants reported that flying through the Moon as though it were a gas planet made the experience less authentic. They reported that use of the controls would have been enhanced using some audio cues and that the general lack of sounds when using the device was a constraint. Physically the MSD gave some participants problems because they became tired of standing and using their arms during the five minutes they were allowed to explore the flyby. Some participants reported becoming bored and wrote that experiencing the MSD simulation was pointless.

Participants reported a wider variety of experiences using the VR headset and overall reported a more favorable experience with this tool. This could be because when data collection started this version of the VR headset used had only been on the market for a few months and participants were interested to try the new tool. MSD technology had been on the market since the 1980s so most of the participants grew up with these devices making the VR headset the more interesting tool because it was so new. Participants reported that they experienced the realism, graphics, and visuals as detailed and immersive. They had the option of turning on labels using a hand control and they felt that this option was useful for learning and exploring the surface of the Moon and its craters. The VR headset also had sound effects and participants reported that this added to their immersive experience. During data analysis, it was discovered that the VR headset enhanced concentration by keeping participants focused. This worm's eye view mentioned in the multimedia principle under the cathedral effect came out during data analysis using the Immersion Questionnaire. Participants experienced no frustration or boredom when using the tool or the game controller. Overall, they wanted more time to use the VR headset.

Gathering information on the different experiences participants have with the MSD and the VR headset in a learning situation gives both students and instructors more information for learning and for teaching. Participants reported that the VR headset induced more focus and concentration when they put on the headset as opposed to the open spaces, freedom and creativity that working with the MSD in the planetarium gave them. This knowledge is useful because each tool offers different affordances and constraints. Having this information makes choosing the right simulation easier.

Comparison of Commonalities and Differences

Experiences participants had with the tools were examined for physical experiences participants had with symptoms of nausea, oculomotor symptoms, and disorientation (Kennedy et al., 2009) and also through the lens of immersion (Lidwell et al, 2010). Dizziness on the disorientation scale was the most common physical experience when using these tools. Other experiences included a range of affordances and constraints where participants make suggestions for improvement of the tools and for future use of the tools. Most participants were enthusiastic about the use of these simulations for teaching college astronomy. Differences and comparisons can be made for use when choosing a tool in instruction. The MSD used in a fulldome planetarium to create a group experience; in this case the fulldome planetarium used with this device had 68 participant seats. The MSD can be operated by the student or the instructor and allows all participants to consume the same content at the same time. The VR headset affords users the opportunity to customize content and to consume content at their own pace. The VR headset affords a single user experience in most instances, but VR headsets can also be linked and controlled by an instructor to give a group experience. Both of these tools offer multimedia experiences for teaching observational science. Because of the observational aspect of astronomy, use of VR headsets and motion sensor devices to teach this subject offer research opportunities beyond experiences students have with these tools.

Limitations of the Study

Limiting factors emerged while conducting data collection are discussed here but first let me say that during data collection my observations were backed up by face validity when operating the MSD with a professional colleague. Although not a severe limitation, some of the decisions I made to changing the flyby speed came not solely after a strict statistical descriptive analysis and qualitative data reduction and coding, but were also informed by observations and comments participants made while the participants used the MSD in real time and reacted to the speed of the flyby. Face validity was done to adjust MSD flyby speeds in real time during design-based research, mainly during the Fall semester and somewhat during the Spring semester. After the Fall semester data of Simulator Sickness and Immersion Questionnaires were analyzed I determined Spring data would be collected in the same manner as Fall–starting with the slower flyby speeds and increasing the speed of the flyby in the MSD software. Real-time data analysis during the Fall semester was strictly through consultation with one professional colleague who acted as timer during the treatment. I used face validity during the second semester because I acted as the timer during these MSD sessions while a colleague worked with participants using the VR headset. I saw this as a limitation because changes were made quickly rather than thoughtfully after data analysis.

During the Spring semester, a professional colleague worked with participants using the VR headset. This colleague was an emeritus pre-engineering and physics professor with over 30 years of college teaching experience. I am a graduate student with K-12 teaching experience and five years of college teaching experience. I noticed the difference those 30 years made when analyzing data from the small group interviews. Having a more experienced instructor may have affected student's experience between use of the MSD, instructed and guided by me, and the VR headset, instructed and guided by a more experienced educator. During the small group interviews participants commented that they wish they would have known they could use the stop function on the device as there were a few times I forgot to inform them that this was an option, as opposed to the instruction given by the more experienced educator directing the VR headset. His direction was more consistent across treatments.

Another limitation noticed was with instructors. Working with participants across two semesters involved having these classes taught by different instructors. The Fall classes were both taught by the same instructor (instructor #1), but when this instructor moved out of state the college hired two new instructors to teach those classes in the Spring. This change increased limitations on the study since there were no set lab syllabi and labs were taught at the discretion of the instructors. Instructors created their own curriculum and from instructor to instructor this content had different emphasis on the Moon. When I began data collection in the Fall with instructor #1, this instructor had a syllabus that involved study of the Moon that dovetailed well with my data collection. There was less alignment with study of the Moon and data collection in the syllabi of instructor #2 and instructor #3. This may have impacted the data results if one group of participants could see a direct correspondence with what they were learning in lab and with my study but the other set of participants saw the study as somewhat random to what they were learning in lab.

It was noted that participants were eager to give me the data they thought I wanted and since they were using two different simulation tools, the VR headset and the MSD they wanted to compare the tools and say which one they thought was "better." During the small group interviews I would gently intervene and re-direct the comments back to the prompts. In some cases, I would inform participants that this was not about comparing tools but eliciting comments on their experience with each tool. That usually got the comments back on the topic of affordances and constraints.

Data were collected over two semesters. Participants were grouped rather than treating the entire class at the same time because of equipment availability. Limitations to doing data collection over time rather than on the first (highly attended) day of class included participants being absent during their assigned treatment day or declining participation because they had missed a few classes and no longer wanted to take the time to participate in the study. The rationale for sub-dividing the class into smaller subgroups was to facilitate the small group interview (Krueger & Casey, 2014) and because in order to take turns using equipment I had to take participants down to the planetarium and virtual reality lab in small groups because I was aware of taking their time out of regular lab activities.

A limitation of the study had to do with novelty effect when participants used the VR headset. The VR headset used was the first commercial roll-out of the Oculus Rift. I purchased this headset soon after it was available and participants had increased interest in this new technology. Most of the participants were in their mid-20s in age and would have been born after MSD technology was introduced in the 1980s making MSD technology seem common place to them. The effect of novelty could account for the higher attention spans and more favorable comments about the VR headset than were recorded for the MSD.

The tools were expensive (Bysaha, 2017); the two original DK1 and DK2 purchased using grant monies and private funds ceased to be supported after the release of the commercial Oculus Rift in the Fall of 2016. I only had one MSD and this could only be used one at a time in the planetarium. This reduced the ability to work with more than one participant at a time and was a limiting factor. A pilot study done in the Summer of 2016 showed the best use of both the participants' time and my time was to enlist the help of a volunteer to work with participants on the VR headset while I worked with different participants using the MSD. In a perfect study situation, I would have liked to work individually with all participants but time and the amount of equipment made this difficult.

The last limitation that I noticed was the type of comments participants that only used one tool made about the experience. Participants in the Spring semester had the opportunity to use both tools. During examination of the data, participants that used only the MSD mentioned boredom and pointlessness to the project more than participants that used both tools. This may have been because during the Fall semester I was new to data collection and was less experienced at moving participants into and out of the simulation smoothly, getting them the questionnaires and providing them with places to comfortably fill them out. I was more nervous at operating the equipment in the planetarium then during the Spring semester when I had all those weeks of projecting the simulation under my belt and the knowledge analysis all of the Fall data revealed. It also could have had something to do with the novelty effect VR technology. The VR headset technology was a recent innovation. The MSD technology dated from the 1980s (not this particular piece of equipment, but the technology has been around since 1981) and some participants saw this as "old" technology.

Despite these limitations there is merit to exploration of these two tools for teaching and learning. College students get younger every year compared to their instructors and these students expect a degree of technology in the classroom. They are also consumers of technology and often learn faster in a technology rich learning environment. As educators, instructors of college students are compelled to stay current with the latest pedagogical techniques and use of technology is only one of the tools in an instructor's toolbox.

Practical Significance for Instructors, Designers, and Researchers

Despite the limitations to this study, these tools offer practical significance to instructors, designers, and researchers. Table 14 and 15 were created to provide organization to the results in a convenient way for professionals and consumers alike to select the appropriate tool for their chosen purpose. I listed affordances of the MSD in the left column of Table 14 and affordances of the VR headset on the far-right column of the table. The center column lists crossover affordances, these are items that both tools afford. Table 15 shows the same three column arrangement for constraints. Notice there are fewer crossover constraints because constraints are more specific to each tool than affordances.

Table 14

MSD and VR Headset Affordance Table for Instructors, Designers, and Researchers

MSD Affordances	MSD & VR Headset Crossover Affordances	VR Headset Affordances
Group immersive experience	Ability to simulate content	Single user experience
Manipulation of content	Ability to simulate concepts	Music & sound effects
Group learning option	Affords presence	Differentiated experience
Supports face-to-face instruct.	Affords real-time interactions	Supports online instruction
Flying ability	Accommodates learning style	Student-centered learning
Affords freedom	Affords motivation	Affords portability
Use of an avatar	Affords realistic content	Use of a game controller
Direct use of body motions	Affords altered reality	Content at your own pace
Free roaming ability	Affords persistence	Affords flexibility
Affords creativity	More time on task	Focus & concentration
Worm’s eye view	Supports hands on learning	Realism /High fidelity
Content script based	Supports strong visuals	Three dimensional
Supports demonstrations	Affords customized content	Strong graphics & visuals

Note. Affordances of the MSD and the VR headset, with crossovers applying to both tools.

Table 15
MSD and VR Headset Constraint Table for Instructors, Designers, and Researchers

MSD Constraints	MSD & VR Headset Crossover Constraints	VR Headset Constraints
Participants use standing	Tools are expensive	Participants use sitting
Content creation script based	Technical requirements	Content creation code based
Tiredness in arms and legs	Hardware requirements	Headset bulky
Lack of game controller	Software requirements	Noncompliant to physical laws
Participant dizziness	Learning curve for operators	No sharing unless linked
Less authentic		Headset cord problematic
Light clothing problematic		Difficult when wearing glasses
Lack of labels and markers		
Lack of audio cues		
Responds to laws of physics		

Note. Constraints of the MSD and the VR headset, with crossovers applying to both tools.

Practical Significance for Instructors

Motion sensor devices used in conjunction with fulldome planetarium software and VR headsets to teach college astronomy and to personalize planetarium visits present opportunities for instructors to enhance learning. Use of the MSD extends teaching astronomy in the college planetarium, supporting lecture by providing strong visuals. It opens up opportunities for active learning by breaking away from a strictly lecture note-taking experience to more student-directed learning. More active learning is valuable because when students direct their own learning they can concentrate how they best learn information. The MSD frees the instructor from being behind the planetarium console as it is a hands-free device and allows the instructor or presenter to move about the planetarium to engage the patrons.

Use of the VR headset offers possibilities for teaching both face-to-face and online courses in astronomy. Instructors can use a VR headset and its content for assigned topics in astronomy much like reserve readings are held at the college library. A student could “check out” the reserve headset and consume that content using a library computer. Inexpensive VR headsets such as Google Cardboard can be used with a smart phone and content posted online to supplement readings and assignments in both face-to-face and in online courses.

Each of these tools offers a different affordance for learning. The MSD is an appropriate choice for teaching topics that need, are best learned, or content that is best expressed in an environment where you need to enhance a feeling of freedom, openness or creativity. Topics best handled when dealing with information seen from a worm's eye view to better understand are topics such as viewing weather systems on the Earth from space or tracking global climate conditions. The MSD affords working creatively and collaboratively with other people or groups and for doing demonstrations. A VR headset affords focus and concentration for topics that require a bird's eye view when dealing with close and independent work. VR headsets also offer possibilities to collaborate with others because of the ability to link these devices or use them for linked immersion such as an interactive direct instruction or a collaborative meeting.

Practical Significance for Designers

Motion Sensor Devices and VR headsets offer practical significance for instructors and designers of educational content and for professionals in the building trades and construction, the military, the fashion industry, business, sports, entertainment, museum and historic interpretation, telecommunications, media, and film. For these simulations to be effective the content must have a good sense of realism and creating that sense of realism falls on the skills and resources available to the designer.

Tables 14 and 15 are resources for designers of content to draw upon when considering a new project. A designer may be tasked with creating a venue for showing a spring line of fashions to potential buyers. Using the affordances and constraints tables shown above this designer chooses specific variables for this project. The designer wants a group immersive experience (MSD) that supports demonstration (MSD) so that the user can show patrons details of each garment. Creativity and expansiveness (worm's eye view – MSD) would be a plus because clients need to imagine how these fashions would appeal to buyers. All these mentioned variables point to the use of a motion sensor device for this project and include the crossover variables of presence and real-time interaction.

Perhaps a designer is tasked with creating training content for a business that has new employees across the world. Looking at the affordances and constraints tables the variables that would suit this task include a device that supports portability, a single user experience with student-centered learning options that support different learners and supports a flexible schedule (VR). These requirements point to designing using a VR headset. The crossover variables for this task are that the device supports hands on learning, and time on task, both favorable variables for achieving this design goal.

Practical Significance for Researchers

The affordances and constraints tables are useful for educational researchers in the fields of informal and formal education, astronomy, healthcare, scientific visualization, and for the overarching topic of teaching and learning. Using simulations for doing educational research facilitates large groups and also individual interactions within a three-dimensional environment. Simulations are used in the field of scientific visualization to express complex ideas, for example molecular models or statistical results and to explore abstract or hazardous concepts. Across the sciences simulations are used in physics, chemistry, biology, engineering, medicine, and Earth science.

Practical examples of simulations used in research are animations in the U.S. Chemical Safety Board (CSB) video room. The CSB is an independent federal agency that investigates chemical accidents to protect workers, the public, and the environment and as part of its public outreach and accident investigation it posts safety videos on its website. An example of how the CSB uses simulations in an investigation documents a chemical accident and then uses simulation to explain and demonstrate best practices in chemistry safety and how these practices were either disregarded or misunderstood. Simulation reproduces the stages to the accident to demonstrate cause and affect (Cohen, 2016). Another practical example of using simulations in chemical education involves plant processes. Many processes in chemical plant operation are large scale, expensive, and hazardous. Simulations are used to trouble shoot and identify hazards during critical plant start up or maintenance operations (Xu, Yang, Liu, Li, Lou, & Gossage, 2009). In all of these instances designers are charged with the task of creating simulations to train, trouble shoot, or investigate possibilities in potentially hazardous chemical processes. The affordances and constraints table can help designers of content choose a simulation device that best serves the purpose desired.

Further Research to Extend these Findings

Further research to extend this study and continue investigating experiences students have using these tools to learn about planets and moons through flybys would add to the knowledge of how these tools can aid instruction. From participant comments, we know what prevents immersion, but we don't completely know what promotes it. It would be helpful to conduct more research on this topic under conditions to control the confounding variables. When this research was done, the optimal speed was only calculated for data collected from the MSD. Another study would extend this research to take data on changes to lunar flyby speed when participants used the VR headset. Creators of content would then be able to use this speed to target content to introductory astronomy students by their preferred flyby speed. This is research that still needs to be pursued.

Another suggestion for continued research would be to gather data using participants from introductory astronomy classes over two additional semesters to further the investigation of immersion. It would also be useful to conduct the small group interviews according to Krueger et al. (2014) by extending the time from the 12 minutes used in this study to a full hour. This would give the opportunity to ask a more in-depth line of questioning and drill down to more detailed explanations of participant experience. Further extension of this research would also determine if data were skewed due to the boredom issue mentioned by participants who only experienced the MSD and not both tools.

Further research with the MSD and the VR headset within astronomy education concerning student knowledge changes still needs to be done. Using an astronomy assessment inventory as a pre-test before students used the MSD and the VR headset to learn introductory astronomy content and as a post-test at the end of the course, would yield valuable data. This data, on what students actually learn about astronomy content when using these devices can inform instruction. Using a pre- and post-testing with an appropriate concept inventory could help instructors learn how astronomy education could be enhanced using simulation devices.

Conclusions

This dissertation offers a snapshot into the rapidly changing world of simulation technology. It examined introductory astronomy students' experiences using a motion sensor device and fulldome planetarium software and a virtual reality headset to manipulate a flyby of the Moon. Using design-based research and data analyzed using questionnaires to elicit immersion using the multimedia design variables of the effects of biophilia and cathedral as well as assessment simulator sickness using the figure-ground relationship principle the optimal flyby speed for college students to manipulate the Moon was determined to be .04 × the radius of the Earth or 160 mps. Participants reported that the MSD would be helpful for teaching and learning about Moon phases, the vast distances of space and other abstract concepts, for free roaming and flying in space using the avatar, and that this tool would be good for hands on learners. Participants reported that the realistic graphics and visuals of the VR headset were helpful to hold their attention span because they were engaging because of the multimedia aspect. The participants wished that the headset was cordless because the cord took them out of the simulation. Downsides to the MSD were that operating it made their arms tired and that it followed the laws of physics so well that it was difficult to stop in space. Both of these tools offer new possibilities for teaching and learning introductory astronomy using simulations. It is my hope that this study opens the door for future research into this topic.

APPENDIX A: SOCIAL/BEHAVIORAL IRB APPROVAL

UNLV

UNLV Social/Behavioral IRB - Expedited Review
Approval Notice

DATE:	October 17, 2016
TO:	Hasan Deniz, PhD
FROM:	UNLV Social/Behavioral IRB
PROTOCOL TITLE:	[965154-1] USING TWO SIMULATION TOOLS TO TEACH CONCEPTS IN INTRODUCTORY ASTRONOMY: A DESIGN-BASED RESEARCH APPROACH
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	October 16, 2016
EXPIRATION DATE:	October 15, 2017
REVIEW TYPE:	Expedited Review

Thank you for submission of New Project materials for this protocol. The UNLV Social/Behavioral IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a protocol design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

PLEASE NOTE:
Upon approval, the research team is responsible for conducting the research as stated in the protocol most recently reviewed and approved by the IRB, which shall include using the most recently submitted Informed Consent/Assent forms and recruitment materials. The official versions of these forms are indicated by footer which contains approval and expiration dates. If your project involves paying research participants, it is recommended to contact Carisa Shaffer, ORI Program Coordinator at (702) 895-2794 to ensure compliance with subject payment policy.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved.

ALL UNANTICIPATED PROBLEMS involving risk to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NONCOMPLIANCE issues or COMPLAINTS regarding this protocol must be reported promptly to this office.

This protocol has been determined to be a Minimal Risk protocol. Based on the risks, this protocol requires continuing review by this committee on an annual basis. Submission of the **Continuing Review Request Form** must be received with sufficient time for review and continued approval before the expiration date of October 15, 2017.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

APPENDIX B: DATA COLLECTION PROTOCOLS

No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Immersion Questionnaire

Adapted from:

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., and Walton, A. (2008). Measuring and defining the experience of immersion in games. *International journal of human-computer studies*, *66*(9), 42-44.

Your Experience of the Simulation

Please answer the following questions circling the relevant number. In particular these questions are asking you how you feel at the end of the simulation.

1. To what extent did the simulation imagery reduce stress?

Not at all 1 2 3 4 5 A lot

2. To what extent did the simulation imagery enhance focus?

Not at all 1 2 3 4 5 A lot

3. To what extent did the simulation imagery enhance concentration?

Not at all 1 2 3 4 5 A lot

4. To what extent did the simulation imagery induce harmony?

Not at all 1 2 3 4 5 A lot

5. To what extent was the simulation imagery comforting?

Not at all 1 2 3 4 5 A lot

Small Group Interview Protocol

Participants were asked broad, general questions. Open-ended questions encouraged participants to expand upon or clarify their responses as needed. Attention was focused on gathering data to reveal the variety of experiences of the participants.

1. What have you experienced in terms of a fulldome planetarium MSD and a virtual reality headset simulation?
2. What contexts or situations have influenced or affected your experiences of these simulations?
3. What was your experience with rotation ability and rotation speed of the Moon?
4. What was your experience with the zoom-out ability and zoom-out speed of the Moon?
5. What was your experience with the zoom-in ability and zoom-in speed of the Moon?
6. Is there anything else you would like to mention on how these tools were easy/hard to learn to manipulate or how you felt using them?

APPENDIX C: PERMISSION TO USE FIGURES

Permission to use Copyrighted material from the German Federal Archives (Figure 1.)

License - CC BY-SA 3.0 de
File:Bundesarchiv B 145 Bild-P018935, Berlin, Planetarium.jpg
Created: 31 December 1938

Permission to use Copyrighted material from NYC Resister (Figure 2.)

Licensing [edit]

I, the copyright holder of this work, hereby publish it under the following license:

This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.

CC SOME RIGHTS RESERVED

You are free:

- **to share** – to copy, distribute and transmit the work
- **to remix** – to adapt the work

Under the following conditions:

- **attribution** – You must attribute the work in the manner specified by the author or licensor (but not in any way that suggests that they endorse you or your use of the work).
- **share alike** – If you alter, transform, or build upon this work, you may distribute the resulting work only under the same or similar license to this one.

File history

Click on a date/time to view the file as it appeared at that time.

	Date/Time	Thumbnail	Dimensions	User	Comment
current	**01:56, 3 July 2013**		2,183 × 2,058 (469 KB)	Autopilot (talk I contribs)	User created page with UploadWizard

Permission to use Copyrighted material from Loch Ness Productions (Figure 3.)

Re: Request for use of table

Carolyn Collins Petersen [carolyn@lochnessproductio...

To: Maher, Pam

Wednesday, March 30, 2016 13:45

- You replied on 3/30/2016 13:47.

Pam,

Glad to be of some assistance -- you're venturing into an interesting area there!

Is this the one you want to use?

http://www.lochnessproductions.com/reference/2014state/slide05.jpg

If so, if you can use as is, and also credit Mark C. Petersen, Loch Ness Productions, then you can use in your dissert proposal.

good luck!

carolyn

Permission to use Copyrighted material from Paethon (Figure 5.)

Request for use of photo Inbox x

Pamela Maher <maherp@unlv.nevada.edu>
to stabinger

3:41 PM (21 hours ago)

Hello Sebastian;

I would like to use a photo of yours in my doctoral dissertation proposal (see page 13 of attached). If this is possible if you could reply to this email in that regard then I can go forward with the appropriate documentation. As you can see, I am doing educational research on simulation tools.

Best regards,

Pam

Maher_Dis_Prop...

Sebastian Stabinger
to me

6:46 AM (6 hours ago)

Sure, no problem. If you can cite my name somewhere in the dissertation that would be great.

Cheers, Sebastian

PS: Good luck with your dissertation :)

Permission to use Copyrighted material from the National League for Nursing (Figure 6.)

Permission for NLN/Jeffries Simulation Framework

Inbox x

Amy McGuire <amcguire@nln.org Apr 15 (7 days ago)

to me

Dear Pamela:

The NLN has received your request for permission to include the figure of the NLN/Jeffries Simulation Framework in your doctoral dissertation proposal. We are pleased to grant you copyright permission according to the following.

"The NLN/Jeffries Simulation Framework," developed as part of the 2003 - 2006 NLN/Laerdal Simulation Study and most recently published on page 37 of the work noted below, may be used within your doctoral dissertation.

Jeffries, P. R. (2012). Simulation in nursing education: From conceptualization to evaluation. New York, NY: National League for Nursing.

In granting permission to use this Framework, it is understood that the following assumptions operate and "caveats" will be respected.

- The Framework will only be used for the purpose outlined above.
- The Framework will be included in its entirety and not modified in any way.
- The National League for Nursing is the sole owner of these rights being granted.
- No fees are being charged for this permission.

Respectfully,
Amy

Amy McGuire | Administrative Coordinator, NLN Chamberlain Center | National League for Nursing | www.nln.org |
amcguire@nln.org | Tel: 202-909-2509 | The Watergate | 2600 Virginia Avenue NW, 8th Fl, Washington, DC 20037

Amy McGuire

amcguire@nln.org

Recent photos

Show details

Permission to use Copyrighted material from The International Planetarium Society (Figure 7.)

Maher, Pam

To: joanne@av-imagineering.com

Attachments: Figure 1 The 4 quadrants o~1.png (169 KB)

Sent Items

Monday, April 04, 2016 12:47

Hi Joanne;

I have a question about using materials from this article from the Planetarium:

"A Guide to Conducting Educational Research in the Planetarium," by J. D. Plummer, S. Schmoll, K. C. Yu, and C. Ghent, 2015, The Planetarian, 44(2), p. 11. Copyright 2015 by International Planetarium Society.

I would like to use this figure in my doctoral dissertation proposal and need written permission. Is this copyrighted by IPS? If so could I use the figure attached from the article above.

Best regards,

Pam

Pam Maher, MAT
CSN Planetarium / NASA ERC
702-651-4505

Sharon Shanks [sharon.shanks@gmail.com]

Monday, April 04, 2016 16:56

Hi Pam...

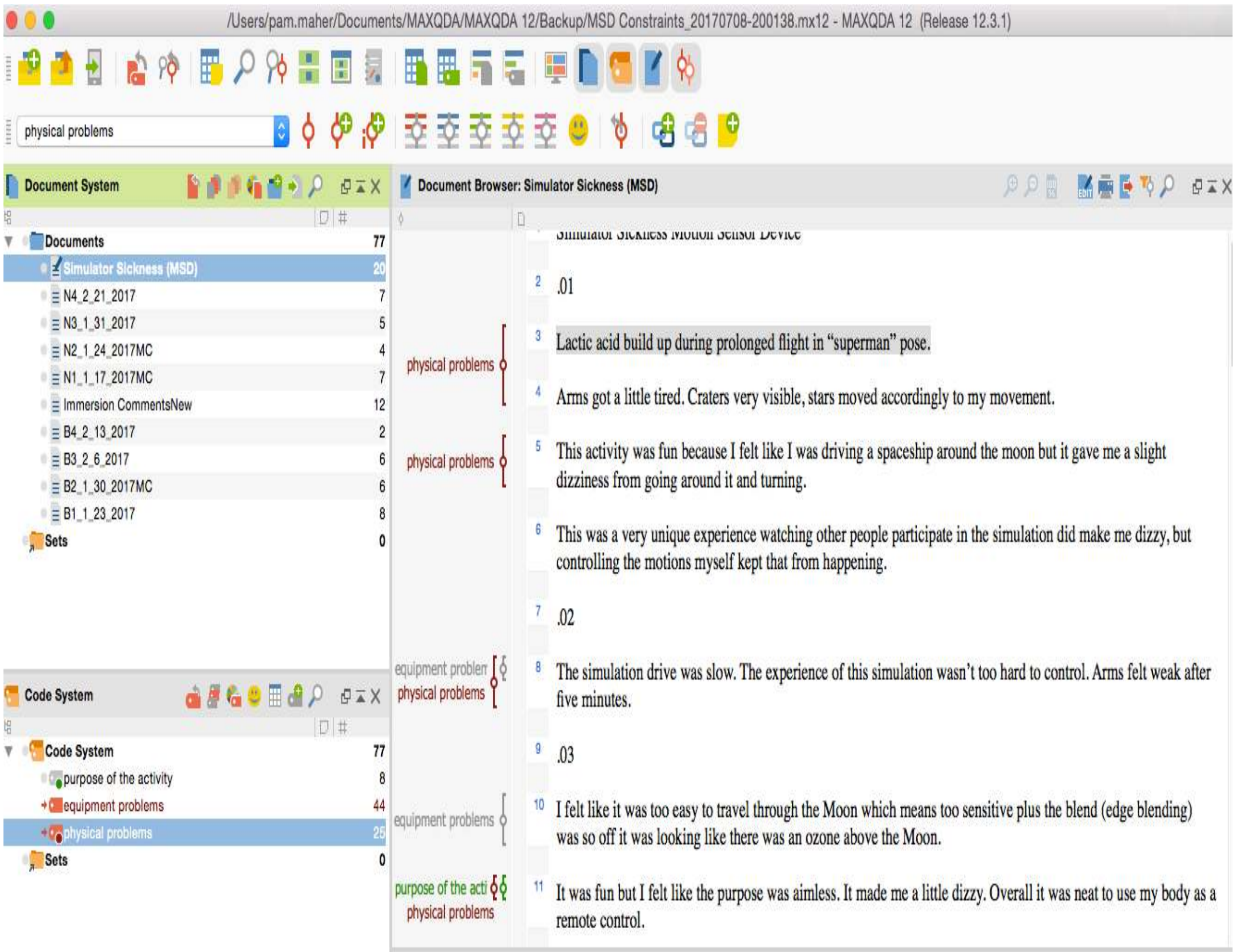
This is the official permission.

I will trust you on the wording.

If you are using the paper proposal, can I infer that planetarium research is involved? Is so, please keep us in mind when the time comes for dissemination of the research. ☺

Sharon

APPENDIX D: EXAMPLE OF CODING USING MAXQDA SOFTWARE



Screen shot of the MAXQDA working document system used for coding texts from the eight group interviews and comments from the Simulator Sickness and Immersion Questionnaires. Upper left shows the documents loaded into the system.

Note, Simulator sickness comments gathered when participants were working on the MSD at different speeds is currently being coded. Upper right shows the document browser with sections coded by physical problems, equipment problems, and purpose of the activity. Lower left shows the code system created.

REFERENCES

Aguilera, J. (2016). Planetariums in the era of VR. *The Planetarian*, *45*(1), 30-33.

Baldwin, A. L. (2012). How do plants in hospital waiting rooms reduce patient stress? *Journal of Alternative and Complementary Medicine, 18*(4), 309-310. doi:10.1089/acm.2012.0116

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences*, *13*(1), 1-14. doi:10.1207/s15327809jls1301_1

Bell, R. L., & Trundle, K. C. (2008). The use of a computer simulation to promote scientific conceptions of moon phases. *Journal of Research in Science Teaching*, *45*(3), 346–372. doi:10.1002/tea.20227

Berger, C. F., Lu, C. R., Belzer, S. J., & Voss, B. E. (1994). Research on the uses of technology in science education. In D. L. Gabel, (Ed.) *Handbook of research on science teaching and learning* (pp. 466-492). New York, NY: McMillan.

Boas, Y. A. G. V. (2013). Overview of virtual reality technologies. In *Interactive Multimedia Conference 2013* (pp. 1-6). Southampton, United Kingdom. Retrieved from http://mms.ecs.soton.ac.uk/2013/papers/yavb1g12_25879847_finalpaper.pdf

Bodner, G. M., & Orgill, M. (2007). *Theoretical frameworks for research in chemistry/science education.* Upper Saddle River, NJ: Prentice Hall.

Bouchard, S., Robillard, G., & Renaud, P. (2007). Revising the factor structure of the Simulator Sickness Questionnaire. *Annual review of cybertherapy and telemedicine*, *5*, 128-137.

Boulos, M. N. K., Blanchard, B. J., Walker, C., Montero, J., Tripathy, A., & Gutierrez-Osuna, R. (2011). Web GIS in practice X: A Microsoft Kinect natural user interface for Google Earth navigation. *International Journal of Health Geographics*, *10*(1), p. 45. doi:10.1186/1476-072X-10-45

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions. *Journal of the Learning Sciences, 2*(2), 141-178. doi:10.1207/s15327809jls0202_2

Bysaha, T. (2017, February 24). How much does VR application development cost? Web log comment. Retrieved from https://thinkmobiles.com/blog/how-much-vr-application-development-cost/

Carini, R. M., Kuh, G. D., & Klein, S. P. (2006). Student engagement and student learning: Testing the linkages. *Research in Higher Education, 47*(1), 1-32. doi:10.1007/s11162-005-8150-9

Chartrand, M. R. (1973). A fifty-year anniversary of a two thousand year dream: The history of the planetarium. *Planetarian*, *2*(3), 95-101.

Cheng, C. C., Li, C. T., Tsai, Y. M., & Chen, L. G. (2009). Hybrid depth cueing for 2D-to-3D conversion system. In A. Woods, N. Holliman, & J. Merritt (Eds.), *Proceedings Stereoscopic Displays and Applications XX* (p. 723721). San Jose, CA: SPIE.Digital Library. doi:10.1117/12.805938

Chiao, M. (2017). Cosmological simulations: Beyond the standard muddle. *Nature Astronomy*, Vol 1, id. 0081. doi:10.1038/s41550-017-0081

Civet, F., & Le Mouélic, S. (2015). VR-Planets: A 3D immersive application for real-time flythrough images of planetary surfaces. In *Proceedings EGU General Assembly Conference Abstracts* (p. 5036). Vienna, Austria.

Cobb, P., Confrey, J., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher*, *32*(1), 9-13. doi:10.3102/0013189X032001009

Cobb, S., & Fraser, D. S. (2010). Multimedia learning in virtual reality. In Mayer, R. E. (Ed.), *The Cambridge handbook of multimedia learning* (pp. 525-548). New York, NY: Cambridge University Press.

Cohen, H. (2016, January 29). *Dangerously close: Explosion in West, Texas* [video file]. Retrieved from http://www.csb.gov/videos/dangerously-close-explosion-in-west-texas/

College Institutional Research. (2013). *Facts in brief.* North Las Vegas, NV: CSN Print Services.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology*. (pp. 15-22). Berlin, Germany: Springer. doi:10.1007/978-3-642-77750-9_2

Collins, A., Joseph, D. & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences 13*(1), 15-42. doi:10.1207/s15327809jls1301_2

Creswell, J. W. (2012). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks, CA: Sage.

Creswell, J., & Miller, D. (2000). Determining validity in qualitative inquiry. *Theory into Practice 39*(3), 124-130. doi:10.1207/s15430421tip.3903_2

Crosier, J. K., Cobb, S., & Wilson, J. R. (2002). Key lessons for the design and integration of virtual environments in secondary science. *Computers & Education*, *38*(1), 77-94. doi:10.1016/S0360-1315(01)00075-6

Crow, F. C. (1978). The use of grayscale for improved raster display of vectors and characters. In *Proceedings of the 5th annual conference on computer graphics and interactive techniques.* (pp. 1-5). New York, NY: ACM. doi.10.1145/800248.807359

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process.* Thousand Oaks, CA: Sage.

Csikszentmihalyi, M. (2000). *Beyond boredom and anxiety*. San Francisco, CA: Jossey-Bass.

Cyril, U. N. (2014, May). Multiple VR headsets on one PC [Online forum comment]. Message posted to https://forums.oculus.com/community/discussion/8600/multiple-vr-headsets-on-1-pc

Davies, B., & Harré, R. (1990). Positioning: The discursive production of selves. *Journal for the Theory of Social Behavior*, *20*(1), 43-63. doi:10.1111/j.1468-5914.1990.tb00174.x/abstract

Day, T. W. M. (2015). *The Oculus Rift as a portal for presence: The effects of technology advancement and sex differences in the horror video game genre.* (Unpublished doctoral dissertation). Lansing, MI: Michigan State University.

Dede, C. J., Salzman, M., & Loftin, R. B. (2005). The development of a virtual world for learning Newtonian mechanics. In P. Brusilovsky, P. Kommers, & N. Streitz (Eds.), *Multimedia, hypermedia, and virtual reality models, systems, and applications* (pp. 87-106). Berlin, Germany: Springer

de Jong, T. (2011). Instruction based on computer simulations. In P. A. Alexander, & R. E. Mayer (Eds.), *Handbook of research on learning and instruction* (pp. 446-466). New York, NY: Routledge.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201. doi:10.3102/00346543068002179

Desai, P. R., Desai, P. N., Ajmera, K. D., & Mehta, K. (2014). A review paper on Oculus Rift-A virtual reality headset. *International Journal of Engineering Trends and Technology, 13*(4), 175-177. doi:10.3102/00346543068002179

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32(*1), 5-8. doi:10.3102/0013189X032001005

Detlefsen, J. (2014). *The cosmic perspective: Teaching middle-school children astronomy using ego-centric virtual reality*. (Master's thesis). Retrieved from http://projekter.aau.dk/projekter/en/studentthesis/the-cosmic-perspective-teaching-middleschool-children-astronomy-using-egocentric-virtual-reality(80634264-1c4d-47c5-b81a-ca809a8ee7e6).html

Drew, N. (2004). Creating a synthesis of intentionality: The role of the bracketing facilitator. *Advances in Nursing Science, 27*(3), 215–223. doi:10.1097/0012272-200407000-00006

Elliot, J. L., Person, M. J., & Qu, S. (2003). Analysis of stellar occultation data. II. Inversion, with application to Pluto and Triton. *Astronomical Journal*, 126, 1041-1079. doi:10.1086/375546

Ellis, G. (2014). Dale Etheridge: A lifetime under the dome. *The Planetarian*, *43*(2), 33.

El-Mounayri, H. A., Rogers, C., Fernandez, E., & Satterwhite, J. C. (2016, June). *Assessment of STEM e-learning in an immersive virtual reality (VR) environment*. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.26336. doi:10.18260/p.26336

Ennico, K. (2015, August). *New Horizons successful. Completes the historic first flyby of Pluto and its moons.* Paper presented at the American Institute of Aeronautics and Astronautics, Reston, VA. Abstract retrieved from http://ntrs.nasa.gov/search.jsp?R=20150018394

Faidit, J. M. (2011). Planetariums in the world. *The Role of Astronomy in Society and Culture, Proceedings of the International Astronomical Union,* IAU Symposium, Volume 260, p. E9. doi:10.1017/S1743921311003292

Fokides, E., Mastrokoukou, A., & Astsikpasi, P. (2017). Teaching basic astronomy concepts to pre-service teachers using 3D virtual environments: Results of a study in Greece. In P. Tripathi & S. Mukerji (Eds.), *Handbook of research on technology-centric strategies for higher education administration* (pp. 175-194). Hershey, PA: IGI Global. doi:10.4018/978-1-5225-2548-6.ch011

Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society*, *48*(10), 1037-1041. doi:10.1057/palgrave.jors.2600946

Frankl, A. (1938, December). *B 145 Bild-P018935*. Berlin, Germany: Bundesarchiv.

Fusch, P. I., & Ness, L. R. (2015). Are we there yet? Data saturation in qualitative research. *The Qualitative Report*, *20*(9), 1408-1416.

Gadamer, H. G., & Fantel, H. (1975). The problem of historical consciousness. *Graduate Faculty Philosophy Journal*, *5*(1), 8-52. doi:10.5840/gfpj1975512

Gearing, R. (2004) Bracketing in research: A typology. *Qualitative Health Research, 14*(10), 1429-1452. doi:10.1177/1049732304270394

George, D. & Mallery, P. (2009). *SPSS for windows step by step: A simple guide and reference, 16.0 update* (9th ed.). Boston, MA: Pearson Education.

Goradia, I., Doshi, J., & Kurup, L. (2014). A review paper on Oculus Rift & Project Morpheus. *International Journal of Current Engineering and Technology, 4*(5), 3196-3200.

Grinde, B., & Patil, G. G. (2009). Biophilia: Does visual contact with nature impact on health and well-being? *International Journal of Environmental Research and Public Health*, *6*(9), 2332-2343. doi:10.3390/ijerph6092332

Gullone, E. (2000). The biophilia hypothesis and life in the 21st century: Increasing mental health or increasing pathology? *Journal of Happiness Studies*, *1*(3), 293-322. doi:10.3390/ijerph6092332

Hagar, C. F. (1960). *The Zeiss Planetarium*. Los Angeles, CA: Griffith Observatory.

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational Psychologist, 39*(4), 203-212. doi:10.1207/s15326985ep3904_2

Hudson, T. (2013, June). *Space Rocks (game)*. Brooklyn, NY: NYC Resister.

Husain, I., Sancar, G. B., Holbrook, S. R., & Sancar, A. (1987). Mechanism of damage recognition by Escherichia coli DNA photolyase. *Journal of Biological Chemistry*, *262*(27), 13188-13197.

Iribe, B. (2014). Re: Announcing the Oculus Rift Development Kit 2 (DK2) (Web log post). Retrieved from http://www.oculusvr.com/blog/announcing-the-oculus-rift-development-kit-2-dk2/

Jeffries, P. R. (2005). A framework for designing, implementing, and evaluating simulations used as teaching strategies in nursing. *Nursing Education Perspectives*, *26*(2), 96-103.

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human-computer Studies*, *66*(9), 641-661. doi:10.1016/j.ijhcs.2008.04.004

Ju, G., Pollock, T., & Junkins, J. L. (2000). DIGISTAR II micro-star tracker- Autonomous on-orbit calibration and attitude estimation. *Astrodynamics 1999*, 2025-2037.

Juanes, J. A., Gómez, J. J., Peguero, P. D., Lagándara, J. G., & Ruisoto, P. (2015). Analysis of the Oculus Rift device as a technological resource in medical training through clinical practice. In *Proceedings of the 3rd International Conference on Technological Ecosystems for Enhancing Multiculturality* (pp. 19-23). New York, NY: ACM. doi:10.1145/2808580.2808584

Kennedy, R. S., & Fowlkes, J. E. (2009) Simulator sickness is polygenic and polysymptomatic: Implications for research. *The International Journal of Aviation Psychology, 2*(1), 23-38. doi:10.1207/s15327108ijap0201_2

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, *3*(3), 203-220. doi:10.1207/s15327108ijap0303_3

Kennedy, R. S., Lilienthal, M. G., Berbaum, K. S., Baltzley, D. R., & McCauley, M. E. (1989). Simulator sickness in US Navy flight simulators. *Aviation, Space, and Environmental Medicine*, *60*(1), 10-16.

Kottak, C. P. (1996). *Mirror for humanity: A concise introduction to cultural anthropology*. New York, NY: McGraw-Hill.

Krueger, R. A., & Casey, M. A. (2014). *Focus groups: A practical guide for applied research*. Thousand Oaks, CA: Sage.

Kubota, C. A., & Olstad, R. G. (1991). Effects of novelty-reducing preparation on exploratory behavior and cognitive learning in a science museum setting. *Journal of Research in Science Teaching*, *28*(3), 225-234.

Kuh, G. D., Cruce, T. M., Shoup, R., Kinzie, J., & Gonyea, R. M. (2008). Unmasking the effects of student engagement on first-year college grades and persistence. *The Journal of Higher Education*, *79*(5), 540-563.

Lantz, E. (2009). Immersive scientific visualization in education, storytelling and art. In M. Okyudo, & T. Ebisuzaki (Eds.), *Proceedings of the immersive scientific visualization conference* 2009 (pp. 73-76), Tokyo, Japan: IMERSA.

Lantz, E. (2011). Planetarium of the future. *Curator: The Museum Journal*, *54*(3), 293-312.

Lee, K. M. (2004). Presence, explicated. *Communication Theory*, *14*(1), 27-50.

Lidwell, W., Holden, K., & Butler, J. (2010). *Universal principles of design, revised and updated: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Bellevue, WA: Rockport.

Loftin, R. B., Pettitt, B. M., Su, S., Chuter, C., McCammon, J. A., Dede, C., & Ash, K. (1998). PaulingWorld: An immersive environment for collaborative exploration of molecular structures and interactions. In *Proceedings of the 17th Nordic Internet Conference Nordunet* (pp. 1-13). Helsinki, Finland: Nordunet.

Marche, J. (2005). *Theaters of time and space. American planetaria, 1930-1970.* New Brunswick, NJ: Rutgers University Press.

Marton, F. (1981). Phenomenography – Describing conceptions of the world around us. *Instructional Science, 10,* 177-200.

Mason, M. (2010, August). Sample size and saturation in PhD studies using qualitative interviews. In *Forum qualitative Sozialforschung/Forum: qualitative social research* (Vol. 11, No. 3).

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist*, *32*(1), 1-19.

Mayer, R. E. (2003). The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction, 13*(2), 125-139.

Mayer, R. E. (2009). *Multimedia learning*. New York, NY: Cambridge University Press.

McCloy, R., & Stone, R. (2001). Virtual reality in surgery. *British Medical Journal*, *323*(7318), 912-915.

McLellan, H. (1996). Virtual realities. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 457-487). New York, NY: Macmillan.

Meyers-Levy J., & Zhu, R. J. (2007). The influence of ceiling height: The effects of priming on the type of processing that people use. *Journal of Consumer Research, 34*(2), 174-186.

Minsky, M. (1980). Telepresence. *Omni*, *2*(9), 44-52.

Mortari, D., & Angelucci, M. (1999). Star pattern recognition and mirror assembly misalignment for Digistar 2 and 3 multiple-FOV star sensors. *Advances in Astronautical Sciences*, *102*, 1175-1184.

Moustakas, C. (1994). *Phenomenological research methods.* Thousand Oaks, CA: Sage.

Naval Aerospace Medical Institute. (1968). *The Pensacola motion sickness history.* (NAMI Form No. 6500/24). Pensacola, FL: National Alliance on Mental Illness.

Norton, R. O. (1968). *The planetarium and atmospherium (an indoor universe).* Healdsburg, CA: Naturegraph.

Orgill, M. (2011). Phenomenography. In N. M. Seel, (Ed.) *Encyclopedia of the sciences of learning* (pp. 2608-2611). New York, NY: Springer.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, *42*(5), 533-544.

Patton, M. Q. (2005). *Qualitative research*. New York, NY: John Wiley & Sons.

Pearl, L. H., & Honegger, A. (1983). Generation of molecular surfaces for graphic display. *Journal of Molecular Graphics*, *1*(1), 9-12.

Petersen, M. C. (2014, March). *Systems installed/new facilities*. Denver, CO: Loch Ness Productions.

Plait, P., Silva, S., Graves, T., Reed, J., & Cominsky, L. (2006). The eXtreme universe: A portable planetarium program. *Bulletin of the American Astronomical Society*, *38*(12), 1034.

Plummer, J. D. (2009). Early elementary students' development of astronomy concepts in the planetarium. *Journal of Research in Science Teaching. 46*(2), 192-209.

Plummer J. D., Schmoll, S., K., Yu, K. C., & Ghent, C. (2015). A guide to conducting educational research in the planetarium. *The Planetarian*, *44*(2), 8-24.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*(1), 4-15.

Reid, D. (2002). Virtual reality and the person-environment experience. *CyberPsychology & Behavior, 5*(6), 559-564. doi:10.1089/109493102321018204

Reimann, P. (2011). Design-based research. In L. Markauskaite, P. Freebody, & J. Irwin (Eds.), *Methodological choice and design, Methodos Series 9* (p. 37-50). New York, NY: Springer. doi:10.1007/978-90-481-8933-5_4

Rheingold, H. (1991). *Virtual reality*. New York, NY: Summit Books.

Rieber, L. P. (2010). Multimedia learning in games, simulations and microworlds. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 549-568). New York, NY: Cambridge University Press.

Ryan, M. L. (2001). *Narrative as virtual reality: Immersion and interactivity in literature and electronic media*. Baltimore, MD: Johns Hopkins University Press.

Sandoval, W. A., & Bell, P. (2004). Design-based research methods for studying learning in context: Introduction. *Educational Psychologist*, *39*(4), 199-201.

Schloerb, D. W. (1995). A quantitative measure of telepresence. *Presence: Teleoperators and Virtual Environments, 4*(1), 64-80.

Shevchenko, V., Rodionova, Z., & Michael, G. (2016). *Thematic mapping of the Moon*. Cham, Switzerland: Springer International.

Shin, N., Jonassen, D. H., & McGee, S. (2003). Predictors of well-structured and ill-structured problem solving in an astronomy simulation. *Research in Science Teaching, 40*(1), 6-33. doi:10.1002/tea.10058

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist, 50*(1), 1-13. doi:10.1080/00461520.2014.1002924

Slater, M., & Usoh, M. (1993). Representations systems, perceptual position, and presence in immersive virtual environments. *Presence: Teleoperators and Virtual Environments, 2*(3)*,* 221-233.

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education. 34*(9), 1337-1370.

Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1983). *Manual for the State-Trait Anxiety Inventory*. Sunnyvale, CA: Consulting Psychologists Press.

Squire, K. (2011). *Video games and learning: Teaching and participatory culture in the digital age. Technology, education--connections (the TEC Series)*. New York, NY: Teachers College Press.

Stabinger, S. (2013). *Back and control box*. Tirol, Austria: Paethon.

Star Chart: World's first Virtual Reality Planetarium. (2016, 8 January). *VR Perception Virtual Reality News.*

Sutherland, I. E., & Hodgman, G. W. (1974). Reentrant polygon clipping. *Communications of the ACM*, *17*(1), 32-42.

Sweller, J. (2010). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. (19-30). New York, NY: Cambridge University Press.

Tavakol, M. & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education. 2*, 53-55. doi:10.5116/ijme.4dfb.8dfd

Töytäri, A., Tynjälä, P., Piirainen, A., & Ilves, V. (2017). Higher education teachers' descriptions of their own learning: A quantitative perspective. *Higher Education Research & Development*, 1-10.

Travers, P. J., & Yee, Y. S. (1994). *U.S. Patent No. 5,373,857*. Washington, DC: U.S. Patent and Trademark Office.

Trundle, K. C. & Bell, R. L. (2003). Using planetarium software to teach standards-based lunar concepts. *School Science and Mathematics*, *103*(8), 397-401. doi:10.1111/j.1949-8594.2003.tb18125.x

Tufford, L., & Newman, P. (2012). Bracketing in qualitative research. *Qualitative Social Work*, *11*(1), 80-96.

Türk, C., & Kalkan, H. (2014). The effect of planetariums on teaching specific astronomy concepts. *Journal of Science Education and Technology. 24*(1), 1-15. doi:10.1007/s10956-014-9516-6

Urhahne, D., Nick, S., & Schanze, S. (2008). The effect of three-dimensional simulation on the understanding of chemical structures and their properties. *Research in Science Education, 39*(4), 495-513. doi:10.1007/s11165-008-9091-z

van Joolingen, W., & de Jong, T. (1993). Exploring a domain with a computer simulation: Traversing variable and relation space with the help of a hypothesis scratchpad. In D. M. Towne, T. de Jong, & H. Spada (Eds). *Simulation-Based Experiential Learning: Proceedings of the NATO advanced research workshop on the use of computer models for explication, analysis and experiential learning* (pp. 191-206). Bonas, France. doi:10.1007/987-3-642-78539-9

Vazquez, J. J., & Chiang, E. P. (2016). Preparing students for class: A clinical trial testing the efficacy between multimedia pre-lectures and textbooks in an economics course. *Journal of College Teaching & Learning (Online)*, *13*(2), 37-46.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Walker, J. L. (2012). Research column. The use of saturation in qualitative research. *Canadian Journal of Cardiovascular Nursing*, *22*(2), 37-46.

Walker, R. (2011). Design-based research: Reflections on some epistemological issues and practices. In L. Markauskaite, P. Freebody, & J. Irwin (Eds.), *Methodological choice and design*, *Methodos Series Book 9.* New York, NY: Springer. doi:10.1007/978-90-481-8933-5_4

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5-23.

Wells, N. (2000). At home with nature: Effects of greenness on children's cognitive functioning. *Environment and Behavior, 32*(6), 775-795.

Weigel, A. D. & Moraitis, C. D. (2017, January). Virtual reality astronomy education using AAS WorldWide Telescope and Oculus Rift. In *American Astronomical Society Meeting Abstracts* (Vol. 229). 43). IEEE. doi:10.1109/ISEMANTOC.2016.7873807

Winarno, S., Muthu, K. S., & Ling, L. S. (2016, August). A proposed conceptual framework for computer network multimedia learning integrated with direct problem-based learning approach. In *Technology of Information and Communication (ISemantic), International Seminar on Application for Technology of Information and Communication 2016* (pp. 39-43). IEEE. doi:10.1109/ISEMANTIC.2016.7873807

Winn, W., Stahr, F., Sarason, C., Fruland, R., Oppenheimer, P., & Lee, Y.L. (2005). Learning oceanography from a computer simulation compared with direct experience at sea. *Journal of Research in Science Teaching. 43*(1) 1-18. doi:10.1002/tea.20097

Wherry, R. J. (2014). *Contributions to correlational analysis*. Cambridge, MA: Academic Press.

Wu, P. H., Hwang, G. J., Yang, M. L., & Chen, C. H. (2017, February 28). Impacts of integrating the repertory grid into an augmented reality-based learning design on students' learning achievements, cognitive load and degree of satisfaction. *Interactive Learning Environments (online)*, February 23, 2017. doi:10.1080/10494820.2017.1294608

Xu, Q., Yang, X., Liu, C., Li, K., Lou, H. H., & Gossage, J. L. (2009). Chemical plant flare minimization via plantwide dynamic simulation. *Industrial & Engineering Chemistry Research*, *48*(7), 3505-3512. doi:10.1021/ie8016219

Zhang, Z. (2012). Microsoft Kinect sensor and its effect. *MultiMedia, IEEE*, *19*(2), 4-10. doi:10.1109/MMUL.2012.24

Zhao, D., Chowdhery, A., Kapoor, A., & Bahl, S. (2015). Games of drones: An affective game with cyber-physical systems. *Proceedings of the 14th International Conference on Information Processing in Sensor Networks* (pp. 410-411). Seattle, Washington: ACM. doi:10.1145/2737095.27425

Zhou, B. (2016). Smart classroom and multimedia network teaching platform application in college physical education teaching. *International Journal of Smart Home*, *10*(10), 145-156. doi:10.14257/JSH.2016.10.10.14

Zielinski, D. J., Rao, H. M., Sommer, M. A., & Kopper, R. (2015, March). Exploring the effects of image persistence in low frame rate virtual environments. In *Virtual Reality (VR), 2015 IEEE* (pp. 19-26). IEEE. doi:10.1109/VR.2015.7223319

Zotti, G., Wilkie, A., & Purgathofer, W. (2006, May). Using virtual reconstructions in a planetarium for demonstrations in archaeo-astronomy. *Third Central European Multimedia and Virtual Reality Conference (Proc. CEMVRC 2006)* (pp. 43-51).

CURRICULUM VITAE

Pamela A. Maher

E-mail: maherp@unlv.nevada.edu

EDUCATION

Doctor of Philosophy, Science Education Research

University of Nevada Las Vegas, Nevada, 2017

Research interest: Simulation tools for teaching astronomy.

Minor: Multimedia Technology

Individual Study

College of Southern Nevada, Las Vegas, Nevada, 2008-2010

Pacific University, Forest Grove, Oregon, 2003-2004

Portland Community College, Portland, Oregon, 1999

Portland State University, Portland, Oregon, 1980

Master of Arts in Teaching, Education

Lewis and Clark College, Portland, Oregon, 1984

· Graduate emphasis on visual arts and secondary education

Bachelor of Arts, Education

Oregon State University, Corvallis, Oregon 1977

· Emphasis on visual arts and secondary education

LICENSES / ACADEMIC AFFILIATIONS

State of Nevada, License for Educational Personnel K-8

State of Oregon, Teaching Certificate – Standard K-12

Member, American Association of Physics Teachers

· Committee on Space Science and Astronomy

Member, International Planetarium Society

RELEVANT WORK EXPERIENCE

Coordinator – NASA Nevada Educator Resource Center

College of Southern Nevada 2006 to 2017

· Delivered programing to in service and preservice teachers and students in the Planetarium (annual average 14,300 attendees)

· Presented informal science education programs to the general public (annual average 4,420 attendees)

· Wrote and administered informal science education grants as well as managed planetarium revenue and gifts budget working closely with the office of finance, the CSN foundation and CSN grants and contracts to maintain fiduciary and fiscal accountability (grant funding amounts $4,000 to $20,000)

· Worked with the office of institutional research and general counsel, public and college relations, student recruitment, diversity and cultural affairs to promote college programs and maintain a consistent message to the general public in accordance with college policies.

·Coordinated with Office of Technology Services to ensure proper use of planetarium equipment, work with vendors and supervise upgrades

· Worked with facilities management and public safety and police services to maintain safety and integrity of program facility
· Supervised staffing, inventory, budget and finances for the Planetarium Astronomy Store
· Developed curriculum and teach in-service K-12 teacher professional development

Affiliate Faculty – College of Professional Studies
Regis University 2011 to 2016

· **Taught undergraduate college courses:**
EDFD 404 Foundations of Teaching
EDFD 448 Designing Instruction for All Learners
EDFD 470 The Effective Classroom
EDEL 662 Nature and Practice of Science, Health and PE
EDEL 441 Child and Adolescent Literature
EDEL 461 Elementary Methods II; Mathematics, Science, Health and PE
· **Course writer for:**
EDEL 662 The Nature and Practice of Science, Health and PE
EDFD 404 Foundations of Teaching
EDFD 470 The Effective Classroom
EDEL 441 Child and Adolescent Literature
EDEL 461 Elementary Methods II; Mathematics, Science, Health and PE
EDFD 470 The Effective Classroom
· **Online course maintainer for:**
EDFD 461 Methods II / Teaching Science and Math
EDFD 448 Designing Instruction for All Learners
EDFD 404 Foundations of Teaching

Adjunct Faculty – College of Education
University of Nevada, Las Vegas 2011 to 2016

· Taught COE 102 – Freshmen First Year Seminar for Persistence and Retention
· Participated in team planning and curriculum development with other instructors

Instructor – Fourth Grade
St. Elizabeth Ann Seton School Las Vegas, NV 2005-2006

· Taught reading, math, and science
· Developed and revised curriculum

Program Associate School of Professional Psychology
Pacific University Forest Grove, Oregon 2000-2005

· Worked with Doctor of Psychology students to prepare internship materials
· Worked with the Director of Clinical Training to develop and maintain integrity and quality of practicum programs
· Performed research for the American Psychological Association

Instructor Substitute Teacher K-8
St. Matthew School Hillsboro, Oregon 1999-2000

· Taught all subjects and all grades
· Responsible for delivery of instruction
· Performed supervision and grading
· Participated and served on committees and school activities

Instructor-Kindergarten
Our Lady of Lourdes School Seattle, Washington 1985-1986
· Taught math, science, pre-reading skills, and art
· Developed all program curriculums
· Performed duties of supervision and assessment
Instructor-Fifth Grade
Pope John XXIII Portland, Oregon 1981 - 1985
· Taught math, science, reading and language arts
· Developed curriculum
· Participated in the planning, structuring and updating of curriculum
Instructor – Third Grade
St. Charles School Portland, Oregon 1980-1981
· Taught math, science, reading and language arts
· Team taught for reading and math leveled groupings

COMMUNITY SERVICE

Board Member Caring Hands Offering Lifelong Learning Adventures Museum Consortium
Las Vegas, Nevada 2008-2015
· Represented the Planetarium to form policy and enact procedures when dealing with kids
· Interfaced with other museum professionals and Clark County School District on standards and safety
Chairperson Citizens Participation Organization
Washington County, Oregon 1991-1992 and 1999-2000
· Planned agenda for public meetings
· Engaged speakers on a wide variety of land use topics
· Acting chairperson this quasi-governmental body for two years
· Served on Transportation Plan Update
· Served on Committee for Citizen Involvement
Board Member Tualatin River Watershed Council
Washington County, Oregon 1999-2005
· Developed policy to implement the Clean Water Act at the local level
Interfaced with county and regional government in issues of watershed management

GRANTS / RESEARCH EXPERIENCE

Graduate and Professional Student Association of University of Nevada, Las Vegas Conference Travel Grant / College of Education Awards (GPSA)
GPSA Grant awarded Winter 2017 travel
· $250.00 competitive GPSA award
· Poster Presented - American Association of Physics Teachers Meeting Cincinnati, Ohio
Using Two Simulation Tools to Teach Concepts in Introductory Astronomy
GPSA Grant awarded Winter 2016 travel
· $650.00 competitive GPSA award
· Paper Presented - American Association of Physics Teachers Meeting New Orleans, Louisiana

Latency Toward Public Speaking in Pre-engineering and Physics Students at a Two-Year College

GPSA Grant awarded Winter 2015 travel

· $200.00 competitive GPSA award
·Poster Presented - American Association of Physics Teachers Meeting
San Diego, California
Two Simulation Tools to Promote Learning in Science

GPSA Grant awarded Winter 2014 travel

· $750.00 award / $500.00 competitive GPSA award / $250 COE award
· Paper presentation – National Assoc. for Research in Science Teaching
Pittsburgh, Pennsylvania
Latency Toward Public Speaking in Pre-engineering and Physics Students at a Two-Year College

GPSA Grant awarded Summer 2013 travel

· $540.00 award / $375.00 competitive GPSA award / $250 COE award
·Paper Presented - American Association of Physics Teachers Meeting
Portland, Oregon
Using da Vinci's Machines to Demonstrate Physics at a Planetarium

GPSA Grant awarded Winter 2013 travel

· $625.00 award / $290.00 competitive GPSA award / $250 COE award
· Paper Presented - The Association of Science Teacher Education
Charleston, South Carolina
What Influence Can Working with Content Faculty Mentors have on Changing Pre-Service Teachers' Beliefs Toward STEM Fields?

GPSA Grant awarded Winter 2012 travel

· $600.00 award / $350.00 competitive GPSA award / $250 COE award
· Poster Presented - American Association of Physics Teachers Meeting
Ontario, California
Understanding Physics Through the Machines of Leonardo Da Vinci

NASA Informal Science Education Grant
Origins of Life/Analogs with Extremophiles
Researcher 2011-2012

· $11,500 award / $5,750 federal funding / $5,750 institutional match
· Co-wrote grant with Dr. Camille Naaktegeboren, principal investigator
· Supervise student projects, obtain permits from agencies, BLM, NPS
· Budget oversight, NASA reporting
· Support the efforts of the principal investigator

NASA Informal Science Education Grant
Understanding Physics through the Machines of Leonardo da Vinci
Researcher 2011-2012

· $10,000 award / $5,000 federal funding / $5,000 institutional match
· Structure the research for the principal investigator
· Data gathering, writing and filing of progress reports
· Supervision of students presenting projects
· Poster presentation on the research – American Association of Physics Teachers National Conference 2012

Target Corporation Grants to Education
Planetarium Field Trip Grants (3)
Facilitator and Writer 2011-2012

· Total Awards $2,020 / Three schools were awarded funding
· Coordinated with Clark County School District Partnership Office
· Supported the grant writing efforts for competitive funding

Nevada System of Higher Education
College Access Challenge Grant
Contributing Writer 2010-2011 reauthorized for 2011-2012

· $85,962 award / $59,443 funding / $26,517 institutional match
· Contributed to the grant structure at the writing stage
· Worked with the principal investigator to draft grant language

Nevada NASA Space Grant Consortium
Pre-Service Educator Program Grant
STEMulating Teacher Training
Researcher 2010-2011

· $20,019 award / $10,000 federal funding / $10,019 institutional match
· Structure the research for the principal investigators
· Data gathering, filed reports for CSN and NASA
· Supervision of students presenting projects

Library of Congress UNC Regional Project Grant
Teaching with Primary Sources
Principal Investigator 2009-2010

· $4,022 award from University of Northern Colorado
· Wrote curriculum for in-service teacher professional development
· Gathered Data, filed reports
· Team Taught a three-day wksp on space science using primary sources

Oregon Watershed Enhancement Board Grant
Watershed rehabilitation project to enhance salmon recovery
Principal Investigator 2003-2004

· $6,578 award
· Directed and supervised student and professional work crews
· Managed budget
· Filed reports
· Hosted Bureau of Land Management Director and US Department of Interior staff for project open house to review project

PUBLICATIONS / CONFERENCE PRESENTATIONS

Publications

Maher, P. A., Schrader, P. G., Ormord, J. & Kerr, A. W. (2016). Can simulations promote learning in science? An exploratory study to examine two simulation tools. *Journal of the International Planetarium Society. 44*(4), 24-38. doi:10.13140/RG.2.1.1229.4801

Maher, P. A., Naaktgeboren, C. E. (2014). Analogs with extremophiles; informal science education and inquiry by undergraduates attending a two-year college. *Journal and Review of Astronomy Education and Outreach*, *1*(1), 41-44.

Maher, P. A., Bailey, J. M., Etheridge, D. A., & Warby, D. B. (2013). Preservice teachers' beliefs and confidence after working with STEM faculty mentors: An exploratory study. *Journal of Teacher Education and Practice, 26*(2), 266-284.

Presentations

Maher, P. A., & Bailey, J. M. (2017, July). *Using two simulation tools to teach concepts in introductory astronomy*. Poster presented at the 2017 Summer Meeting of the American Association of Physics Teachers, Cincinnati, OH.

Maher, P. A. (2016, March). *Using virtual reality to improve pedagogy and ontological commitments – A design-based research approach.* Poster presented at the 2016 Instructional Design & Technology Learning Fair, Regis University, Denver, CO.

Maher, P. A., Bailey, J. M., & Tucka, A. M. (2016, January). *Latency toward public speaking in pre-engineering and physics students at a two-year college.* Paper presented at the 2016 Winter Meeting of the American Association of Physics Teachers, New Orleans, LA.

Maher, P. A., Humphrey, P., & Giacomini, J. (2015, March). *Investigating how to improve courses by collecting student feedback in Desire 2 Learn.* Poster presented at the 2015 Instructional Design & Technology Learning Fair, Regis University, Denver, CO.

Maher, P. A., Bailey, J. M., Schrader, P. G., & Ormord, J. (2015, January). *Two simulation tools to promote learning in science.* Poster presented at the 2015 Winter Meeting of the American Association of Physics Teachers, San Diego, CA.

Maher, P. A., Bailey, J. M., & Tucka, A. M. (2014, April). *Latency toward public speaking in pre-engineering and physics students at a two-year college.* Paper presented at the 2014 National Association of Research in Science Teaching – Annual International Conference, Pittsburg, PA.

Maher, P. A. & Naaktgeboren, C. E. (2014, January). *Using project based learning and inquiry in an authentic environment to support engagement and retention in STEM.* Poster presented at the 2014 Motivating Students for Successful Learning Fair, College of Southern Nevada, North Las Vegas, NV.

Maher, P. A., Bailey, J. M., Etheridge, D. A., & Warby, D. B. (2013, November). *An exploratory study of preservice teachers' beliefs and confidence after working with STEM faculty mentors.* Paper presented at the 2013 Nevada Educational Research Alliance Symposium, University of Nevada, Reno, Reno, NV.

Maher, P. A., Bailey, J. M., & Tucka, A. M. (2013, July). *Using da Vinci's machines to demonstrate physics at a planetarium.* Paper presented at the 2013 Summer Meeting of the American Association of Physics Teachers, Portland, OR.

Maher, P. A. (2013, March). *What influence can working with science and math faculty mentors have on changing dispositions toward science, technology, engineering, and math (STEM) fields in preservice teachers?* Paper presented at the 2013 Graduate and Professional Research Forum, University of Nevada, Las Vegas, Forum Award, Honorable Mention, Las Vegas, NV.

Maher, P. A., (2013, January). *What influence can working with content faculty mentors have on changing preservice teachers' beliefs toward STEM fields?* Paper presented at the 2013 Association of Science Teacher Education International Conference, Charleston, SC.

Maher, P. A., Bailey, J. M., & Tucka, M. A. (2012, February). *Understanding physics through the machines of Leonardo da Vinci.* Poster presented at the 2012 Winter Meeting of the American Association of Physics Teachers, Ontario, CA.