Build Your Own Trigonometric Adventure in Virtual Reality

Catherine Borisova* Ruth Mesfin* Tongyu Nie Evan Suma Rosenberg†

University of Minnesota

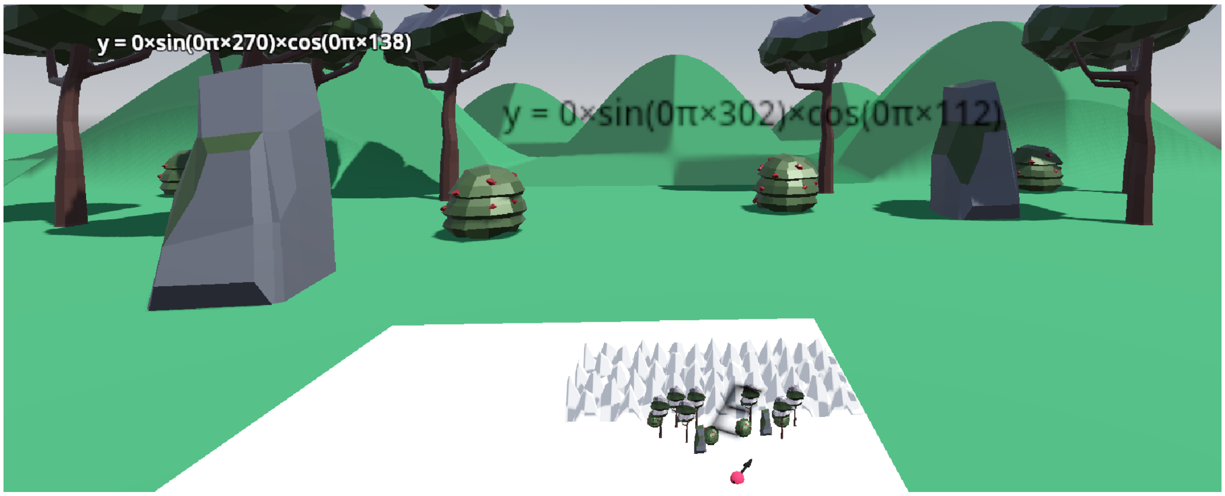

Figure 1: A screenshot of the user's first-person perspective in BYOTA. The user starts in an empty field where they can place objects on the WIM map. Full-size copies of these objects appear in the virtual world with their corresponding equations.

Abstract

Trigonometry is important to a diverse set of fields. However, it is often a difficult topic for students to learn. This is most commonly due to a difficulty of visualizing the concepts and understanding how they are related. Currently, there are not many widespread tools that encourage the exploration and physical interaction of trigonometry. Build Your Own Trigonometric Adventure (BYOTA) aims to help students gain a better understanding of trigonometric concepts by using them to manipulate terrain geometry in a virtual reality experience. Users can build the terrain around them by modeling a trigonometric equation, view their rotations in multiple unit circle modes, and view the equations that were used to create the specific hills and valleys. They can also directly manipulate the virtual world using World-in-Miniature (WIM), which allows them to customize the terrain and place objects in the environment using a handheld 3D map. BYOTA's objective is to enhance comprehension and encourage playful exploration of trigonometry in virtual reality, offering a concrete way to engage students with abstract mathematical concepts that they often struggle to learn.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality;

*equal contribution
†e-mail: {boris040, mesfi020, nie00035, suma}@umn.edu

1 Introduction

"Trigonometry is an area of mathematics that students believe to be particularly difficult and abstract compared with the other subjects of mathematics", thus causing them to "hate and struggle with [it]" [1]. According to Rahmawati et al., using Virtual Augmented Reality (VAR) educational games is an effective way to teach students trigonometry [2]. Students who interacted with educational VAR games were able to perform better than students who were not when answering trigonometric questions. Taking inspiration from these findings, Build Your Own Trigonometric Adventure (BYOTA) was created to help students understand and become more comfortable with trigonometry in a fun and interesting way.

BYOTA represents an immersive and interactive approach to learning trigonometry. Unlike traditional educational tools, BYOTA leverages virtual reality to transform abstract trigonometric concepts into 3D virtual worlds that can be directly experienced. Students can manipulate the terrain using trigonometric functions and then walk through the environment with visual feedback to help understand the underlying mathematics. This novel approach aims not only to improve comprehension, but also to foster a positive attitude towards learning trigonometry, potentially addressing the difficulty and disinterest often associated with the subject.

2 Trigonometry Visualization and Interaction

Students can easily interact with trigonometry in BYOTA in several ways, most prominently by generating the terrain around them. After opening the WIM-influenced map, users can select a portion of the map by holding a button on the controller. While held, a dynamic selection box appears, with one corner being fixed to the position at which the controller was when the button was pressed, and the opposite corner dynamically moving to the current position of the controller. When the button is released, the selection is created with diagonal corners being that of the button activation and release coordinates of the controller. Once an area on the map is selected, hills and valleys can be created using the following formula:

$$y = amplitude \cdot \sin(x \cdot freq_x) \cdot \cos(z \cdot freq_z) \quad (1)$$

Where $amplitude$, $freq_x$ and $freq_z$ are variables defined by the user, and x, y and z are coordinates in the virtual world. $freq_x$ and $freq_z$ are defined in radians. Users interact with an intuitive 3D graph and model of the terrain by using their controller to hold and move a selector. Moving a selector allows users to stretch and shrink the different axes to see how the user defined variables change, and how they also change the shape of the hills and valleys (see Figure 2). Users can also grab onto the map with both hands to stretch, shrink, and rotate the the graph to see it from different perspectives. Then users can use ray casting to press a green check mark to create their terrain. The terrain changes appear in the map and real world.

BYOTA also gives students the opportunity to familiarize themselves with the unit circle, which acts as a compass on the map. The compass has the following modes: cardinal (north, south, east, west), radians, degrees, and sine/cosine coordinates. As users rotate, their current direction is displayed based on the mode chosen, and changing modes offers different perspectives into the relationship between units of measurement on a unit circle.

Every object, including the user, can display the equation used to generate the terrain at its position. The user also has the ability to view their coordinates instead. As the user explores the terrain in virtual reality, walking up and down the hills and valleys, they can see how the x and z coordinates affect the height (y coordinate) given the $amplitude$, $width$ and $height$ that they specified. When the user is within proximity to an object in the full-scale virtual world, these equations appear over the objects automatically to give the user more context about the mathematical relationship between the trigonometric terrain and the object.

3 World-in-Miniature Manipulation

BYOTA makes extensive use of the World-in-Miniature (WIM) technique, drawing inspiration from the foundational work of Stoakley et al. [3]. The WIM presents a handheld representation of the virtual world, including the user's position, depicted through a red dot and compass on the map (see Figure 1). This miniature representation allows users to conceptualize and modify the terrain more effectively. For instance, when users interact with the 3D map to manipulate the terrain or place objects, these changes are mirrored in the virtual environment, providing visual feedback and reinforcing the connection between trigonometric functions and the resulting geometry.

The WIM interface in BYOTA is designed to alleviate common virtual reality challenges such as motion sickness and disorientation. The ease of manipulating the virtual environment through a handheld map minimizes the need for extensive virtual locomotion through the full-scale virtual world. However, when the user does want to move to a different location, they can teleport themselves by simply picking up their miniature virtual representation and placing it in the desired position in the 3D map.

4 Design and Implementation

This project began as a class project and was subsequently extended for the IEEE VR 3DUI Contest. To complete the project by the deadline, we implemented the Agile method, holding scrum meetings every week to plan our sprints for the week, and kept a shared Google Calendar to stay up to speed with deadlines and meetings. We were able to work individually and split up tasks by creating a GitHub repository and working on our code in separate branches until they were ready to be merged into the main branch. We developed, ran, and tested our code on Lenovo Legion laptops in Godot 4 with Meta Quest headsets.

For the user to have a template world to start with and customize, WIM was implemented by giving the user a map that visualizes the virtual world they exist in. The map represents any changes made to the virtual world, and even shows where the user is walking with a simple red dot and compass. Instancing was used to create new objects from those in the toolbox to be placed by the user onto the map, subsequently creating one in the virtual world in its full size.

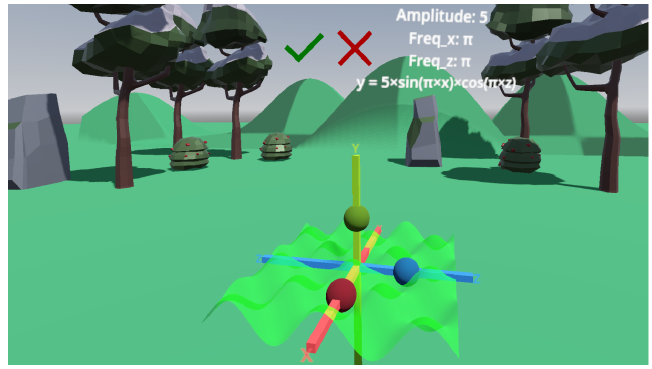

Figure 2: The user can create hills by selecting a part of the map and manipulating the trigonometric features of the 3D terrain model.

The ground and map are made out of HTerrain nodes, a tool that helps create heightmap-based terrains in Godot Engine, and is what allows the user to add hills and valleys with specified variables. A selection tool was created with a shader to allow the user to select the part of the virtual terrain they would like to manipulate on the map. After selection, a 3D model appears for the user to manipulate and interact with to create the desired hill and valley shape that they would like to add to the world. The user is able to interact with the axes on the graph, and view how the model and equation change with instant visual feedback. Once the user is finished, the terrain waves will appear in the virtual world as hills that the user can walk and place objects on. This interaction helps the user understand how cosine and sine can be visualized in a more physical setting than what is usually taught in class.

5 Conclusion

Students often have to relearn trigonometry later in life because they struggled to comprehend or retain the concepts when first exposed to them. There are many different approaches to teaching trigonometry, and BYOTA offers a new way by giving students the opportunity to get hands-on experience with topics that might not make sense on paper. With this tool, students are able to apply trigonometric concepts in a physical setting, and create a unique learning experience. Conducting a user study could shed light on the efficacy of BYOTA and its interaction techniques, including WIM. In the future, BYOTA could be extended to allow generation and manipulation of other types of virtual world geometry beyond terrain, support a wider variety of mathematical equations, and even add collaborative features for multiple users.

References

[1] H. Gür. Trigonometry learning. *New Horizons in Education*, 57, 05 2009. 1

[2] N. D. Rahmawati, A. Buchori, and A. Wibisono. Effectiveness of VAR (Virtual Augmented Reality)- Based Educational Games in Trigonometry Learning in University. *Advances in Social Science, Education and Humanities Research*, 630. doi: 10.2991/assehr.k.220103.039 1

[3] R. Stoakley, M. J. Conway, and R. Pausch. Virtual reality on a wim: Interactive worlds in miniature. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '95, p. 265–272. ACM Press/Addison-Wesley Publishing Co., USA, 1995. doi: 10.1145/223904.223938 2