Board 60: Work in Progress - Development and implementation of a virtual reality application in high school geometry education.

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I am Chinyere Offor, an international student at Lincoln University of Pennsylvania. I am a rising junior, and I am Double majoring in Computer Science and mathematics. My passion for this research topic was born out of her familiarity with both fields. Dr Smith will be presenting this paper on my behalf because I am away on an Internship.

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Dr. Tiffanie R. Smith is currently an Assistant Professor of Computer Science at Lincoln University of PA. She received her Ph.D. in Human Centered Computing from the University of Florida in the Department of Computer and Information Sciences and Engineering in 2019 . Her research interests include educational technologies, embodied learning, culturally relevant education, and broadening minority participation in STEM.

Development and Implementation of a Virtual Reality Application in High School Geometry Education

Introduction and Goal

The average Geometry classroom is too traditional in its teaching methods. The emphasis on numeracy, arithmetic and algebraic reasoning has caused many a student to struggle in grasping Geometry by its fundamental principles. Although numeracy should not be undermined for its mathematical importance, Geometry and spatial sense are best acquainted for effective interpretation and understanding. Virtual reality (VR), which has been defined to be “the sum of the hardware and software systems that seek to perfect an all-inclusive, sensory illusion of being present in another environment” [1], deals mainly with spatial sense. This technology continues to show massive potential in improving the quality of education at various levels and disciplines. It is wise to capitalize on VR's potential in optimizing our human engagement and integrate it into Geometry education. This will remove the disunion between students and the subjects by bridging the disparity in enjoyment of games and enjoyment of reality. This research will focus on the development of a virtual reality game, based on the Van Hiele Model of Geometric Learning [2]. The game will benefit from the positive effects of immersion and presence in VR, and the Van Hiele sequential phases.

Immersive Experiences in Geometry Education

The National Council of Teachers of Mathematics (NCTM) lists four main objectives of geometry teaching that relate to analyzing characteristics of shapes, applying transformations and using spatial relationships and spatial reasoning to solve problems [3]. The Van Heile Model of Geometric Learning coincides with the NCTM’s objectives and breaks down the learning of geometry across five phases: visualization, analysis, informal deduction, formal deduction and rigor [1]. Phases one and two require that students are able to recognize common geometric shapes and identify properties of those shapes, respectively. At phase three, students should be forming relationships amongst shapes. When students reach phase four, they should be able understand and appreciate the various geometric theorems and proofs. Phase five is where students further their deductive abilities by developing the ability to make more abstract deductions. Teaching these phases using pencil and paper usually leads to students memorizing these concepts and proofs without the actual deep understanding of such abstract concepts which may be more suitable for hands-on methods of learning [5][6].

One such method of learning is via immersive educational technology tools, such as those that utilize virtual reality (VR) and augmented reality (AR) technology. VR and AR has been shown to help students become more engage, learn effectively (geometry included), acquire better cognitive, psychomotor, and affective skills and visualize abstract concepts in a concrete manner which is crucial in advancing in the phases of the Van Heile model and accomplishing the NCTM objectives [7][8][9]. There are some geometry VR based applications that currently exist as the technology becomes more readily available [10][11][12]. This work hopes to add to the growing number of such VR applications, while focusing on circle geometry.

Application Flow and Design

The application is designed in the style of a racing game. This decision was made because racing games were deemed as the most popular among students [13].

Registration:

First time users (both students and instructors) will be prompted register with an account tied to their school. Students will also be required to select their instructor. The instructor will receive progress reports from that student. On the instructor's interface, it will be possible to check a student's progress both individually and as a group. It will also be possible to give assignments, tests, review materials and make additions.

Modules:

The application will be divided into eight modules, each consisting of three major parts: Prep room, Preparatory race, Race.

Module 1- Introduction to the circle and a vocabulary of its parts.

Prep room: The user will first be directed to a prep room to prepare them for the race. Here, they will be able to alter the properties (i.e. color, model) of the vehicle they race with. Also, the user will be made to view an interactive preparatory video. This video will contain the learning material to be covered in the module- in this case, it is the vocabulary of the circle's parts. The user will be introduced to language like chord, diameter, radius, tangent, and other circle vocabulary. Also, the user will be able to interact with the circle and compare its shape to other similar ones like oval, etc.

Preparatory race: Just as the name implies, this is a preparation for the race. It is divided into two parts: crystal collection phase and race.

In the crystal collection phase, a total of 20-24 crystals needs to be selected from a clutter on the racetrack. For module 1, a crystal will be a circle whose associated parts can be named. This means that if an object is picked, the user will have to decide if it is a circle or not. After that they will be prompted to name specific parts of the circle. If they are successful, the object will be transformed to a crystal. After this phase, the player will have accumulated at least 20 crystals which they will use in the race.

The race will be designed in such a way that the successful use of 16 crystals is imperative. The race commences, and it is just like a regular racing game; players are able to steer their vehicles as they please. However, as the first 20 seconds of the game progresses, the user will notice that their vehicle moves relatively slower than their competitors. This will make them fall behind and to need a powerup. At this point, they will enter their first timezone.

In a timezone, the race is paused, and a crystal is lost. The player can either succeed or fail the powerup challenge. For module 1, the challenge will be to identify all circles in 2 dimensional scenes, and name all the unlabeled parts. A player succeeds when all circles are identified, and the parts are assigned to their correct vocabulary; they are rewarded with a power up. After the time zone, the player returns to the race and can now employ the powerup as a speed booster. The power up boosts their speed, and places them well in front of the other racers. After another

20 seconds, the player starts to be in desperate need of another power up. They enter another time zone.

Each race will have a total of 20 power zones. A player will have to be successful in 16 time zones to win the race.

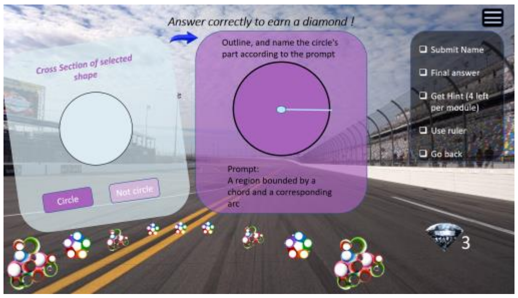

Figure 3: Mockup Scene from Crystal Collection Phase

Figure 4: Mockup Scene from Time zone Area

Race: The race comes after the preparatory race. The player must win this race to progress to the next module.

Module 2-8 -

These modules are like module 1, except for a few differences.

- In the preparatory video, the students will be introduced to one of the theorems of circle geometry as follows:
  Module 2: “The perpendicular from the center of a circle to a chord bisects the chord.”
  Module 3: “The angle at the center is twice the angle at the circumference.”
  Module 4: “The angle in a semicircle is 90 degrees.”
  Module 5: “Angles in the same segment are equal.”
  Module 6: “Angles in alternate segments equals 180 degrees.”
  Module 7: “Opposite angles of a cyclic quadrilateral equals 180 degrees.”
  Module 8: “Angles between a tangent and radius equals 90 degrees; tangents which meet at a point are equal in length.”

- In the crystal collection phase, for an object to be transformed to a crystal, it has to be correctly identified as a circle, with all its parts correctly stated, and angles correctly calculated.
- Success in the power zones is achieved when all circles are correctly identified with all its parts correctly stated, and angles correctly calculated.

Final Exam

This will be a final race with the same format as the ones before; it will incorporate all the mathematical knowledge learned. The crystal collection phase of the final race will test the students’ ability to identify circles/objects with circular cross sections based on the parts of the circle highlighted. The standard for this phase in the final exam will be much higher, in order to test the student’s improvement on their knowledge of this concept over time.

In the power zones, the students will be tested on their understanding of all of the eight theorems of circle geometry. Each theorem will be relevant in order for the student to correctly calculate all the angles in the circle.

Application Design and the Van Hiele Model of Geometric Learning

The Van Hiele model of geometric learning outlines the sequential phases in the process of learning geometry as: Visualization, Analysis, Abstraction, Deduction and Rigor.

The first module of this game combines visualization and analysis in proper order. The user is forced to see the circle for its holistic appearance before any proper consideration of its parts is made. Each power zone also champions in this order, by making the player select the circle, or circular shapes, from a 2D picture. The analysis phase of the theorem is put into even more practice by making the students familiar with the circle's parts at the very beginning of the course. They get to analyze different shapes and decide as regards it being a circle or not, based on its parts. The theorems come after the students are familiar with the circle. This is because abstraction succeeds visualization and analysis. The students understand that theorems imply certain rules when trying to find certain angles. They can employ their knowledge about the circle and these new laws in solving for different angles within and outside the circle. Deduction and rigor are incorporated as more and more theorems are introduced. The students can employ a previously taught theorem to get basic angles needed to solve a new theorem. They get to deduce their own proofs from previous knowledge. Rigor comes into play towards the end. The student slowly learns that cumbersome definitions play no role in successfully understanding mathematical concepts.

Unity will be used as the game engine for this application. Its prowess in rendering virtual reality environments was the driving factor behind this choice. Due to its consistently proven capability in virtual reality development, Oculus Quest 2 will be the device that the game will be built on. At the conclusion of the development phase, the application will be studied to determine whether VR enhances a student's academic performance, or not. Examinations will be administered at the onset and conclusion of the process. The attention and engagement levels of the students will be closely monitored during the process through observations and metrics which utilize Keller's ARCS motivation model which analyzes a learner's attention, relevance, confidence, and satisfaction of educational materials [14]. The Van Hiele model of geometric learning will also be evaluated for its practicality and usefulness. The goal of this research is to raise student's engagement levels and overall performance. This research hopes to revolutionize mathematics education in the world and transform mathematics from being "nobody's favorite subject", to a subject met with resounding excellence.

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