The Impact of An Immersive Virtual Reality Learning Environment with Computer-Aided Design and Three-Dimensional Modeling Through Stem Middle-School Education Programming

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ABSTRACT

THE IMPACT OF AN IMMERSIVE VIRTUAL REALITY LEARNING ENVIRONMENT WITH COMPUTER AIDED DESIGN AND THREE-DIMENSIONAL MODELING THROUGH STEM MIDDLE-SCHOOL EDUCATION PROGRAMMING

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Northern Illinois University, 2021
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Immersive virtual reality as a tool in the middle-school classroom is a promising avenue to aid in cognitively challenging tasks requiring access to visual processes. As these tools become ever present in society, the expectation of school districts to include them into classroom curricula has become challenging, as there is inconsistent data connecting to beneficial learning outcomes. Middle-School STEM classrooms experience an exceptional challenge in the expectation to build strong spatial reasoning skills on rudimentary geometry concepts. It is with that in mind that many 21st-century technology classrooms turn to immersive virtual reality, such as Oculus Rift, as a tool to bridge the gap between conceptual and skill-based expectations. Therefore, this study explored the connections between spatial reasoning skills and the immersive virtual reality learning environment (IVRLE) in order to identify any correlation between access to the immersive nature of the platform and the ability to apply spatial processing by engaging in the full experience of building an object and visualizing its dimensions. This experimental study found no statistically significant data to support the conclusion that the completion of a task through the experience of the IVRLE (treatment group) provided any additional benefits, when measured with the Middle Grades Mathematics Project Spatial Visualization Test, as compared to those who completed the same task within a traditional PC environment (control group).
Additionally, building within the IVRLE produced a negative effect on the outcome when the
three-dimensional models created were printed through a 3D printer and evaluated. It is
recommended that further research continue the important task of evaluating the specific value of
tools such as Oculus Rift and other immersive virtual reality platforms in the middle-school
classroom.
THE IMPACT OF AN IMMERSIVE VIRTUAL REALITY LEARNING ENVIRONMENT
WITH COMPUTER AIDED DESIGN AND THREE-DIMENSIONAL MODELING
THROUGH STEM MIDDLE-SCHOOL EDUCATION PROGRAMMING

BY

DANIELLE EVE SCHNEIDER
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A DISSERTATION SUBMITTED TO THE GRADUATE SCHOOL
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ASSESSMENT

Doctoral Director:
Ying Xie
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To my mom, your absolute belief in me has been infinitely motivating and uplifting. You have been my role model because of your dedication and drive. You’ve kept me infinitely motivated to be the best me I can be. Thank you for patience.

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To my sister, every doubt, every shadow, every fear, you lifted for me. This is for you, this is for us. The curse is now lifted.
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CHAPTER 1

INTRODUCTION

This dissertation is the third in a series of research publications exploring the immersive virtual reality learning platform. While the current investigation stands alone in the design and execution of its elements, the fundamental links between it and the two previously published studies (Schneider, 2019; Ladendorf et al., 2019) lay foundational groundwork delineating the vital importance and value in research directed at instructional technologies and design with immersive technologies in the middle grades.

The initial publication, titled “The Impact of Immersive Virtual Reality on Learning, Post-Hoc: A Cautionary Tale,” investigates the impact of the immersive virtual reality learning environment on student engagement post-hoc. Middle-school students engaged in an immersive virtual reality learning environment in their Science class. Their engagement levels were measured at two specific time points. The outcomes of this study identified that affective and behavioral engagement were affected post-hoc when participating in the immersive VR learning environment, but cognitive engagement and disengagement were not affected.

The second publication, “Mobile-Based Virtual Reality: Why and How Does it Support
Learning, "focusses on developing the hypothetical model of immersive cognition to explain how the brain processes input when learning within an immersive virtual reality learning environment. Additionally, the paper details the importance of authentically implementing virtual reality in the classroom, providing extensive design and instructional considerations.

Virtual Reality in Today’s Classroom

The use of the immersive virtual reality learning environment (IVRLE) is becoming a mainstay in the public education realm. As this technology becomes more readily available and affordable, it continues to entice administrators to incorporate it into the technology education classroom (Dede, 2009; Fowler, 2015). The virtual learning environment can be dated as far back as the late 1960s and 1970s with Tom Furness and the creation of the Supercockpit and the US Airforce creating head-mounted displays as flight simulators (Bye, 2015). These Immersive tools are not immune to that growth and have been infiltrating the educational environment unfettered for decades (Fowler, 2015), and while there is no uncertainty of their impressive nature and ability to transport the user to simulated environments, the question continues to beleaguer the educational arena; is virtual reality a valuable tool for a classroom learning environment (Bailey & Bailenson, 2016; Deroualle et al., 2015)? With the application of immersive technologies, a more engaging opportunity for educators has arisen in which students can directly apply content to action and produce a solution. This highly interactive approach adds a new interactive layer to the classroom.
Background

Spatial Reasoning in the STEM Classroom

In both real-life STEM fields and academic, much of the work that unifies spatial reasoning components is founded in simple dimensioning (Yeh, 2010). Visualization skills are critical to success in STEM (science, technology, engineering, and mathematics) fields. One of the key factors underlying this is a strong sense of spatial reasoning or mental modeling (Katsioloudis, et al., 2014). It is the idea that one can visualize an object, recognize it as both parts and whole, while working with it in relation to other objects within one’s mind. In mathematical terms, it is often described as spatial transformation and spatial reasoning (Battista et al., 2017; Battista & Frazee, 2018; Wai et al., 2009). Without the ability to think in a spatial context, we would not have such groundbreaking STEM concepts such as the DNA molecule and the theory of relativity.

A clear definition of spatial reasoning was set forth by Sutton and Williams (2010) as “the performance on tasks that require mental rotation of objects and an understanding of how objects relate to each other in space” (p.3). Mental rotation is considered a construct of spatial reasoning as it requires a model to represent the visualization one creates in one’s mind. Spatial ability or intelligence refers directly to one’s skill level of these tasks (Sorby, 2008).

Numerous studies have demonstrated that students with low spatial ability struggle to focus on relevant data within spatially challenging environments, such as the STEM classroom; however, Uttal et al. (2013) have shown that spatial thinking is malleable and can positively benefit from hands-on interventions (Stieff et al., 2020). Nonetheless, there is a deficit of
enriching, spatially engaging lessons in middle-grade instruction, as practitioners often themselves are unskilled in spatial reasoning (Seago et al., 2013).

Theoretical Foundations

Cognitive Mapping Theory

The theory of cognitive mapping (CMT) is built upon the concept of spatial relationships being drawn from the logical interpretations individuals make between the connections in their environment from an allocentric view; one creates a code to connect events, sequences, and ultimately relationships (Kelly & Gibson, 2007). Cognitive maps are a way to allow one’s mind to solidify these relationships as a visual image in order to heighten one’s memory. This theory has further been solidified through functional magnetic resonance imaging (fMRI) studies which identified specific neural place cells firing as a means of “navigation-by-memory” within the hippocampal region of the brain in both human and non-human subjects during recall events (Jeffery, 2010).

Cognitive Load Theory

The overall concept of the cognitive load theory (CLT) is based on the idea that working memory is limited and can be overwhelmed when instruction and/or input is designed with higher level task connectedness, redundancy of tasks, or a general overloading of tasks. CLT can be divided into three main subsets: intrinsic, extraneous, and germaine (Chandler & Sweller, 1991).
Statement of Purpose

The purpose of this quantitative, experimental study seeks to investigate the benefit of using the immersive virtual reality learning environment (IVRLE) when applied to three-dimensional modeling in middle-school STEM programming.

Definition of Terms

1. Immersive virtual reality learning environment: A computer application providing the user an immersed, simulated learning environment/interaction within a three-dimensional experience (usually with a head-mounted display that inhibits one's field of view from the outside [real] world.

2. Immersive virtual reality: A computer application providing the user an immersed, simulated environment/interaction within a three-dimensional experience (usually with a head-mounted display that inhibits one's field of view from the outside [real] world.

3. Spatial visualization: The ability to mentally move an object in its place in space while keeping the proper perspective.

4. Spatial orientation: The ability to mentally picture an objects direction in space.

5. Spatial transformation: The ability to move around an object in space without losing the size or proper orientation of the object as one moves it.

6. Visuospatial: A term used to describe the visual perception of how objects are spatially related.


8. Allocentric view: Perceiving objects in relation to each other.
9. STEM: A blending of disciplines; science, technology, engineering and mathematics organized to teach 21st-century skill sets.

10. Orthographic drawing: A group of 2D sketches from different viewpoints to represent a 3D object.

CHAPTER 2

REVIEW OF LITERATURE

This chapter reviews the literature related to the immersive virtual reality learning environment in relation to the STEM classroom and spatial reasoning, as well as the theories that are used to ground the phenomena observed within this experiment.

Even as the IVRLE has become more accessible, few studies exist linking immersive technologies with the use of three-dimensional model creation, as few IVR applications are able to allow students to create within them (Battista et al., 2017; Linn & Peterson, 1985; NRC, 2006; Wai et al., 2009). The fundamental illusion behind VR is the believability. The user must be able to immerse oneself into the environment. This can only happen if they are sufficiently visually stimulated and can navigate within the virtual world (Schneider, 2019).

Theory

While no specific theories exist to address the complexity of spatial learning within the constructs of immersive technology, connecting foundational cognitive theories to the effects of the immersive virtual reality learning environment (IVRLE) will provide a framework to ground the factors that impact learning within it.
Cognitive Mapping Theory

The theory of cognitive mapping was first identified through laboratory studies with animal models as the ability to build a mental map based on cues or stimuli from one’s environment (O’Keefe & Nadel, 1978). However, what has made this theory unique is the identification of spatial learning in the hippocampus, thereby connecting it to an allocentric viewpoint instead of those from an egocentric one (Kelly & Gibson, 2007). This is an important distinction as the visual memory mapping construct is built between objects and not between the individual and each object one interacts with.

Moreover, a breakthrough in this theory was the discovery of neuronal place cells firing as the animal moves within the environment, as it seemingly acquires a spatial map during locomotion, as if the cells are taking in visuospatial notes. This was replicated through fMRI studies in virtual environments, showing the same areas of the hippocampus stimulated both on initial experience of map building and during recall when accessing the stored map (Botinni & Doeller, 2020; Nau, et al., 2018).

The importance of the CMT application within IVR is the active weaving of real-world visual cues to the virtual world proxy as it creates a spatial navigation map. “Cognitive maps and image spaces may be two sides of the same coin: they may be specific manifestations of a more general propensity of the human brain to organize knowledge” (Botinni & Doeller, 2020, p.611).
Cognitive Load Theory

The cognitive load theory (CLT), simply stated, refers to the limits of working memory within a given task, as the system can be easily overloaded, as well as the determination of whether that learning will be retained based on the load (Baddley, 2003; Sweller, 2010). CLT is dependent on many underlying components. Primarily, an individual’s foundational understanding of the requested task, the complexity of the task and the nature of the connection between tasks. When any component of this is surpassed, learning is no longer deemed effective. There are three subtypes of cognitive load: intrinsic, extraneous, and germaine.

Intrinsic cognitive load is directly related to the learning outcome. Sweller (2010) refers to it as “anything that needs to be or has to be learned” (p. 124). It is dependent upon the amount of prior knowledge the learner has and triggered when tasks push the individual to draw upon the long-term memory’s (LTM) integration for input. This is often seen when higher level prior knowledge is required for task completion, as the magnitude of the load is directly correlated to the level of information being accessed (Sweller, 2010).

The extraneous cognitive load is not directly related to the learning outcome of the task but is impacted based on expected ancillary tasks. In a STEM classroom, this could be simple tasks such as turning on a computer, manipulating a program, or reading and interpreting instructions. The extraneous cognitive load often creates a “split-attention” situation in a high-tech environment (Kalyuga & Liu, 2015). The cognitive load theory in relation to IVR is viewed as highly relevant due to the volume of input that targets the user’s visual register (Schneider, 2019).
The germane cognitive load is defined as cognitive effort. It is the component of the design built for each student to attain the knowledge and should not be beyond their ability to achieve. It is thought of as the component that supports learning, or a strategy to enhance one’s ability to learn (Debue & van de Leemput, 2014).

Summary of Theories

There are two main theories used to ground this research, they are the cognitive mapping theory and the cognitive load theory. The cognitive mapping theory is an allocentric-based theory building connections of events, objects, and ideas into a visual picture. The cognitive load theory is comprised of three components: intrinsic, extraneous, and germane. If one’s cognitive load is exceeded, learning will not successfully take place.

Spatial Learning in VR

STEM curricula and environments continue to drive much of the research in the validity of the immersive virtual reality learning environment (IVRLE), and therefore, the specific skills of the successful STEM student are becoming more highly scrutinized. One of the most significant skills for the STEM student’s success is spatial learning (Molina-Carmona et al., 2018; Sorby et al., 2013; Uttal et al., 2013; Uttal & Cohen, 2012). This has directed a significant amount of research to focus on the visual processes within the IVRLE and spatial reasoning and orientation (Branoff & Dobelis, 2012; Buckley & Seery, 2018; Ha & Fang, 2018; National Council of Teachers of Mathematics, 2000; Rodriguez-Andres et al., 2018; Wai et al., 2009). It is understood that spatial reasoning is developed over an individual’s lifetime through exposure within one’s environment; there are other factors involved as well (Paes et al., 2017). They range
from items as simple as stereoscopic vision and depth perception to overall strategies put in place to identify ones' place in space, both egocentric and allocentric (Figure 2; see also Figure 1).

Figure 1. Graphical representation of allocentric and egocentric views.

Figure 2. How the VR user creates depth perception with stereoscopic vision.

The ability to have accurate orientation within a three-dimensional plane, whether in a VR or non-VR environment, is vital for the skill and application of simple shape identification and rotation in the STEM environment (Cherep et al., 2020). Orienting oneself in maps and
determining landmarks' placement are the neurological processes of shape formations built into spatial relations. The connection of the body's cues to the brain's processing of the visual input creates a re-orientation of the brain, bringing about spatial orientation and spatial scaling, allowing one to have stronger spatial reasoning abilities (Newcombe & Frick, 2015). Yue (2008) and Sweller (2010) have documented that while object transformation is active well before prepubescent age, it is a complex and taxing skill on one's mental resources to retrieve an image and properly manipulate it to create a final solution.

In an extensive study conducted by Rodriguez-Andres et al. (2018), researchers investigated the visuospatial skills of children aged 5-10. They were unable to identify a significant difference in object location ability in a virtual environment based on age, gender, or previous videogame usage. They noted that children who had more experience with videogames, were quicker at navigating within the virtual environment, but the speed did not afford an advantage in object location. However, their data did show a correlation between a child’s spatial ability within the virtual environment to their existing visuospatial skills. This initial visuospatial data was collected as pretest data to index students’ skill sets.

Lee and Wong (2014) identified the positive effect VR had with Biology students who were struggling with spatial reasoning. While they found no difference in student performance within the group that had high spatial reasoning skills, there was a difference within the low spatial reasoning group. They believe the effect found in the lower performing group was due to the reduction in extraneous cognitive load afforded through the VR environment.
Using two distinct populations of students, Batinov, Whitney, Miller, Nusser, Stanfill, and Ashenfelter (2013) compared students’ spatial abilities to map neighborhoods in both the real and virtual environments. Groups consisted of both students with high and low spatial abilities. Their results yielded no significant difference within either group regardless of environment.

Castillo Escamilla et al. (2020) used the Boxes Room memory task as a virtual environment to identify allocentric spatial memory performance. Subjects were initially given a standardized test to establish working memory (WM) before the experiment. Researchers were able to correlate the benefit of a strong WM to strong spatial navigation abilities, regardless of gender.

Summary and Gap in Literature

The existing research includes a multitude of studies that all present a similar conclusion. Individuals with higher initial spatial skills are more successful in visually challenging environments. Additionally, IVRLE and spatial learning research continues to focus on many strands of topical learning with a curricular focus while looking to link covariates such as gender and age. This presents a gap in the literature examining how spatial learning is influenced when one creates or builds within the IVRLE.

Spatial Learning and CAD

Piaget’s theory of cognitive development reminds us that young children are developing and building concrete operational skills and still working on summarizing concepts of shapes and
pictures. The current process by which students are learning to manipulate objects on a 2-D plane through Computer-Aided Design (CAD) applications continues to plague STEM programs as we push challenging content to the lower grades. When adolescents are asked to perform abstract tasks, they are often being pushed past their developmentally cognitive limits (Swafford, Jones & Thornton, 1998; Thompson, 2007).

The current approach in many STEM classrooms is the implementation of computer-aided design (known as CAD) with the inclusion of three-dimensional printing. Students as young as ten are learning and using the same programs that are being used in professional architecture and design firms. Often, they do not have the geometry skill set nor spatial learning foundation to support a full understanding to utilize these applications and are forced to work based on an a priori foundation (Passig et al., 2016).

In a 2015 study with fifth-grade students, Sung, Shih, and Chang added a 3D modeling application to their geometry curriculum in order to identify the benefits for students when working with surface area and dimension. They found students in the treatment group (access to the program) were not as strained by the mental modeling and rotation aspects and were able to focus on the specific tasks. Additionally, they reported increased retention of understanding for the treatment group.

Ng and Chang (2019) infused mathematics into a STEM-CAD component for design with 12- to 13-year-old students. They identified that students were more productive with modeling per their ability to create shapes and identify volume. However, the results of this experiment were provided anecdotally, and no statistical data was revealed to support
conclusions. Through published graphical representations, the student designs were complex, providing visual evidence to both advanced geometric understandings and CAD skill sets.

Li, Cheng, and Yuan (2018) demonstrated how implementing a computer-based CAD component to an existing graphic arts landscape curriculum increased efficiency of teaching and increased student learning through a greater level of access to students' ability to visualize content. Furthermore, access to CAD removed the burdensome component of sketching for some, as well as a database of materials to lighten the cognitive load.

Samsudin, Rafi, and Hanif (2011) investigated differential training methods of engineering students to determine if CAD programming would increase students' spatial abilities when looking at orthographic projections. Using a printed handout (control) and 3D CAD applications (animation and interaction enabled) as the treatment, they compared male to female students. The results identified that females showed significant growth regardless of treatment to all three. In contrast, male students showed substantial progress only when exposed to animation and interaction-enabled treatments. They further posited that the experience of the 3D media provided additional supports to enhance the learning environment that allowed all students to limit their need to access cognitive components of their own.

Chang (2014) compared students’ output in 3D CAD programming and found that those who had higher spatial skills could engage at higher levels within the 3D CAD programming. However, those who had lower level spatial skills struggled to access the content and the output was deemed “less functionally creative.”
Summary and Gap in the Literature

The literature connecting CAD and spatial learning presents a promising vision to the benefit of CAD supporting visuospatial learning. All but one study shows CAD as a tool to support student learning. The data provide arguments for how spatial learning through CAD, grounded in the CLT, is impacted both positively and negatively. The complex skill set required to manipulate images within CAD supports the argument of an additive extraneous cognitive load to the user. However, it appears that any added extraneous load that could split the attention of the learner may be offset by the scaffolding benefits provided through the CAD’s rich platform of user tools, removing a data grab from an individual’s WM. Nonetheless, a significant gap in the research exists as there is no research linking the transformative nature of CAD when creating physical objects to enhance students’ spatial learning in a manner that allows them to truly visualize the objects as they build them.

Conclusion

There have been a variety of studies that continue to research the efficacy of software and hardware as effective platforms in digital literacy as strong spatial reasoning abilities are becoming highly valued job skills in STEM fields such as engineering, architecture, medicine, chemistry and mathematics. In response, educators are turning to computer-aided design (CAD) and virtual reality as methods to support and modify the curriculum (Buckley et al., 2018; Gonzales-Campos et al., 2019). Capitalizing on this, STEM educators are working to develop concepts through three-dimensional modeling, recognizing the need to build upon the foundation created from early elementary geometry modeling concepts, understanding that geometric skills
require a great deal of multidimensional and spatial reasoning abilities (Johnson & Bouchard, 2005; NCTM, 2000; Samsudin et al., 2011). However, the majority of the literature remains focused on the macro-successes of our students in their quest for acquisition of knowledge in the STEM fields while ignoring the tool itself as a scaffold to benefit spatial learning.

While there is extensive literature published connecting mathematics and spatial reasoning, as well as spatial reasoning and STEM education, I have identified a clear gap in the research, specifically relevant to the practitioner of STEM education.

The challenge is for students to effectively engage in the three-dimensional modeling practice while successfully and authentically interacting with design and modeling elements regardless of their math foundational skills connected to the IVRLE (Martin-Dorota et al., 2008; Young et al., 2018).

Research Questions

This study seeks to answer the following questions:

1. Did the use of the immersive virtual reality learning environment influence student spatial reasoning ability, as measurable on the Middle Grades Mathematics Project Spatial Visualization Test?

   • Was there an interaction effect of time and treatment on student spatial reasoning ability?

   • Was there a main effect of time on student spatial reasoning ability?
• Was there a main effect of the treatment on student spatial reasoning ability?

2. Was there a statistically significant difference in student outcome (3D-printed object scored through a standard rubric) for students in the IVRLE and students in the traditional learning environment?

While there is no one theory that effectively represents this study’s theoretical foundations, the theory of cognitive mapping and the cognitive load theory together were used jointly.
CHAPTER 3

METHODOLOGY

Participants

This experiment was set up using voluntary response sampling. This sample group was comprised of students who volunteered from the population of the seventh-grade class at Golf Middle School in Morton Grove, Illinois. The group (N=30) was comprised of 16 male students and 14 female students, eighteen 12 years of age (60%) and twelve 13 years of age (40% ; see Table 1). The participants were comprised of multiple ethnicities: Asian (40%), Caucasian (33.3%), Hispanic (20%), and African American (6.6%). Data from the Measure of Academic Progress (MAP) Geometry test for winter 2019 was collected from all student participants, and scores fell between 219-233, which was within the normal equivalency curve (NCE) range of 65-72 (NWEA, 2020).
Table 1

**Student Demographic Data**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>16</td>
<td>53.3</td>
<td>53.3</td>
<td>53.3</td>
</tr>
<tr>
<td>Male</td>
<td>14</td>
<td>46.7</td>
<td>46.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18</td>
<td>60.0</td>
<td>60.0</td>
<td>60.0</td>
</tr>
<tr>
<td>13</td>
<td>12</td>
<td>40.0</td>
<td>40.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Each student had been given prior instructions with both the Oculus Rift and TinkerCAD programs through previous STEM classroom lessons in Grade 6, as well as participation in a design modeling unit. The students had studied National Governors Association Center for Best Practices in mathematics based on the Mathematics Common Core State Standards Initiative (2010), providing a Geometry foundation from Grades K-7. Participation was completely voluntary, and individuals did not receive any extra credit or compensation for their collaboration.

**Instruments**

The first research question was measured using a pretest and posttest of the Middle Grades Mathematics Project Spatial Visualization Test (MGMP-SVT; Lappan, 1981). For the second research question, the students’ 3D models were scored against a provided standard classroom rubric modified from the Project Lead the Way Design and Modeling course (2017), to assess the 3D model, scored by two individuals to ensure inter-rater reliability (Appendix B).
Procedure

As this experiment used human subjects (minor children), three weeks prior to the start of the experiment, all parents and students were provided with informed consent documentation of the study (Appendix A). Upon acceptance, each student was assigned a randomly generated identification number. Even numbers were treatment and odd numbers were control (Figure 3). This number was also used when completing the MGMP-SVT. This allowed for students to be tracked anonymously. Students were unaware whether they were part of the treatment or control group at this point.

![Diagram of Experimental Procedure]

Figure 3. Experimental Procedure.

Pretest (two weeks prior to Day 1): Once the entire sample group was in place, students took the pretest MGMP-SVT
Days 1-14: Students were given a pre-arranged time to arrive to the classroom. The students entered the classroom and signed in with their number.

Treatment students: Each student was given a quick refresher of the Oculus Rift and students went through the Oculus tutorial in the specific program “Blocks” (see Figure 4). Upon completion, students were handed a specific shape to design on the Oculus Rift. This was placed in front of them and they could sit or stand as they worked in the Oculus platform. They were also told they could lift the headset if they wanted to look back at the shape at any time. Once students were ready, a timer was started, and they began to build the shape in “Blocks.” When they were finished, the timer was stopped, and their design was saved using their identification number. Their time was recorded on the data document and their item was saved on a flash drive. Immediately following the completion of the design, the students completed the MGMP-SVT posttest.
Control students: Students were given a quick refresher on how to use the “TinkerCAD” program. Upon completion, students were shown a specific shape to design using the “TinkerCAD” program on the desktop computer with an optical mouse (see Figure 4). The shape was then placed in front of them and they were instructed to build it. They were also told they could refer to the shape at any time, pick it up and move it around. Once students were ready, a timer was started, and they began to build the shape in “TinkerCAD.” When they finished, the timer was stopped, the time was recorded on the data document, and their design was saved using a flash drive. Immediately following the completion of the design, the students completed the MGMP-SVT posttest.
Once all subjects completed their participation, the 3D models were printed on the MakerBot Replicator 3D printer. They were independently scored using the rubric (Appendix B) by both the researcher and a colleague to ensure inter-rater reliability of data. The results of the inter-rater analyses, using the average of the two raters, fell into the substantial range of agreement with a $K = 0.71 , p < 0.001$ (Landis & Koch, 1977).

**Statistical Analysis**

The Statistical Package for the Social Science (SPSS®) was applied to evaluate the data. Descriptive statistical analysis was used to identify similarities and differences in the population. Chronbach’s alpha was run to measure reliability across items in the MGMP-SVT and, a mixed ANOVA was run to identify statistical significance of the data, as well as a Cohen’s kappa and one-way ANOVA for the rubric data.
CHAPTER 4

RESULTS

Overview

This chapter presents the findings of this experiment. Multiple analyses were performed to identify all significant variations, associations, and interactions between the treatment and control groups. The relationships to the null hypotheses were evaluated.

The purpose of this quantitative, experimental study was to investigate the benefit of using the immersive virtual reality learning environment (IVRLE) when applied to three-dimensional modeling in the middle-school STEM programming. Thirty students (N=30) took the MGMP-SVT, participated in either the treatment or control environment tasks (randomly assigned), and upon completion immediately took the MGMP-SVT as a posttest. Within the treatment or control environment task, students built a 3D object, which was printed through a 3D printer and scored twice to ensure inter-rater reliability using the classroom 3D Model rubric.

Descriptive Statistics

The pretest/posttest mean scores were evaluated (Table 2). The control group increased from a mean of 13.07 (SD =5.25) to a mean of 15.36 (SD =5.30). The treatment group increased from a mean of 13.19 (SD =4.31) to a mean of 16.69 (SD =6.32). The overall sample score
increased from a pretest mean of 13.13 (SD=4.69) to a posttest mean of 16.07 (SD=5.81). The control group rubric mean score was 13.43 (SD =1.56) and the treatment group rubric mean score was 12.00 (SD =1.27).

Table 2

Statistical Analysis of Control Group vs. Treatment Group Pre/Posttest MGMP-SVT Scores

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample Size N</th>
<th>Pretest Score M</th>
<th>Pretest-SD</th>
<th>Posttest Score M</th>
<th>Posttest-SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>N=14</td>
<td>13.07</td>
<td>5.25</td>
<td>15.36</td>
<td>5.30</td>
</tr>
<tr>
<td>Treatment</td>
<td>N=16</td>
<td>13.19</td>
<td>4.31</td>
<td>16.69</td>
<td>6.32</td>
</tr>
</tbody>
</table>

The MGMP-SVT test consisted of 32 multiple-choice questions. A Cronbach’s alpha was implemented to ensure the reliability of the pretest/posttest questions. Cronbach’s alpha yielded results of 0.877. Further data to support the overall test construct validity exists in the literature through Lapan (1981, pp.74-76) as well as Gorska and Sorby (2008).

An equal variance analysis was carried out prior to mixed ANOVA to determine if there was a significant difference between the treatment and control groups. Results of Levene’s statistic revealed that the P-values are greater than $p=.05$, indicating that the variances between the populations were not significant, shown in Table 3.
Table 3

Levene’s Test Statistic

<table>
<thead>
<tr>
<th>Between Group</th>
<th>Levene’s Test Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest Scores</td>
<td>F(1.28)=.602, p=.444</td>
</tr>
<tr>
<td>Posttest Scores</td>
<td>F(1.28) =1.102, p=.303</td>
</tr>
</tbody>
</table>

The first research question aimed to identify if there was a benefit to students using the IVRLE when creating 3D models. A mixed ANOVA analysis identified no statistical difference between the treatment and the control group from their pre to posttest scores. F(1,28) = .159, p=0.693. This is additionally supported through a visual representation of the estimated marginal means (Figure 5). There was not a statistically significant interaction effect of time and treatment F (1,28) = .678, p=.417. However, the data did support a significant difference between the pretest scores and the posttest scores overall F (1,28) =15.38, p=.001. These data are shown in data table 4.
Each student constructed the model while using either the immersive application (treatment) or traditional application (control). Once these models were printed with a 3D printer, it created the physical manifestation of the students’ CAD experience, which was then evaluated with the rubric. Cohen’s kappa was used to evaluate inter-rater reliability of the rubric evaluation data. The statistic was validated and is shown below in Table 5.
Table 5.

*Cohen’s Kappa Measuring Inter-rater Reliability of Rubric Evaluation from Mean Rubric Scores*

<table>
<thead>
<tr>
<th>Measure of Agreement</th>
<th>Cohen’s K Value</th>
<th>Asymptotic Standard Error</th>
<th>Approximate Tb</th>
<th>Approximate Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa</td>
<td>0.710</td>
<td>0.097</td>
<td>8.250</td>
<td>0.000</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A one-way ANOVA was used to evaluate each student’s average rubric score from both the treatment and control groups. There was a significant difference shown between groups: \( F(1,28) = 7.37, p = 0.011 \) (see Tables 6 and 7).

Table 6

*Statistical Analysis of Rubric Data*

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample Size</th>
<th>M Rubric Score</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>N=14</td>
<td>13.36</td>
<td>1.55</td>
</tr>
<tr>
<td>Treatment</td>
<td>N=16</td>
<td>11.98</td>
<td>1.31</td>
</tr>
</tbody>
</table>

Table 7

*ANOVA Data of Rubric Scores*

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>15.048</td>
<td>1</td>
<td>15.048</td>
<td>7.372</td>
<td>.011</td>
</tr>
<tr>
<td>Within Groups</td>
<td>57.152</td>
<td>28</td>
<td>2.041</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>72.200</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 5

DISCUSSION

This study explored the use of the immersive virtual reality learning environment in the Middle School classroom as a tool to engage and enrich learning in the field of spatial reasoning. It investigated the relationship between the IVRLE and spatial reasoning ability through a pretest and posttest model. It utilized a modified rubric (Design and Modeling Student Course, 2017) to score the 3D model created within either the treatment (IVRLE) or control (traditional PC environment) group when given a specific object to replicate. Few research studies in the field of immersive virtual reality education have studied the use of creation during student participation in the IVRLE to affect learning, despite significant research supporting the fundamental concept of how learning emerges during active, engaged experiences (Appleton et al., 2008; Bodemer et al., 2004; Dede, 2009; Ha & Fang, 2018).

Q1. Did the use of the immersive virtual reality learning environment influence student spatial reasoning ability, as measurable on the Middle Grades Mathematics Project Spatial Visualization Test?
• Was there an interaction effect of time and treatment on student spatial reasoning ability?

• Was there a main effect of time on student spatial reasoning ability?

• Was there a main effect of the treatment on student spatial reasoning ability?

The null hypothesis was retained for time and treatment, treatment alone and was rejected for time alone.

While the data showed the increase in student scores on the Middle Grades Mathematics Project Spatial Visualization Test (MGMP-SVT) from pretest to posttest as significant across both groups, the mixed ANOVA identified that there was no significant difference between the groups. Therefore, this experiment was unable to identify the use of the Oculus Rift IVRLE as superior for learning spatial reasoning as compared to a traditional 3D CAD learning platform.

Implications and Discussion of Question 1 and the Immersive Virtual Reality Learning Environment and Spatial Relations

As the data indicated, there was no statistically significant difference in spatial reasoning skills based on the change in scores from pretest to posttest between the treatment and control groups ($F(1,28) = .159, p = 0.693$) or an interaction effect of the treatment and time ($F (1,28) = .678, p = .417$), yet both groups did experience a statistically significant increase in score over time ($F (1,28) = 15.38, p = .001$).
The results of this experiment did not support the construct that the IVRLE provided a more accurate representation of reality in order to suspend or overcome the components of cognitive processing and memory demands that beleaguer the mind when working with the complex skill of spatial reasoning. Instead, it is possible that both the students in the IVRLE and those using the desktop-computing CAD program were positively impacted through the cognitive load theory. Pillay (1994) eloquently addressed causative agents of CLT in relation to the minds’ architecture as the working memory’s limited capacity forcing one to rely on simple transactions and experiences during learning. If that does not happen the cognitive load imposed upon the individual exhausts one’s resources, thereby affecting learning (Halford, 1993). I believe both the treatment and control groups experienced small shifts in their novel understanding of geometric shapes provided by the user tools within the platform. These visually rich tools within both applications provided a “rest stop” for the working memory through the presentation of an object bank, tools with which to work, and the attributes built in to manipulate the shapes. This provided a scaffolding effect lessening the load on the WM during the mentally complex task of dimensioning, potentially offsetting the need to access LTM to complete tasks and overload the system. However, when building the shape inside of the Oculus Rift, there was still the burdensome “old-school” action of erasing and physically redrawing. The tools themselves inside the Oculus Rift required more steps to select the shape, as opposed to it being readily available on the desktop of the TinkerCAD platform. I believe these additional cognitive tasks may account for the significant difference in outcome of the rubric-rated model.

Additionally, I believe the visual access to objects and the ability to “grab and add” to create 3D output allowed students unfettered cognitive access to their own graphical
representation or map, enabling an allocentric viewpoint in order to build their final shape. As the VR shapes were constantly available within the platform, the need for the cognitive map to be transformed into long-term memory storage was deemed unnecessary, thereby putting less strain on the cognitive load.

While these results are consistent with similar IVR research from Katsioloudis et al. (2014), they posited that the reasoning behind the absence of any statistical advantage of the treatment group within the IVR environment was a lack of complexity in the modeling. This is an interesting perspective as the design of our experiment purposefully applied simple models with the CLT in mind.

A future research study could investigate the implementation of spatial modeling with a range of graphically more complex shapes looking to forcibly create a higher cognitive load. Additionally, test subjects would be divided into two treatment groups: one IVRLE and one using 3D modeling with the control group modeling with pencil and graph paper. This would allow a clearer correlation to cognitive load and at what point, if at all, there is a benefit to the IVR tool over traditional classroom applications.

Implications and Discussion for Question 2 and the Immersive Virtual Reality Learning Environment and CAD

Q2. Was there a statistically significant difference in student outcome (3D-printed object scored through a standard rubric) for students in the IVRLE and students in the traditional learning environment?
When evaluating the models against the rubric, the data showed a statistically significant difference between the treatment and control groups \( (F(1,28) = 7.37, p = 0.011) \). However, the higher overall scores were in the control group, not the treatment (IVRLE) group.

When comparing the physical attributes of the outcome from this research question, the 3D models printed from the treatment group were severely distorted compared to those of the control group. This could be due to a variety of reasons. While addressed previously, the tools, shapes, and a visually pleasing environment were present in the IVRLE. It is possible that the treatment group may have been distracted and removed from the real world by the virtual environment itself, as it was colorful and pleasing. This could be seen as extraneous load. Students often enjoyed the creative aspects irrespective of the detrimental consequences (Kalyuga & Liu, 2015). They had the ability to fill in the shapes with color, make them larger or smaller, and would often do so. Occasionally, students would become so engrossed in moving and throwing the shapes in the virtual environment, they would lose them, as they would “fall off” the visual plane. While these effects may be seen as motivating, and therefore germane load, the overwhelming nature of the motivation cannot be grounded through the CLT.

Students who participated in the control group had only the PC and sat at their desks, completing the tasks with minimal distractions. Even though the control group did not experience the same elements of engagement through their interface, as it was less realistic and engaging in nature, it is unclear if the difference between groups was due to the extreme engagement within the IVRLE or a benefit afforded to the control group through a combination
of calm environment and scaffolding of relevant tools lessening WM exertion (Branoff et al., 2012; Hong et al., 2016).

The excessive cognitive load required in the IVRLE can also be corroborated by the hypothetical model of immersive cognition (HMIC) theory (Ladendorf et al., 2019). Research has shown the IVRLE acts as an effective tool to stimulate relevant factors to trigger the brain and that VR enhances the three-dimensional perception of shapes and spatial relationships through visual processes in cognition (Hong et al., 2016). Therefore, it is a logical position to connect IVR and CAD. However, while this scaffolding effect has the potential to eliminate some of the cognitive load, it does not fully account for how the cognitive processes are affected by the influx of visual stimuli and the sense of presence in the immersive environment. The HMIC theory posits that the sense of presence created through the use of immersive virtual reality activates visuospatial channels, bypassing the working memory to activate long-term memories and learning. Therefore, in this situation, without the opportunity to break down the photorealistic information into comprehensible shapes, according to the cognitive mapping theory, the human mind could have difficulty building shapes in an allocentric viewpoint since it was still viewing the environment and the shapes in it from an egocentric one. As a result, there was an overload with the procedural functionality of the processes within the Oculus platform. Ultimately, when the entirety of the cognitive load became too excessive, the ability to complete the task was diminished (Arvind et al., 2014; Ladendorf et al., 2019; Pavone et al., 2016; Schneider, 2019; Woodman & Vecera, 2011). This is illustrated in the graphic of the HMIC model (see Figure 6).
Current STEM classrooms often implement innovative tools with spatial input as the cornerstone of the learning experience, such as CAD and VR, in an effort to engage and enhance the learner’s experience. With high levels of cognitive input, there is a greater potential that the experience itself is detrimental to achievement. Research has shown that even students using traditional CAD programming continue to struggle with dimensioning and geometric concepts (Branoff et al., 2012; Panorkou & Pratt, 2016). If the expectation of our students is to increase their visuospatial abilities, we must look to limit all aspects of cognitive load.

Further studies could investigate the effects of the learning tools themselves over a longer span of time. While many studies are limited due to financial or scheduling constraints, allowing the user to build memory and skill would provide a more accurate picture of the efficacy of the tool to support learning. When thinking about it logically, students have been using pencil, paper, calculators, and desktop computers their entire academic careers. These basic tools hold little excitement; however, IVR is still a novel technology for learners. Molina-Carmona et al. (2018)
found that when a group of students was given a long-term IVRLE (treatment group) as compared to their classmates (standard PC control group), they were able to achieve enhanced spatial abilities. What makes this study unique is the multiple weeks of IVRLE engagement presenting academic growth over their peers in a traditional learning environment. This presents a valuable framework for research moving forward, as it would make more sense that students could garner more success and spatial understanding inside the IVR environment if they had greater VR skills and were not “star struck” by the novelty of the VR environment itself.

Limitations

A significant challenge during this study was the COVID-19 outbreak of 2020. During data collection, the entire state of Illinois went into lockdown. I was fortunate enough to continue collecting data within the school building while implementing safety protocols. However, I was limited in my sample size, as many students/families were no longer interested in participating due to health issues or safety concerns, which may have altered the ethnic demographic of the study in relation to the school population. The school demographic is Caucasian (48.9%), Asian (39%), Hispanic (8.9%) and African American (3.9%). While the percent of Asian students who participated was in line, both the percent of Hispanic and African American students was higher, and Caucasian student participation was lower. Additionally, as school was no longer in session physically, I had to rely on parents bringing their children back to the school building instead of the students already being in school, allowing for the mass data collection events. I was also limited to one student per hour.
As stated previously, the sample size was N=30; there were two individuals (not included in N) who did take the pretest and were originally assigned a random number. However, they did not attend the data collection event nor participate in the posttest, therefore their initial pretest data were removed before any data analysis began. This did not impact any outcome or groupings. No outliers were removed.

There may have been a visual disadvantage through the physical limitation of the head-mounted device of the Oculus Rift. This may have acted as a hindrance when modeling the shape because the students using the Oculus had to lift the headset off if they wanted to look back to the shape (see Figure 4d and 4e), whereas the students in the control group always had the model directly in their line of sight (see Figure 4b).

An additional element that played a critical role in evaluating the outcome of this experiment is the actual tool itself. The MGMP-SVT is the only research-based test that is specifically designed as a pretest/posttest for spatial visualization in the middle-grades (Lappan, 1981). While others have been evaluated, adapted, and modified, the MGMP-SVT still stands alone. The MGMP-SVT is predicated on student exposure to advanced design/modeling components of isometric drawings, orthogonal drawings, and orthogonal mat plans. There were many questions within this test that proved to be challenging to the students as their design and modeling unit, which incorporates these concepts, was in the sixth grade (Cunningham et al., 2007; Swafford et al., 1998; Yue, 2007). Therefore, in future studies we must ensure the results of this test determine their visual and spatial relation skills, not if they understand the question. Incorporating concepts such as reference images, which offer the student an opportunity to
visualize and process the concept before attempting to complete each question, may eliminate guessing and confusion while supporting students with different learning abilities (Nurhanutawanti & Sutiarso, 2018).

Conclusion

Spatial learning is a critical component of STEM education (Yeh, 2010). Research suggests that with enhanced instructional design, students can improve their spatial abilities through greater access to immersive virtual reality learning tools and CAD programming (Levin & Tsybulsky, 2017). Integrating the IVRLE and CAD has the potential to catapult students’ visuospatial learning by immersing them in a visually rich learning environment.

The purpose of this experiment was to investigate the benefit of using the immersive virtual reality learning environment (IVRLE) when applied to three-dimensional modeling in middle-school STEM programming. The experiment did not yield expected results. It identified that there are scaffolding benefits in both CAD applications and the IVRLE when looking to impact students’ visual learning abilities. Additionally, this study was not able to identify the benefit of using the IVRLE as a proxy environment when constructing 3D objects. The data suggests using traditional methods such as CAD programming through a desktop PC will yield more successful results.

The connection between spatial reasoning and immersive environments is a natural relationship that promotes an abundance of academic skills supporting many levels of learning. Looking at this research experiment, linking 3D printing, allowing for a physical manifestation of the modeling element while tapping into the learner’s spatial reasoning skills between the
visual and physical world, builds on that natural progression. However, as technology in education tends to remain nascent in some realms, we must temper our excitement while we look to find grounded, aligned methodologies and identify the best applications for learning.

Future Research

This researcher suggests further studies are needed to expand upon the data from this experiment and existing research to build upon the uses of the IVRLE in the middle-school classroom:

- Expand student experiential learning with the IVRLE over the course of a full unit to determine if there will be less distraction due to the "excitement" of the environment.
  - Run the experiment with students completing a task in multiple treatments to compare changes in spatial reasoning:
    - TinkerCAD followed immediately by IVRLE
    - IVRLE followed immediately by TinkerCAD
    - Control IVRLE alone
- Compare Geometry MAP scores in relation to changes in spatial relations with either current experimental design or updated design.
- Continue this experiment with a larger sample size, outside of extreme conditions.
- Identify extraneous cognitive load factors using incrementally challenging shape building within the IVR environment and traditional CAD settings with paper/pencil modeling as a control.
REFERENCES


https://doi.org/10.1177/0963721413484756


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https://doi.org/10.3389/fpsyg.2018.00755


APPENDIX A

CONSENT FORMS
Your child is invited to participate in a research study titled “The Impact of an Immersive Virtual Reality Learning Environment and Three-Dimensional Modeling through STEM Middle School Programming”. This study is being conducted by Mrs. Danielle Schneider-Maldonado, a PhD student at Northern Illinois University. The purpose of this study is to identify if the use of virtual reality in the classroom can aid in the ability to perceive 3-dimensional modeling.

Your child’s participation in this study will last approximately 30 minutes. Before and after participating in the actual lesson where students are coming into the innovation lab and participating in 3-D modeling activity, Mrs. Schneider-Maldonado is requesting that your child complete an anonymous, multiple choice questionnaire to identify spatial/visualization abilities.

This questionnaire will be administered (at home-online) approximately one week before the 3-D modeling activity in the innovation lab and then, the identical set of questions will be administered immediately following the lab activity.

This study connects to our existing curricular lessons. Participating in the survey presents no discomforts for your child. All school safety guidelines will be followed to ensure the safety of all participants.

Students will be scheduled at one-hour intervals, so there will be no risk of students making contact with one and other. All Students will be required to wear masks, and all adults coming in contact with students will be wearing masks.

Parents will deliver students to the outside South doors of Innovation lab where they will be met by Mrs. Maldonado for both pick-up and drop-off.

Students will use their personal chrome book. All VR materials will be sanitized using school sanitizing protocols.

Information obtained during this study may be published in scientific journals or presented at scientific meetings, however, as no information which could identify your child has been collected, there is no way to identify them in anyway. This assures complete anonymity.

Participation in this study is voluntary. Your decision whether to allow your child to participate, as well as his or her assent to participate will not negatively affect you or your child.

Any questions about the study should be addressed to Mrs. Danielle Schneider-Maldonado at (847) 965-3740 ext. 304.

If you wish further information regarding your rights or your child's rights as a research subject, you may contact the Office of Research Compliance at Northern Illinois University at (815) 753-8588.

Should you accept, you will receive a follow up email for a sign-up time to participate.

I give permission to have my child participate in the survey relating to this research study.

I do NOT give permission to have my child participate in the survey relating to this research study.

____________________________
Signature of Parent/Guardian

____________________________
(child’s first & last name-PLEASE PRINT)

Date

Board of Education: Mr. Richard Toth, President

Ms. Nada Ardeleanu  Dr. Guy Hollingsworth  Ms. Samina Hussain  Dr. Ashwini Kumar  Mr. Jermaine Lindsay  Mr. Joel Mehr

Superintendent: Dr. Beth Sagett-Flores
Oral Assent form for MINORS

1. The purpose of this experiment is to gather your opinions and feelings about using VR with your class lesson. You will be asked questions about motivation and engagement.

2. The Survey before the lesson should take anywhere from 5-10 minutes and the post survey will happen right after the lesson and will take 5-10 minutes. The surveys will be completed on Google forms and will be completely anonymous.

3. Participation is voluntary, and refusal to participate or discontinuation of participation is possible at any time, without penalty or loss of benefits. (It will not affect your grade.)
APPENDIX B

3D-MODEL RUBRIC
## Rubric for 3D Printed Model

<table>
<thead>
<tr>
<th>Item</th>
<th>Correct</th>
<th>Correct with few errors</th>
<th>Correct with multiple than errors</th>
<th>Absent or significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>The item is accurate.</td>
<td>The item as a whole is significantly accurate, but 1-2 details are not correct</td>
<td>The item as a whole for the most part is accurate, but 3-4 details are not correct</td>
<td>The item as a whole is mostly inaccurate; many details need refinement</td>
<td></td>
</tr>
<tr>
<td>3D model faces measure 1cm x 1cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D model has the same number of model faces as the sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D model has the identical shape as the sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D model has 90 angles, identical to the sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Points</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from: Project Lead the Way® 2017

Total points: _________