INTEGRATION OF LEARNING PRINCIPLES INTO AN EDUCATIONAL VIRTUAL REALITY SYSTEM

by

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This thesis is dedicated to my family,

who supported me through all my issues and lifted me up to do my best.
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by

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Educational applications using virtual reality have been regarded as mostly successful. These applications have been demonstrated to engage students, who will learn the same amount, if not more than those using traditional learning methods. However, these applications are rarely evaluated empirically, apart from subjective questionnaires.

Traditional educational means often use certain principles of learning that have evolved over the years. Incorporating these principles into educational methods has been demonstrated to make these methods more effective for learning. However, these principles have not been thoroughly investigated for applications created on other platforms, namely, virtual reality (VR). In this research, we create an educational VR-based application that leverages and incorporates prior design principles for learning. We have also designed numerous experiments to determine the VR-based application’s efficacy, including comparisons to traditional and online learning mediums.
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CHAPTER 1

INTRODUCTION

1.1 Background

In the past few decades, various applications have been created on different platforms. People have tried to use new media to inculcate an interest in education, as opposed to the traditional pen and paper. Some examples include websites where a person can learn languages one phrase at a time, or learning high school chemistry through online flashcards. Even though education using alternate media originally had some backlash, successful research and applications have shown that such education is just as effective as, if not better than, traditional methods of teaching.

As we practice and perfect existing technology-based applications and try to solve unique issues that come up while trying to incorporate technology into the classroom, new technology is still emerging. We went from slides being used in class, to having completely online classes with slides provided. Similarly, we have contributed to discussions on a forum-based discussion board, and now have these applications on our phones where we can save videos and watch them at any time of the day. As new technology continues to emerge, virtual reality (VR) has started making its mark in the educational domain as well.

VR is, essentially, a virtual 3D environment that can be viewed in first-person point of view by the user. Due to the essence of virtual reality, we can create entire worlds that surpass real life. VR has recently gained popularity due to immersive games. However, there are many other possibilities and opportunities for VR to be used for. Research has shown that VR can be used to transfer learning to real life. Some of this research is described in the later chapters.
1.2 Education in Virtual Reality

In traditional teaching, certain methodologies have been proposed and used through the years with regards to the content and how it is taught. One math-based example would be going through a problem step-by-step with the students, then letting them solve one on their own with similar complexity, then increasing the complexity. Another example would be task decomposition, where the user would go through explicitly defined steps. This would decompose the whole process into smaller sub-tasks, which would provide better results compared to a process with no sub-tasks, where the student might miss a few steps. However, considering that VR is still an evolving field, no official design principles have been identified for VR-based education.

With respect to classroom education, VR headsets are usually recommended not to be used by children under the age of 13, thus eliminating students who are 12 or younger. However, research has been undertaken for high school and college curricula. Research has been conducted on educational applications that give additional help to the content taught using traditional methods, as well as on applications that can be stand-alone methods for learning. Chapter 2 reviews studies comparing VR-based and traditional methods, as well as studies that attempt to evaluate the efficacy of VR applications.

A common point in all of these studies, however, is that they have not empirically evaluated the VR applications. The studies undertaken usually have a presence-based questionnaire, or a more informal questionnaire, where they ask the participants how they felt about the application as well as the traditional approach. We present a protocol for measuring the efficacy of educational applications in the VR spectrum.
1.3 Purpose for Thesis

For this research, I enhanced an existing VR-based educational application by employing traditional design principles for learning. The original application focused on the spatial understanding of 3D shapes [14], and had a 3D version of several geometric shapes, designed such that a user could manipulate each dimension of the figure and see the changes to the shape of the figure. A target volume was provided for the user to reach, which they could do by manipulating the dimensions of the figure accordingly. However, initial testing showed some users trying to win faster by manipulating just one dimension all the way. Changes were then made to emphasize the number of moves as well by penalizing the user if he or she took too few or too many moves to reach the target volume.

The research presented in this thesis focused on modifying this application to introduce design principles from the learning domain, and retain the concept of spatial understanding from the original VR application. Two of the new features included were scaffolding and the introduction of constant factors, which will be explained in the next chapters. Prior research has shown the successful use of these principles in traditional education, and thus were chosen for this application to test their usability on a different medium, namely, VR.

With this modified application, studies can be conducted to determine the efficacy of these principles, which could then be incorporated in other educational applications appropriately. This application would parallel classroom education. The studies can be conducted with the principles built in as a part of the learning process, to determine the effects of the principles on the user’s ability to retain information.
The efficacy of this application can be determined by testing the users on relevant content before and after they use the application. At the same time, this application can be tested against traditional textbook methods, as well as non-interactive videos, to determine the usability of this application. We hypothesize that the application would work well against both methods, and even supersede them. The experimental designs for these evaluations are presented in Chapter 4.

1.4 Broader Impact

The aforementioned studies could be applied to any field of education, however, for the sake of simplicity, our application deals with volumetric formulae of 3D objects such as a cylinder or a pyramid. This domain was chosen due to the spatial understanding obtained by observing and manipulating a 3D shape, whereas traditional textbooks depict 3D shapes using 2D figures. It was also chosen as most students have to learn geometric formulae in high school. This application could be used for making geometry less intense for high school students, who sometimes do not like geometry due to its spatial complexity.

With all this in mind, the design principles applied to our VR application, if successful in the proposed studies, can easily be applied to other educational VR applications. Task decomposition can be used in various simulators, where a whole process has been decomposed down into tasks with certain priorities given to each task. Scaffolding, as a concept, can be used in tasks where all steps are originally provided, but then are partially taken away so that the user would have to actively remember the points made. Thus, these design principles can easily be abstracted to use in educational VR applications in general.

1.5 Thesis Outline

This thesis has been organized into five chapters with appendices:
• Chapter 2 surveys relevant work in the field of education in traditional media, e-learning and VR-based systems, and existing VR-based applications in the field of mathematics. It also discusses prior research done on the selected design principles to show their competence in traditional education.

• Chapter 3 describes our application, Geometry Explorer, in detail with provided examples and variations to be used during the proposed experiments.

• Chapter 4 contains an outline of the experimental designs for future studies, their research questions, and how each design will answer those questions.

• Chapter 5 discusses future work based on the experiments to be conducted, and a short summary of this thesis.

• Appendix A: Informed Consent Form

• Appendix B: Pre-Learning Knowledge Test (to exclude people with prior knowledge)

• Appendix C: Background Survey

• Appendix D: VR Experience

• Appendix E: Interference Task A

• Appendix F: Interference Task B

• Appendix G: Post-Learning Knowledge Test (Cylinder)

• Appendix H: Post-Learning Knowledge Test (Pyramid)

• Appendix I: System Usability Scale (SUS) Questionnaire

• Appendix J: Exit Survey
CHAPTER 2
RELATED WORKS

This section discusses certain design principles in educational systems, and how they worked for specific domains. This is not an exhaustive list, but includes design principles incorporated into the application. This section also talks about prior research in education using VR, including geometry education, and its advantages over traditional methods.

2.1 Design Principles

2.1.1 Scaffolding

According to Wood et al., “comprehension of the solution must precede production” [9]. In their words, “the student must be able to recognize the solution to a class of problems before being able to solve it without assistance.” The concept of scaffolding included dynamic assessment, graded support, and fading of all support once the student demonstrated that they were competent in said domain. In this paper, they also constructed a list of steps in the process of scaffolding. This list has been referenced in several other studies implementing the concept of scaffolding.

In 1992, Merrill et al. stated that students face difficulty when parts of the process to find a solution are left out in the instruction [7], and that educational systems should make information explicitly visible to them. They tested this out with GIL (Graphical Instruction in LISP), an interactive environment. The study showed the students mastering LISP programming through GIL in an easier and faster way compared to a textbook, a text editor and an interactive LISP interpreter [8].
From this research, we can observe that scaffolding techniques have been applied to different domains and has shown improved learning. Due to this observation, our application includes instructional scaffolding with respect to the formula, which will be described in the next chapter.

2.2 Education Applications using Virtual Reality

In 2013, Sacks et al. created a virtual construction site using an immersive virtual environment, and compared it with conventional training methods. One of their hypotheses was that safety training would be more effective in the VR environment [1], with respect to learning and recall. They tested their virtual environment by conducting a safety knowledge test before and after the study, as well as a month after the study.

With respect to the hypothesis, the recall was better from the VR environment in comparison to the traditional methods right after the test, but there was no significant difference when the participants were called back a month from the test. The participants had to fill out a questionnaire as well, which had significant positive results for the VR simulation. Examples include questions like ‘To what extent was the learning a pleasure?’ ($\Delta = 0.5$, $p = 0.01$) and ‘Did you feel like you were concentrating in class’ ($\Delta = 0.8$, $p = 0.0002$). Results from the questionnaire also showed that the participants were engaged in the VR simulation, but needed a break in the traditional method, showing that the virtual environment was effective in sustaining a participant’s attention.

In 2010, McMahan et al. created a virtual simulation of mining worker training, to animate the effects of overlooked defects. They created a desktop simulation using VRML, as well as a virtual environment that was implemented in their CAVE. They conducted a study comparing the
desktop simulation to a desktop presentation [16]. From the study results, the knowledge of the users of desktop VR increased by 32.14%, while the knowledge of the users of the presentation increased by 23.04%. With respect to new knowledge learnt, it was the same across the board, but the desktop VR was chosen as an engaging training tool.

In 2014, Merchant et al. conducted a study to check the learning outcome from a desktop-based virtual environment [10]. Out of the 13 studies conducted, they answered their research question about the quality of VR-based instruction by stating that having a combination of learning outperformed general traditional methods or 2-D images. However, there was no significant difference in the different methods. In their conclusion, they stated that having an unstructured open space in a VR environment would afford the student more flexibility, causing a distraction, and thus time should be an important feature while designing instruction-based applications that requires skill acquisition.

In 2006, Lok et al. conducted a study that compared medical communication education in a traditional environment versus a virtual environment. The latter application contained audio and video input from microphones and cameras. Perspective warping was included to maintain illusion of the virtual room as an extension of the real room. The observations showed that the virtual interaction was preferable as a precursor for interaction with real patients. In their conclusion, they mention that despite not having significantly better results, VR could be used as a suitable alternative to conventional methods in the learning domain [11].

We can observe that so far VR applications have had success equivalent to traditional methods, if not outperforming them with respect to certain scenarios. As Lok et al. mentioned in their paper, “virtual reality could be an alternative in the learning scenario.”
2.2.1. Geometry Education using Virtual Reality

2.2.1.1 Construct3D

Kaufmann et al. can be credited for the majority of research on geometry education with VR over the span of many years. Kaufmann started on a similar note as the original application [14], comparing points needed to design a well-made AR/VR application. [2]

Around 2003, Kaufmann et al. started designing Construct3D, an application that would work using augmented reality (AR). Their research question was to verify whether working in 3D space would allow better and faster comprehension of spatial problems than traditional methods [3]. In 2006, students attended training sessions and filled out an ISONORM questionnaire, which resulted in the highest points in favor of the AR application for suitability for learning and suitability for task. However, an observation made was that an hour of training was too long to work with an HMD. Dünser et al., including Kaufmann, undertook a comparison study of their application against a computer aided design program, wherein they came to the conclusion that their application did not have major advantages compared to the computer program, since both methods had their advantages and disadvantages [4]. One of their conclusions stated that the application could be used to improve learning along with the traditional method.

In 2009, Kaufmann’s paper concentrated on content creation, to complete the analysis of the application. There was no evaluation stated in this paper. Kaufmann observed that the obstructions they faced included expensive hardware and the fact that the content they created would apply only to a few users. However, he claimed in his conclusion that VR could present mathematics in an innovative way to students, by adapting content to become more tangible, visible and understandable [5].


2.2.1.2 CyberMath

This application was created by Taxén et al. with an avatar-based environment to run on desktop systems, and was centered around topics in the math domain as well. Their application had an exhibition hall-based environment, with different areas comprising different presentations. These areas discussed transformations on lines, planes, spheres, cylindrical optics and so on. For this application, two usability tests were undertaken, an interview and a questionnaire. Both tests showed that the environment was engaging and the guided tour was successful. [6]

The chapter has reviewed prior research on education and educational VR applications, however, most of the papers only had overall observations and did not conduct empirical studies. We have developed a detailed experimental design for evaluating the efficacy of our VR-based geometry education application. Prior research on scaffolding has demonstrated that the design guideline for learning is usually effective. Thus, I plan on applying design principles for learning, like scaffolding, by incorporating them into the original Geometry Explorer application and evaluating their usefulness, which has not been determined in prior research.
CHAPTER 3
GEOMETRY EXPLORER - APPLICATION

‘Geometry Explorer’ is the application we have modified to determine how design principles for learning methods can be applied to VR-based educational systems. In Chapter 2, we spoke a bit about scaffolding, and highlighted important factors, and they will appear again in this chapter, but with more detail and relevance.

3.1 Overview

Geometry Explorer is supposed to help the user learn the volume of geometric shapes, specifically, 3D shapes, as a stand-alone application that parallels traditional teaching methods. The original application was meant to facilitate the understanding of spatial skills, so that the users would understand and retain memory of the formulae. Students tend to learn the volume formulae of pyramids and cylinders in high school, which is why those specific shapes were chosen.

Since this was created with high school education in mind, the affordability of the hardware was to be considered. Similarly, the application had to be easy to use, which is generally recommended for all interfaces. Prior works have demonstrated that immersive VR facilitates better spatial understanding, which is why immersive VR was a goal for this application. A hypothesis for the original application was that the immersion would improve the understanding of the formulae, without resorting to rote learning.

3.1.1 Materials

Keeping affordability in mind, the Samsung Gear VR was chosen for the visual display to run the application on. The Gear VR (see Figure 3.1) provides a 96° field of view and a refresh rate of 60 Hz. It has a goggle-like form factor with Velcro straps and weighs about 312 grams.
without the front cover. It also contains a scroll wheel to help with focal adjustments. The application runs on the Samsung Galaxy S6, which can be affixed to the Gear VR. The Samsung S6 has a 1280x1440 resolution per eye.

Figure 3.1. The head mounted device (Samsung Gear VR)

This application has three major features: the 3D object, the cursor and the matrix. Each of these will be explained in detail.
3.1.2 3D Object

In the original application, the 3D shapes used were a prism, a cone, a cylinder, a pyramid, and a sphere. The figures were designed specifically to show how changing the volume would affect its shape. Each dimension had context-sensitive widgets, which could be adjusted with head orientation. Users could select the widget by tapping the touchpad (see Fig 3.1), and then rotate their head accordingly to increase or decrease the values. They would have to tap again to stop the manipulation.

Based on the formula of the shape, some of the dimensions were given mirroring effects using code. For example, the formula of a cylinder is $\pi r^2 h$, so manipulating the widget for one radius dimension would simultaneously manipulate the other one. Above each widget, the initial of the dimension and the value it was manipulated to is given (see Figure 3.2). This is given to emphasize the association between the dimensions and values on the shape’s widgets and the values above the cursor, which will be discussed further in this chapter. The default value on all the dimension is 1, and go up to a value of 12.

![Figure 3.2. A 3D object in our application – Cylinder](image)
3.1.3 Cursor

The cursor (see Figure 3.3(a)) has the vital information for driving each volume problem:

1) The top right number is the current volume based on the shape and its dimensions.
2) The bottom right number is the target volume that the user must obtain.
3) The top left number is the number of manipulations made so far by the user, default at 0.
4) The bottom left number is the target number of manipulations by the user. The user must use exactly these many manipulations to reach the target volume.

With this cursor, the user can identify exactly how many moves they have left and how far they are from the volume needed.

Above the cursor, we have given three representations of the formula. The first one is the formula of the current shape. Below that, we have expanded the formula to show a standard format of a constant factor with three dimensions. The third step includes values correlating to the shape.

As we manipulate the arrows (see Figure 3.3(b)), the values in this representation change as well. This is used to show the correlation between the formula above the cursor and the dimensions and values on the shape.

Figure 3.3. (a) The cursor before any moves are taken (b) The cursor after one move is made
3.1.4 Matrix

Since this application is completely in the virtual world, and the users would not be able to calculate the product of three numbers in their head [15], especially as the products increase. So, we decided to give the user a multiplication matrix. This matrix is a 2D square of X and Y values. Swiping forward and backward would change the Z value. Using this, the user is able to quickly calculate the product of three different values, and thus, obtain the target volume.

Figure 3.4. Pyramid scene, with no expanded values, showing the matrix to the right

In this application, the user can highlight a number to show its breakdown of X, Y, and Z values. For this, the user would have to look at the desired number, which would then change colors. On tapping the touchpad (or mouse equivalent), the number would be highlighted, and its X, Y, and Z values would appear at the bottom of the matrix. These could then be used to manipulate the dimensions of the shape.

This was added to improve the usability of the matrix. Apart from this, we incorporated the concept of certain educational principles to see if this would improve learning for the user.
3.1.5 Motivation

Prior research has proven that gamifying educational applications increases the appeal of learning to users [19]. Keeping this in mind, the original application’s objective was to reach the target volume as fast as possible, which in turn would make the user receive higher scores.

However, with the previous notion of lesser time equating to better scores, the users took the easiest calculation. For example, if they were given a volume of 12 for a rectangular prism, they modified one dimension to be equal to 12, and leaving the other two being equal to 1, as opposed to marking down L = 2, W = 2 and H = 3. This did not help in the comprehension of each factor contributing to the formula. Due to this, the concept of target manipulations was incorporated by placing it on the cursor, where the maximum number of manipulations was relative to the dimensions of the shape. Performing too few or too many moves decreased the score of the user accordingly.

In the updated application, we have not considered time as a factor for scoring the user. Instead, we explicitly state if they made too few, too many, or exactly the expected number of manipulations. Achieving the target number of manipulations triggers positive reinforcement.

3.2 Additions

Since the original development of the Geometry Explorer application, we have introduced new concepts to this application in hope of improving learning for the user.

3.2.1 Explicit Task Decomposition

An informal study showed a user searching through all values of the matrix for the given volume, and the user did not focus on the formula at all. Due to this, we have included explicit selection of constant factors in the existing version of the matrix. These constant factors are the
factors associated with different formulae, namely, $4\pi/3$ for the sphere, $1/3$ for the pyramid and so on. This is incorporated into the task of achieving the target volume.

At the start of each scene, the positions of these constants are randomized, with the default selection being ‘1’. We randomized the positions to avoid users memorizing the position of the necessary constant rather than the constant value itself. On selecting a certain constant using the touchpad, the values in the matrix get multiplied by a factor of that constant. We have given multiple constants apart from the pyramid and cylinder, so the user would have to consciously remember the constant associated with the formula of that shape.

For example, $4 \times 4 \times 3$ gives us 48, however for a cylinder, this would be multiplied by $\pi$, giving us an actual volume of $48\pi$, or 150.7, as shown in Figures 3.5 (a) and (b) below.
In the actual application, the user must select the constant that matches the formula of the shape in the scene, as they would not be able reach the accurate target volume otherwise. This also enforces them to remember the constant associated with the formula, which may not happen otherwise. The amount of retention, specifically for the constant factors, is something we want to evaluate using one of our planned studies.

3.2.2 Scaffolding

In our related works, we mentioned papers stating that learning improves if all the information is given first and then some of it is taken away to make the student memorize the process. Thus, we decided to incorporate this into our application.

Scaffolding was incorporated into our application using gamification. If the users successfully obtain the target volume with the target number of manipulations, they are then taken
to the next scene, which has less help compared to the previous scene. However, if the number of manipulations is not exact, they are taken to the previous level. This is because we assume that the person was not able to perform at this stage successfully, and thus repeating a scene with more learning aids would help them with this stage when they do it again.

The scaffolding in our application has four levels:

1. This level is the tutorial scene, which gives them an explanation and example of what they would be doing.

2. Once the users have completed the tutorial scene, they are provided a similar scene with every formula representation but no explicit instruction, as can be seen in Figure 3.6 (a). Since they went through a step-by-step of the same scene with different values, the assumption is that they should be able to use the same logic to reach the target volume.

3. The expanded formula and the substitution of values are removed at this level, as can be observed in Figure 3.6 (b). This would force the users to mentally expand the formula, rather than depend on the application to do it for them. They would have to look at the values attached to the arrows on each dimension to see the values they have manipulated thus far.

4. This is the last scaffolding level. Here, the formula is removed as well, so all that is left is the cursor with the volume details, as can be seen in Figure 3.6 (c). The idea is that the users should have memorized the formula and would be able to manipulate the shape without having to see the formula.
Figure 3.6. (a) Cursor with the formula, the expanded formula, and the substituted values
(b) Cursor with only the formula, no expanded formula, no substituted values
(c) Cursor with no formula, no expanded formula, no substituted values

The tutorial scene first introduces the main components of the scene: the shape, the cursor, and the matrix. It explains the values on the cursor constantly visible to the user, namely, the target volume, the target number of manipulations, the current volume based on manipulating the shape, and the number of such manipulations done so far.

Based on the shape being used, it introduces the constant factor of that shape and how selecting it changes the values on the matrix. Once the user has learned how to manipulate the matrix, the tutorial helps the user solve an example problem. This makes the user initially find the target volume on the matrix, and then change the shape by manipulating the dimensions. It also emphasizes the usage of the correct number of manipulations, stating that completing in less or more than the target moves would be penalized. The tutorial scene guides the users through manipulating each dimensional widget, and once done, redirects them to a rank scene (see Figure 3.7), which congratulates them on the right number of moves and sends them to the next level.

If the users achieve the target volume in the target number of manipulations, they proceed ahead to the next scene in the scaffolding structure. However, if they get it in too few or more
moves, they are sent back to the previous scene in the scaffolding structure. This is so that they can use the previous scene as practice to succeed when going through the current scene again later.

There might be a possibility that the user could forget the formula, or not remember what to do next. To help the user in this situation, an internal procedure is triggered if the user has not made a change for 60 seconds, and asks if the user wants to return to the previous scene (see Figure 3.8). Thus, on saying yes, the main formula pops up in the last level, the expanded values in the third level and so on. In the second level, the users are given the option to repeat to the tutorial. This help feature is not provided in the tutorial scene, since the scene is based on step-by-step instruction.

![Figure 3.7. Rank scene after the user has successfully completed a scene](image)

![Figure 3.8. Prompt from the application to bring back the formula](image)
CHAPTER 4
PROPOSED EXPERIMENTAL DESIGNS

4.1 Overview

Due to changes in the design of the application, there was no time to evaluate the application created in the duration of this thesis. However, this chapter outlines and explains a robust experimental design that will be used in the near future to answer several research questions, also detailed in this chapter.

The application developed for this experiment design has been described in the previous chapter. From the original application, the changes made for this thesis include the incorporation of scaffolding and the explicit task decomposition. The changes also include the reimplementation of the matrix and the help features for each scene.

4.2 Experimental Design

This experimental design will be used to answer multiple research questions that have arisen. By maintaining a standard design, we can determine whether the design principles provide better results of retention, which could be used for future VR-based educational applications.

We plan to use a within-subject design to avoid large variations due to personal learning differences and aptitudes for 3D geometry knowledge. The ordering of the conditions would be counterbalanced within each proposed study.

4.2.1 Inclusion and Exclusion Criteria

We plan to recruit 30 participants through university mailing lists for each study. The participants would need to be above 18 years of age, since most published VR studies have recruited participants in that age range. We would also have the participants take a pre-learning
knowledge test (see Appendix B), which would test them on the formulae involved in the study. If they obtain a score higher than 10, where the total is 20 points, they would not be allowed to participate in the study, as it might skew the results of the research.

4.2.2 Experiment Tasks

In each study, there would be two tasks: learning how to calculate the volume of a cylinder and how to calculate the volume of a pyramid. We chose these shapes specifically because they have different constant factors (π and ⅓ specifically). They also are of moderate difficulty, compared to a shape like the sphere, in which only one dimension is manipulated.

The conditions for learning the formulae would be different for each shape. For example, one participant might learn the cylinder formula using the Geometry Explorer application with scaffolding but no task decomposition, and the pyramid formula using the textbook materials.

For learning the geometry formulae, we created a gamified application, which required the participants to go through a tutorial of how to manipulate a 3D shape in the virtual environment (see Figure 4.1). They would then be provided a random volume based on the shape that is being considered. They would look up this volume in the matrix, and then move the dimensional widgets on the shape to update the volume. The goal would be to reach the target volume, ideally in the target number of manipulations.

Requiring a target number of moves prevents participants from going to the next round if they just randomly manipulated the shape multiple times. Similarly, they would not go to the next round if they used fewer moves compared to the target number. For example, getting a volume of 12π for a cylinder in 3 moves would mean they would have to manipulate 2, 2, and 3. However, manipulating the dimensions to just 4 and 3 or 6 and 2 would cause them to lose the level.
The current application has two new introductions. One is the scaffolding, with each shape going through four levels. If the participant completed one level, they would then go to the next level on the scaffolding structure. If the participant completed a level successfully, a part of the formula would be removed to make the participant consciously remember the formula. The other introduction is the inclusion of constants (see Figure 4.2), that is, the volume to be calculated includes the multiplication of the constant factors of the formula, to affix said factor in the participant’s memory. The participant would have to select the right constant on the top of the matrix and search for the value of the volume accordingly.
4.2.3 Procedure

Once recruited, the participants would sign an informed consent form (see Appendix A). They would then go through a pre-learning knowledge test (see Appendix B). The users would be provided with a calculator and instructed to give the answer with one’s place accuracy, since the focus of this experiment would be on the memorization of the formula with understanding, not the mental calculation of multiple numbers. If they received a score of 10 or higher, where the total was 20 points, they would not be allowed to participate in the study. Otherwise, they would fill out a background survey (see Appendix C). The experimenter would help the participant wear the HMD and sit them down. They would initially be introduced to a non-educational application, called “theBluVR” (see Appendix D). This application is used to eliminate the “wow” factor that might be introduced with using a VR-based device. This application is chosen as it is engaging, it has 360-degree viewing and it has a definitive end, after which we can switch to the Geometry Explorer application.
The user would start out with the first condition. This task would take place for ten minutes, and would be timed. Once the time was up, they would then have to undertake an interference task, which would induce cognitive load to interfere with the formula recall (see Appendix E). In 2016, Steed et al. had conducted memory research, in which they had included a spatial rotation test between the original observation and the recall, to eliminate the effects of short-term memory, which worked for their application [20]. We have used a similar version of their rotation test to eliminate the effects of short-term memory. The participant would then go on to fill a post-learning knowledge test (see Appendices G and H), which would test the knowledge they gained through the conditions. They would be provided with a calculator at this point as well. After the test, they would fill out a System Usability Scale (SUS) questionnaire for evaluating the first condition (see Appendix I) [12].

After this, the participant would start out with the second condition. This task would also take place for ten minutes, timed. When the time ends, they would be given an interference task similar to the previous one (see Appendix F). They would then fill a post-learning knowledge test (see Appendices G and H), and fill out the System Usability Scale (SUS) Questionnaire for the second question (see Appendix I).

Finally, they would be provided with an exit survey (see Appendix J), which would ask for their detailed opinions on the conditions they experienced, and then thanked for participating in the study.

4.2.4 Materials

As introduced in the previous chapter, we will continue to use the Samsung Gear VR for our experiments.
The VR applications were developed using the Unity Game engine. At the end of every run of the application, the details which we were keeping track of will be written to an Excel spreadsheet, which will later be used for analysis. A dark-colored galaxy-themed environment was chosen as the background for this application. It was chosen as it would be inviting to the participants, but not distract them from the learning task.

4.2.5 Analysis

We will use a repeated measures ANOVA to analyze the effects of the two learning conditions for each study based on the post-learning knowledge test.

In the Geometry Explorer application, certain data would be exported to an Excel spreadsheet for each scene that the participant would complete. This data includes the target volume, the target number of moves, the actual number of moves, the time taken to complete the scene, and other relevant data. Similarly, data would be stored when the participant would practice problems through traditional methods or use the practice module on the desktop computer.

Using this data, we can analyze the average time taken while using the application versus the desktop method and so on.

4.3 Proposed Evaluation of Explicit Task Decomposition

In this study, the two conditions would be: explicit task decomposition (Geometry Explorer with constant factor selection, but no scaffolding) (see Figures 4.3 (a) and 4.3 (b)) and no decomposition (Geometry Explorer with no constant factor selection and no scaffolding) (see Figure 4.3 (c)).
Figure 4.3. (a) Geometry Explorer with Explicit Task Decomposition and Constant Factor 1

Figure 4.3. (b) Geometry Explorer with Explicit Task Decomposition and Constant Factor $\pi$
From our informal observations, we feel that the explicit decomposition would have the greatest impact on retention in this situation. Thus, we plan to implement this study first out of all the studies, which leads to our first research question:

**R1.** Will task decomposition (i.e., requiring the user to select the formula constant) afford better retention of volumetric formulas than not using task decomposition (i.e., automatically calculating the formula constant into the matrix values)?

- We hypothesize that it would increase with the explicit task decomposition. Without the decomposition, the participant would only need to search for the matching dimensional values. However, with the decomposition, the emphasis has been applied not only on the dimensional values, but also the constant factors which is an important part of the formula. According to an article from 2000 that discussed model-based education [18], Janice
Gobert discusses the point of students realizing a causal relationship for learning, as opposed to a direct A causes B relation. Applying that to this context would imply that the user selecting the constant factor as well as the dimensional value would help them retain more information than if the constant factor was automatically multiplied for them.

4.4 Proposed Evaluation of Scaffolding

In this study, the two conditions would be the presence of scaffolding (see Figure 4.4) and the absence of scaffolding. The applications used in this study may include the explicit decomposition, based on the results from the study outlined in Section 4.3.

We feel that the scaffolding would also ensure better learning, leading to our second research question:

R2. Will scaffolding (i.e., starting with cognitive aids and gradually removing them) afford better retention of volumetric formulas than not using scaffolding (i.e., starting with and keeping cognitive aids)?

- We hypothesize that the participants would be able to complete the tasks faster given the scaffolding-type learning, since prior studies show that students should comprehend the solution before producing it again, and that originally providing support and then fading it once the student’s competence was determined, would be a successful way to improve retention of the learning task. [9]
Look at the Z value, which is currently 1. Swipe forward on the touchscreen to increase the value of Z.
4.5 Proposed Comparison to Traditional Textbook Materials

In this study, the two conditions would be the best version of the Geometry Explorer application from the previous studies (see Figure 4.5 (a)) and pertinent chapters from a mathematics textbook, specifically the 12th chapter from the Glencoe Geometry textbook (see Figure 5.4 (b)).

This leads to our third research question:

**R3.** Will the improved Geometry Explorer VR-based application afford better retention of volumetric formulas than a traditional textbook method?

- Prior studies comparing traditional media vs virtual reality methods have been conducted, of which one was conducted by Seymour et al. in 2002. This study showed that the error rate for the traditional learning was higher compared to the error rate when the traditional
learning was combined with the VR experience. [13] Thus, we hypothesize that the participant would be able to retain the same amount of information using the VR application as they would while using the textbook, if not more information.

Figure 4.5. (a) Geometry Explorer Application

Figure 4.5. (b) Screenshot of Chapter 12 from the Glencoe Geometry Textbook
4.6 Proposed Comparison to Multimedia Learning Materials

In this study, the two conditions would be the best version of the Geometry Explorer application from the initial studies (see Figure 4.6 (a)) and online non-interactive videos (see Figure 4.6 (b)). For the multimedia materials, they would learn how to calculate the formulae of the cylinder or the pyramid through the VividMaths YouTube channel, and then use the interactive practice modules on IXL Learning on a desktop computer.

This study leads to our fourth research question:

**R4.** Will the improved Geometry Explorer VR-based application afford better retention of volumetric formulas than online video-based educational tools?

- We hypothesize that the participant would be able to retain information on a higher level using our interface compared to the video-based interface. The interaction level that exists in our application is much higher compared to the non-interactive video content to learn how to use the formulae. Research has been conducted on the necessity of interaction between the students and the content [17], and it has been suggested to improve cognitive learning, although empirical studies have not been conducted on the same.
4.7 Summary of Proposed Experiments

Thus, summarizing the previous sections:
• The first study evaluates the explicit task decomposition in the Geometry Explorer application by marking it against no decomposition. We hypothesize that the results will favor the task decomposition.

• The second study evaluates the effect of scaffolding on retention against the effect of no scaffolding on retention using the Geometry Explorer application. The application may include task decomposition based on the results of the previous study. We hypothesize that the results will favor scaffolding over no scaffolding.

• The third study compares the Geometry Explorer application against traditional textbook materials to learn the volume of shapes. We hypothesize that the results will favor the VR-based application.

• The fourth study compares the Geometry Explorer application against multimedia materials, specifically non-interactive videos. We hypothesize that the results will favor the VR-based application.
CHAPTER 5

CONCLUSION

5.1 Motivation

Prior research has shown that VR-based educational systems are comparable to traditional learning, and can be a stand-alone applications to learn, but can also be used with traditional materials. However, the evaluation of these systems have been mostly informal, and few empirical studies have been conducted to determine the efficacy of these systems. This was a potential line of research that we wanted to explore.

Traditional methods of learning use certain design principles to better the learning of the user. These principles have been tried and tested and works with respect to that medium. However, VR-based educational systems are a more modern concept and do not have any widely adopted design principles associated with them. This domain is something we wanted to conduct more research in.

5.2 Related Works

We surveyed related works in the education domain to determine traditional learning principles, and reviewed certain educational applications in the VR spectrum. We found that scaffolding, a concept where “a student must recognize the solution before solving it without assistance”, was considered as a good learning tool with respect to learning [9]. Several applications have been developed in the VR spectrum for construction site training [1], mining worker training [16], medical communication [11] and so on.

For geometry-based applications, Construct3D is a VR-based application that has certain advantages [5], and CyberMath, a desktop-based virtual environment [6], has been successful as
well. Our application is along the lines as these applications, however, our plan is to conduct an official analysis of the data to determine the efficacy of virtual reality educational systems, which has not been conducted before. At the same time, we have incorporated traditional design principles, like scaffolding, into the application to observe their effects in the VR spectrum.

5.3 Modifications

This research has modified the original Geometry Explorer application by incorporating traditional design guidelines for learning methods and improving general usability of the application. The original application had a free-range option to practice different shapes. Since scaffolding was incorporated and the application reintroduced the scene without certain conceptual aids at each level, we restricted each version of the application to just one shape. This also led to the removal of the prism as an option, since it had no constant factor multiplied and was too easy for participants. The restriction to one shape also led to the creation of a tutorial scene for each shape, accompanied by audio so that the user could go through the tutorial steps while listening to the instructions as well as being able to read them on the screen.

Since the idea of this thesis was to incorporate the design principles to focus on the memorization of the formula, changes were made by introducing the selection of constant factors as a part of the matrix to represent explicit task decomposition. Similarly, a scaffolding structure was created by having a tutorial scene, a scene with the formula and the expanded values, a scene with just the formula, and eventually a scene with no formula. To accompany the removal of conceptual aids, the scenes also included help, which would be triggered if the user made no changes for 60 seconds.
We were not able to conduct the study in the duration of this thesis, but have formulated detailed experiment designs which will be implemented in the near future.

5.4 Experiment Design

We wanted to determine the efficacy of the whole application, as well as the efficacy of the specific principles applied to the application. For this purpose, multiple versions of the same application with slight changes were made, which would apply to each design.

Participants would take a pre-learning knowledge test, which would determine their participation in the research. They would go through “theBluVR”, a VR application, which has 360 degrees viewing, is immersive and has a definitive end (see Appendix D). This would eliminate any “wow” factor which could be introduced while using a head-mounted device. They would go through the first condition, and then give a test for the same, after going through a mental rotation test. They would then repeat this for the second condition with a different shape, since repeating the same shape could include retention from the first condition.

5.4.1 Efficacy of Scaffolding

The applications used in this study may or may not include explicit task decomposition. One condition would have scaffolding, while the other would not. We could analyze the results of this study to determine which application ensured better retention. We hypothesize that the scaffolding would ensure better retention.

5.4.2 Efficacy of Task Decomposition

The applications used in this study would not include scaffolding. One condition would have the constant factor multiplied automatically, while the other condition would have the user manually select the constant factor. We could analyze the results of this study to determine which
application ensured better retention. We hypothesize that the explicit task decomposition would help the retention of the formula better.

5.4.3 Comparison against Traditional Textbook Materials

This would be different from the previous designs as one condition would be the application, while the other condition would be relevant chapters from the Glencoe Geometry textbook. The version of the application would depend on the best result from the previous studies, which we hypothesize would contain both scaffolding and the task decomposition. We hypothesize that the user would retain more using the application than the textbook.

5.4.4 Comparison against Multimedia Learning Materials

In this design, one condition would be the application, while the other condition would be an online non-interactive video for the shape, after which the user would use a website to solve practice modules. We hypothesize that the user would retain the formula better using the application than the video and online module.

5.5 Future Work

The next step for this research is to run the planned studies. Using the results of these studies, we can determine useful design principles with respect to this application and how they could be abstracted and used in other educational applications in the VR spectrum.
Appendix A: Informed Consent

Form is on the following pages
University of Texas at Dallas

CONSENT TO PARTICIPATE IN RESEARCH

Title of Research Project: Integration of Learning Principles into an Educational Virtual Reality System

Investigators: Contact Number
Principal Investigator: Varshini Ramaraj, B.E. 469-877-8581
Co-Principal Investigator: Chengyuan Lai, M.S. 214-686-7456
Faculty Sponsor: Ryan P. McMahan, Ph.D 972-883-6610

Purpose: The purpose of this study is to increase our understanding of 3D Geometry programs by applying learning principles to a VR system and comparing it with paper and online curriculums.

Description of Project: This study will take place in ATC 1.709 on the main campus of the University of Texas at Dallas. The study consists of one session, which will last approximately 60 minutes.

The session will involve:
- Taking a pre-learning knowledge test on 3D geometry concepts
- Taking a background survey about your experiences with various types of learning
- Experiencing an immersive VR application
- Spending 10 minutes learning 3D geometry concepts
- Practicing an interference task
- Taking a post-learning knowledge test on 3D geometry concepts
- Spending 10 minutes learning 3D geometry concepts
- Practicing an interference task
- Taking a post-learning knowledge test on 3D geometry concepts
- Taking an exit survey regarding your opinions of the study

Number of Participants: A maximum of 180 participants will be recruited for this research.

Possible Risks: There are possible risks of slight eyestrain, dizziness, and nausea when using the head-mounted display during the immersive virtual reality experience. Participants reporting these ailments will be excused from the study.
Possible Benefits to the Participant: There are no direct benefits from participating in this study.

Alternatives to Participation: Individuals may choose not to participate.

Voluntary Participation: All individuals have the right to agree or refuse to participate in this study. Individuals who consent to participate also have the right to change their minds while experiencing the experimental procedure. Participants may tell the investigator that they no longer wish to participate. Refusal or withdrawal of participation will not involve any penalty or loss of benefits to which non-participants are entitled. Refusal to participate will not affect participants’ legal rights or the quality of instruction they may wish to receive at UTD.

Records of Participation in this Research:
Information Stored at the University of Texas at Dallas
All of the information participants provide to investigators as part of this research will be protected and held in confidence within the limits of the law and institutional regulation. At the beginning of the study, you will be assigned a randomized study ID that will be used for identification in all parts of the study. The investigators will not keep a permanent key linking your name and study ID. All research data will be stored on encrypted, password-protected computers for five years. All informed consent forms will be stored in a locked cabinet accessible only to the investigators in room ATC 1.602.

Information Available to Others:
Members and associated staff of the Institutional Review Board (IRB) of the University of Texas at Dallas may review the records of your participation in this research. An IRB is a group of people who are responsible for assuring the community that the rights of participants in research are respected. A representative of the UTD IRB may contact you to gather information about your participation in this research. If you wish, you may refuse to answer questions the representative of the IRB may ask.

Publications Associated with this Research: The results of this research may appear in publications but individual participants will not be identified.

Contact People:
Participants who want more information about this research may contact any of the investigators listed at the top of page 1 of this document. Participants who want more information about their rights as a participant or who want to report a research related injury may contact:

The University of Texas at Dallas Institutional Review Board

UTD Office of Research
Signatures

A participant's signature indicates that they have read, or listened to, the information provided above and that they have received answers to their questions. The signature also indicates that they have freely decided to participate in this research and that they know they have not given up any of their legal rights.

--------------------------------------------------

Participant's Name (printed)

--------------------------------------------------

Participant's Signature Date

--------------------------------------------------

Name of Researcher Obtaining Consent

--------------------------------------------------

Signature of Researcher Obtaining Consent Date
Appendix B: Pre-Learning Knowledge Test

Displayed on following pages
Free Response Answers:

Formula

Please review the following example, and then answer the questions below by filling in the blanks.

Symbols:

Use ‘pi’ for \(\pi\)
Use ‘\(^\)’ for power
Use ‘/’ for division

Example Shape: Sphere

What is the formula for the volume of a sphere?

Correct Answer: 

\[ A = \frac{4}{3} \times \pi \times r^3 \]

Shape #1: Cylinder

What is the formula for the volume of a cylinder?

Shape #2: Pyramid
What is the formula for the volume of a pyramid?

Calculation

Please review the following example, and then answer the questions below by filling in the blanks. Use the calculator and stop at one decimal point.

Example shape: Sphere

d = 6
r = 3

What is the volume of the sphere given the volume above?
Correct Answer:
A = 113.1

Shape #1: Cylinder
h = 7
r = 1
What is the volume of the cylinder given the provided values above?

h = 1
r = 4
What is the volume of the cylinder given the provided values above?
h = 7
r = 5
What is the volume of the cylinder given the provided values above?

Shape #2: Pyramid

l = 1
w = 1
h = 5
What is the volume of the pyramid given the provided values above?
l = 4
w = 5
h = 1
What is the volume of the pyramid given the provided values above?

l = 3
w = 7
h = 9
What is the volume of the pyramid given the provided values above?
l = 4
w = 11
h = 12

What is the volume of the pyramid given the provided values above?
Multiple-Choice Answers

Formula
Please review the following example, and then answer the questions below by filling in the blanks.
Symbols:
Use ‘pi’ for π
Use ‘^’ for power
Use ‘/’ for division
Example Shape: Sphere

What is the formula for the volume of a sphere?

O $4 \times \pi \times r^2$  O $\frac{4}{3} \times \pi \times r^3$  O $\pi \times r^2$  O $\pi \times r^3$

Correct Answer:
A = $\frac{4}{3} \times \pi \times r^3$

Shape #1: Cylinder

What is the formula for the volume of a cylinder?

O $2 \times \pi \times r \times h$  O $\frac{4}{3} \times \pi \times r^3$  O $\pi \times r^2 \times h$  O $\pi \times r^3$

Shape #2: Pyramid
What is the formula for the volume of a pyramid?

O $\frac{1}{3} \times l \times w \times h$  
O $l \times w \times h$  
O $\frac{1}{2} \times l \times w \times h$  
O $\pi \times l \times w \times h$

**Calculation**

Please review the following example, and then answer the questions below by filling in the blanks. Use the calculator and stop at one decimal point.

Example shape: Sphere

\[
\begin{align*}
d &= 8 \\
r &= 4 \\
\text{What is the volume of the sphere given the volume above?}
\end{align*}
\]

O 268.1  O 33.5  O 270.1  O 260.8

Correct Answer:
A = 268.1

**Shape #1: Cylinder**
h = 7
r = 1
What is the volume of the cylinder given the provided values above?
O 21.9   O 31.4   O 37.6   O 21.4

h = 1
r = 4
What is the volume of the cylinder given the provided values above?
O 50.2   O 32.6   O 37.6   O 25.1
h = 7
r = 5
What is the volume of the cylinder given the provided values above?
O 549.7  O 219.9  O 370.6  O 214.5

h = 9
r = 7
What is the volume of the cylinder given the provided values above?
O 1385.4  O 395.8  O 153.9  O 1077.5

Shape #2: Pyramid

l = 1
w = 1
h = 5
What is the volume of the pyramid given the provided values above?
O 1.6  O 5.0  O 10.0  O 25.0
What is the volume of the pyramid given the provided values above?

\[ V = \frac{1}{3} lwh \]

1. \( l = 4 \)  
   \( w = 5 \)  
   \( h = 1 \)
   
   What is the volume of the pyramid given the provided values above?
   
   \[ V = \frac{1}{3} \times 4 \times 5 \times 1 = 6.666... \]
   
   - O 6.6
   - O 40.0
   - O 5.0
   - O 10.0

2. \( l = 3 \)  
   \( w = 7 \)  
   \( h = 9 \)
   
   What is the volume of the pyramid given the provided values above?
   
   \[ V = \frac{1}{3} \times 3 \times 7 \times 9 = 63.0 \]
   
   - O 63.0
   - O 378.0
   - O 189.0
   - O 21.0
l = 4  
w = 11  
h = 12

What is the volume of the pyramid given the provided values above?

O 176.0   O 264.0   O 1056.0   O 132.0
Appendix C: Background Survey

Survey is on the following pages
Default Question Block

What is your study ID? (Ask the experimenter)

General

What is your gender (Is this necessary?)

Female
Male
Non-binary

What is your age?

What is your height?

Which is your dominant hand? (Which do you operate a computer mouse with?)

Left
Right

Will you be wearing contacts during the study? Glasses are not permitted due to the head-mounted display.

No
Yes, I will be wearing contacts
Education
What is your highest level of completed education?

If college level, what was your college major?

If other, what was your major?

Math Textbooks
Have you ever used a math textbook to learn about geometry?

Yes
No (You can skip the rest of this section then.)

<table>
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<th></th>
<th>Always True</th>
<th>Mostly True</th>
<th>Sometimes True</th>
</tr>
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<tbody>
<tr>
<td>Math textbooks are helpful to me.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>Math textbooks are too hard to understand or follow.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Math textbooks do not give me all of the information that I</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</table>
need to solve the exercises.

Math textbooks are interesting to read.

<table>
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<th>Math Videos</th>
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<tr>
<td>Yes</td>
</tr>
<tr>
<td>No (You can skip the rest of this section then.)</td>
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<tr>
<td>Math videos do not give me all of the information that I need to solve the exercises.</td>
<td>☒</td>
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</table>
Math videos are interesting to watch.

<table>
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<tbody>
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<td>Have you ever used a math game to learn about geometry?</td>
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<tr>
<td>Yes</td>
</tr>
<tr>
<td>No (You can skip the rest of this section then.)</td>
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<td>Math games do not give me all of the information that I need to solve the exercises.</td>
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</tr>
<tr>
<td>Math games are interesting to play.</td>
<td><img src="Image" alt="Option" /></td>
<td><img src="Image" alt="Option" /></td>
<td><img src="Image" alt="Option" /></td>
</tr>
</tbody>
</table>
Virtual Reality

Have you ever experienced an immersive virtual reality system?

Yes

No *(You can skip the rest of this section then.)*

What types of immersive systems have you experienced? Check all that apply.

☐ Head-mounted display (HMD)

☐ Surrounding displays (e.g., a CAVE)

☐ Wall display (e.g., a Powerwall)

☐ Large display (e.g., a VR arcade game)

☐ Vehicle simulator (e.g., any motion-platform system)
Appendix D: VR experience

Details on next page
THEBLU: ENCOUNTER

“TheBlu: Encounter transports you into a gorgeous virtual reality ocean experience to have a close encounter with the largest creature on the planet. Imagine what it is like coming face-to-face with an 80-foot blue whale, whose eye ball is almost the size of your entire face. An experience which feels real, but clearly couldn’t possibly be so, with a sense of uncanny scale and unexpected empathy.

Wevr signed on independent director Jake Rowell, formerly of Call of Duty and Superman movie, to develop the experience, together with Andy Jones, avatar animation director and Wevr’s team of VR experts. It was no small feat balancing all the visual, audio and interactive systems on a tight schedule – the geometry detail of the whale and species, the shipwreck and environment, the ocean visual fx, dynamic lighting with shadows, texture and shader detail, keeping draw calls in check and consistently running at 90fps stereo. The result is breathtaking example of the power of the feeling of presence afforded by VR.” [21]
Appendix E: Interference Task A

List of tasks on next page
This task requires the participant to choose the figure which is identical to the original figure, aside from its orientation.

Which image is the same as the original image, aside from its orientation?

A. Figure A  
B. Figure B  
C. Figure C  
D. Figure D

Which image is the same as the original image, aside from its orientation?

A. Figure A  
B. Figure B  
C. Figure C  
D. Figure D
Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D
Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D
Appendix F: Interference Task B

List of tasks on next page
This task requires the participant to choose the figure which is identical to the original figure, aside from its orientation.

Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D

Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D
Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D

Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D
Which image is the same as the original image, aside from its orientation?

A. Figure A
B. Figure B
C. Figure C
D. Figure D
Appendix G: Post-Learning Knowledge Test (Cylinder)

Displayed on following pages
Free Response Answers

Formula
Please review the following example, and then answer the questions below by filling in the blanks.

Symbols:
Use ‘pi’ for π
Use ‘^’ for power
Use ‘/’ for division

Example Shape: Sphere

What is the formula for the volume of a sphere?

Correct Answer:
A = 4/3 \pi \cdot r^3

Q.

What is the formula for the volume of a cylinder?
Calculation:
Please review the following example, and then answer the questions below by filling in the blanks. Use the calculator and stop at one decimal point.

Example shape: Sphere

\[ d = 6 \]
\[ r = 3 \]

What is the volume of the sphere given the volume above?

Correct Answer:
A = 113.1

Q.

\[ h = 9 \]
\[ r = 1 \]

What is the volume of the cylinder given the provided values above?

Q.
h = 1
r = 12
What is the volume of the cylinder given the provided values above?

Q.

h = 6
r = 2
What is the volume of the cylinder given the provided values above?

Q.
h = 10
r = 5

What is the volume of the cylinder given the provided values above?
Multiple-Choice Answers

Formula
Please review the following example, and then answer the questions below by filling in the blanks.
Symbols:
Use ‘pi’ for π
Use ‘^’ for power
Use ‘/’ for division
Example Shape: Sphere

What is the formula for the volume of a sphere?
O $4 \pi r^2$       O $4/3 \pi r^3$    O $\pi r^2$    O $\pi r^3$
Correct Answer:
A = $4/3 \pi r^3$

Q.

What is the formula for the volume of a cylinder?
O $2 \pi r h$       O $4/3 \pi r^3$    O $\pi r^2 h$    O $\pi r^3$
Calculation

Please review the following example, and then answer the questions below by filling in the blanks. Use the calculator and stop at one decimal point.

Example shape: Sphere

\[ d = 8 \]
\[ r = 4 \]

What is the volume of the sphere given the volume above?

O 268.1  O 33.5  O 270.1  O 260.8

Correct Answer:
A = 268.1

Q.

\[ h = 7 \]
\[ r = 1 \]

What is the volume of the cylinder given the provided values above?

O 21.9  O 31.4  O 37.6  O 21.4
Q.

\[ h = 1 \]
\[ r = 4 \]
What is the volume of the cylinder given the provided values above?

O 50.2    O 32.6    O 37.6    O 25.1

Q.

\[ h = 7 \]
\[ r = 5 \]
What is the volume of the cylinder given the provided values above?

O 549.7    O 219.9    O 370.6    O 214.5

Q.
$h = 9$

$r = 7$

What is the volume of the cylinder given the provided values above?

O 1385.4 O 395.8 O 153.9 O 1077.5
Appendix H: Post-Learning Knowledge Test (Pyramid)
Displayed on following pages
Free Response Answers

Formula
Please review the following example, and then answer the questions below by filling in the blanks.

Symbols:
Use ‘pi’ for \( \pi \)
Use ‘^’ for power
Use ‘/’ for division

Example Shape: Sphere

What is the formula for the volume of a sphere?
Correct Answer:
\[ V = \frac{4}{3} \pi r^3 \]

Q.

What is the formula for the volume of a pyramid?

Q.
l = 1
w = 1
h = 6
What is the volume of the pyramid given the provided values above?

Q.

l = 2
w = 7
h = 1
What is the volume of the pyramid given the provided values above?

Q.
l = 4
w = 8
h = 3
What is the volume of the pyramid given the provided values above?

Q.

l = 5
w = 2
h = 3
What is the volume of the pyramid given the provided values above?
Multiple Choice Answers

Formula

Please review the following example, and then answer the questions below by filling in the blanks.

Symbols:

Use ‘pi’ for π
Use ‘^’ for power
Use ‘/’ for division

Example Shape: Sphere

What is the formula for the volume of a sphere?

\[ O \quad 4 \times π \times r^2 \quad O \quad 4/3 \times π \times r^3 \quad O \quad π \times r^2 \quad O \quad π \times r^3 \]

Correct Answer:

\[ A = 4/3 \times pi \times r^3 \]

Q.

What is the formula for the volume of a pyramid?

\[ O \quad 1/3 \times l \times w \times h \quad O \quad l \times w \times h \quad O \quad 1/2 \times l \times w \times h \quad O \quad π \times l \times w \times h \]

Q.
What is the volume of the pyramid given the provided values above?
O 1.6  O 5.0  O 10.0  O 25.0

What is the volume of the pyramid given the provided values above?
O 6.6  O 40.0  O 5.0  O 10.0
What is the volume of the pyramid given the provided values above?

O 63.0   O 378.0   O 189.0   O 21.0

What is the volume of the pyramid given the provided values above?

O 176.0   O 264.0   O 1056.0   O 132.0
Appendix I: System Usability Scale (SUS) Questionnaire

Questionnaire is on the following page
1. I think that I would like to use this system frequently.

2. I found the system unnecessarily complex.

3. I thought the system was easy to use.

4. I think that I would need the support of a technical person to be able to use this system.

5. I found the various functions in this system were well integrated.

6. I thought there was too much inconsistency in this system.

7. I would imagine that most people would learn to use this system very quickly.

8. I found the system very cumbersome to use.

9. I felt very confident using the system.

10. I needed to learn a lot of things before I could get going with this system.
Appendix J: Exit Survey

Form is on the following pages
Default Question Block

What is your study ID?

Describe your 1st condition.

What did you like about the 1st condition?

What did you dislike about the 1st condition?

Describe your 2nd condition.

What did you like about the 2nd condition?
What did you dislike about the 2nd condition?

Out of the two conditions provided to you, which one did you prefer?
1st condition
2nd condition

Why did you prefer the selected condition?
REFERENCES


BIOGRAPHICAL SKETCH

Varshini Ramaraj completed her undergraduate degree majoring in Computer Engineering from the University of Mumbai. Having discovered her love for Computer Science, she dabbled in various domains, including front-end development and Artificial Intelligence. Varshini’s foray into research began with a project involving prediction of stock prices in her junior year. This pursuit in Machine Learning led to her capstone project involving prediction of currency exchange rates which resulted in a paper with two colleagues.

Having discovered her innate interest in Virtual Reality quite by surprise in an introductory class her first semester, Varshini worked on research with the same professor for the two years of her Master’s degree. This ultimately culminated in a thesis that she successfully defended last month. In her spare time, besides compensating for her lack of sleep, she enjoys reading great works of fiction and loves the Doctor Who series. Varshini will be graduating with a Master’s degree in Computer Science at The University of Texas at Dallas this Spring.
CURRICULUM VITAE

Varshini Ramaraj

Education

- MS Computer Science, University of Texas at Dallas, Expected May 2017
  - Thesis: “Integration of Learning Principles Into An Educational Virtual Reality System”
  - Committee: Ryan P. McMahan, PhD, B. Prabhakaran, PhD, John Cole

BE Computer Engineering, University of Mumbai, June 2015,
  - Rank: 1 out of 300

Achievements

- Top Ten at HackTX, a Hackathon in Austin, TX. (October 2016)
- Top Seven projects chosen by Samsung (CS 6334, August 2015 – December 2015)

Professional Appointments and Work Experience

- Member, Future Immersive Virtual Environments Lab (FIVE Lab), UT-Dallas, January 2016 to Present
- CS Lab Assistant, UT-Dallas, August 2016 – April 2017
- CS Instructor, UT-Dallas, June 2016 – August 2016
- UI Intern, Tech-Meet, February 2014 – April 2014

Research Interests

Virtual Reality, 3D User Interfaces, Human – Computer Interactions, Machine Learning, Natural Language Processing

Publications