Does it Consider You? What Your Looking Means? Eye Tracking Approach to find Student's feelings in an Immersive VR Math Class

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The focus of this paper is to analyze the eye movements of users as they learn a Math topic in an immersive virtual reality classroom with a virtual teacher, and to find if they have unpleasant feelings when they encounter with math symbols. Our research employs the HCT VIVO Pro 2 eye tracking mechanism to examine users' eye behavior during a Math class. The virtual classroom, teacher, and math content are intentionally designed to promote eye movement, with a focus on collecting accurate data and avoiding any intentional eye movements from the user. The ultimate aim of this experiment is to generate a comprehensive eye movement map that correlates with the user's feelings, which can then be used as input data for an AI-based virtual teacher tasked with teaching Math to the user.

CCS Concepts: • **Human-centered computing → Mixed / Virtual Reality**.

Additional Key Words and Phrases: Immersive Virtual Reality, Virtual Teacher, VR Math, Gaze Detection, Eye Movement, Area of Interest, Understanding Estimation, Eye Behavioral Meaning

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1 INTRODUCTION

Learning Mathematics has always been counted as the one of the most challenging things to learn. Students may not be willing to inform their teachers about what they do not understand in math and the teachers more likely never find which part in a course is challenging for their students. In worst cases a student might not be aware of his misunderstanding or skip a very important content. When we are talking about younger students and basic concepts in math, misunderstanding would trigger significant problems in future. Because, if a student does not understand basic concepts in Mathematics, he or she would be in big trouble when faced with advanced concepts. Although there are plenty of works to avoid the aforementioned issue, most of them are focused on the content itself rather than the person who is learning it. For example, Interactive Learning methods have emerged to solve those kinds of problems in general, it tries to involve learners in different activities such as games, real time tests, group activities, etc. The problem regarding those modern methods is the same, they are not personalized, they are focused on the content and in best cases group of learners not individuals. To bring a highly personalized and optimized method for teaching we are about to take advantage of novel technologies such as VR and Eye Tracking. Nowadays, Virtual Reality (VR) is an emerging technology that is gradually being used as a teaching aid for

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mathematics, it can make it easier for students to learn. Teachers can use VR technology to facilitate students' learning of mathematics and enhance students' motivation to learn effectively [9]. The demonstration of virtual reality teaching can help students understand complex mathematical logical concepts and reduce students' misunderstandings [5]. While VR systems have the potential to enhance the learning process, they often prioritize the content and classroom environment over the needs of individual learners. Incorporating eye-tracking technology alongside VR systems could be particularly valuable. Through eye-tracking, it is possible to collect data on learners' visual attention during the learning process, as noted by [4] and [6]. By analyzing this data, educators can gain insights into which aspects of the VR environment are most engaging, which elements learners tend to ignore, which elements may be causing confusion or distraction, what content might trigger unpleasant feelings for the learner, and what can boost their learning process. Furthermore, eye-tracking can help personalize the learning experience for each individual learner, allowing educators to provide targeted feedback and support to improve learning outcomes.

2 BACKGROUND

While there is currently no research specifically on this topic, there have been numerous studies examining the application of eye-tracking technology within immersive virtual reality learning environments. These studies highlight a very interesting data regarding user's eye behavior which could be inspiring in for the purpose of this paper. Fixation duration and fixation count have been identified as the most frequently used oculomotor metrics in eye movement experiments. A longer fixation duration and more fixation count suggest that the viewer wanted or needed to spend more time on that area to process information, indicating that the content in that area was likely useful and interesting [2]. Saccadic eye movements have also been considered useful indicators of learning attention [8], with saccade being a rapid eye movement between two consecutive fixations [3]. Saccade duration can indicate the level of risk perception and attentiveness to exposed hazards [7]. Previous studies have also shown that the amplitude and velocity of saccadic eye movements are related to task difficulty, with harder tasks leading to increased amplitude and velocity, while lower task performance and tiredness may be indicated by decreased saccade velocity [10]. Baceviciute et al. further confirmed that saccade velocity was faster in the reading condition than in the auditory condition in immersive virtual reality [1].

2.1 Research Questions

This experiment aims to investigate potential obstacles that may impede individuals' learning of mathematics. It draws upon past studies on eye-tracking in educational settings, the application of virtual reality in math instruction, and the interpretation of user eye movements. Throughout this experiment the following question will be answered:

- RQ1: Do people who suffer from math phobia have longer fixations on math symbols such as Sigma and Pi?
- RQ2: Do those symbols stop them from following the course?

3 EXPERIMENT

The experiment is set up to track the user's eye movements as they are presented with a genuine mathematics topic containing advanced symbols, such as Sigma. The environment for the experiment is built using the Unity Game Engine, and the HTC Vive Pro Eye headset is used to run the immersive virtual reality application and gather data on the user's eye behavior. Finally, the data is analyzed using Python programming language and its relevant packages, including Jupyter and

Pandas. To ensure the collection of meaningful data, several critical components of the experiment have been designed as follows.

3.1 Immersive Virtual Reality Environment

The primary objective of the experiment is to capture as much information as possible about the user's eye behavior. In this experiment, particular attention is paid to three main components regarding the virtual environment: the Virtual Classroom, the Content presented within it, and the Virtual Teacher.

3.1.1 Virtual Classroom. The virtual classroom is designed to resemble a physical classroom environment and features a blackboard and chairs for learners. However, the chairs are non-interactive and cannot be selected by the user. Instead, experimenters or those managing the experiments adjust the user's position within the virtual classroom to optimize their eye movement and engagement with the learning materials. (Figure 1)

(a) Blackbaord view (b) Class view

Fig. 1. VR Classroom in unity

3.1.2 Content. The content which is presented in the experiment focuses on a specific topic in mathematics and is delivered over a five-minute period. In the selected topic, the equations contain math symbols get complex more and more by the time (3 different levels of complexity). The content is encoded with information such as the time of presentation, position of aforementioned math symbols, and the coordination of the area of presentation. (Figure 2)

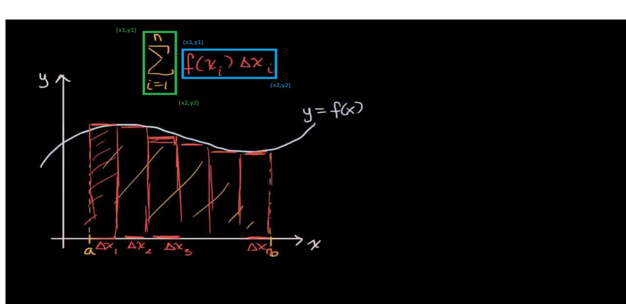

Fig. 2. Content with drawn proper boxes from encoded data on it

Table 1. Content Encoded Data

Complexity	Symbol	Symbol Box	Equation Box	Time (ms)	Content Size
1 or 2 or 3	sigma or pi	(x1,y1,x2,y2)	(x1,y1,x2,y2)	int	(width, height)

3.1.3 Virtual Teacher. The virtual teacher plays a crucial role in introducing the class and the experiment to the user, and guides them through the initial setup process by reading a text. During the learning session, the virtual teacher's behavior is designed to resemble that of a real teacher, including casual hand movements, to create a more realistic learning experience. The behavior of the virtual teacher can be customized by the experimenter to suit the specific requirements of the study (Figure 3).

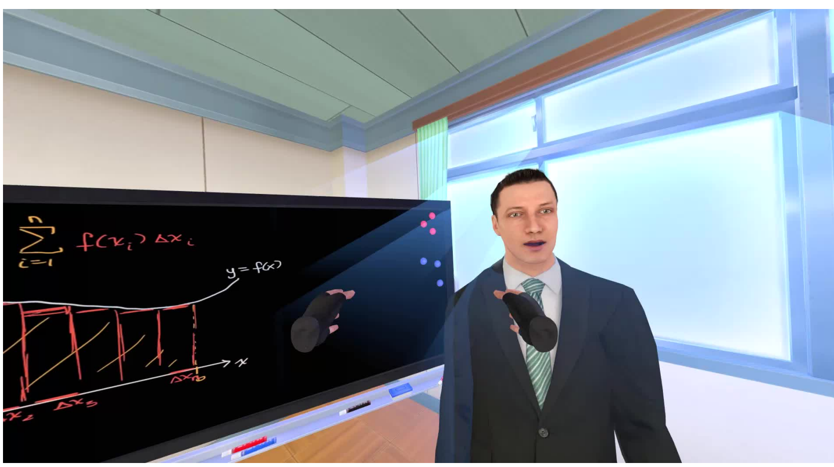

Fig. 3. Virtual Teacher

3.2 Eye Tracking

During the experiment, the user's eye behavior is getting continually captured and saved in a local database for later analysis. As soon as the user puts on the VR headset, the eye-tracking system commences recording their eye movements, which will be then synchronized with the content being presented. This synchronization enables us to investigate the user's eye behavior in connection with the presented material, offering valuable insights into their comprehension and engagement with the content. The headset SDK, ViveSR, provides several types of data for both eyes, and an API method is available that returns combined data for the left and right eyes. We utilize this combined data to determine the intersection of the user's gaze with objects in the scene. At each frame, we records the following data:

Table 2. Eye Tracking Data

Eye Openness	Pupil Diameter (mm)	Distance	Hit Point X	Hit Point Y	Time (ms)	Object Name
float number in [1,0]	int number	int number	float number	float number	int value	string value

3.2.1 Challenges. There are challenges with accuracy in every eye tracking tool, which originate from various sources. The first issue is calibration error, which occurs when the device is not calibrated. The second issue is the natural error of the device, which must be taken into account.

3.2.2 Calibration Issue. To handle the calibration issue, we employ both manual and code-based approaches. During each experiment run, we ask the user to put on the headset and run the eye calibration software provided by the headset while we monitor their actions on the desktop computer. Additionally, we developed a code to check the calibration status while the user is wearing the headset and to initiate the process or inform us of any calibration issues. (Figure 4)

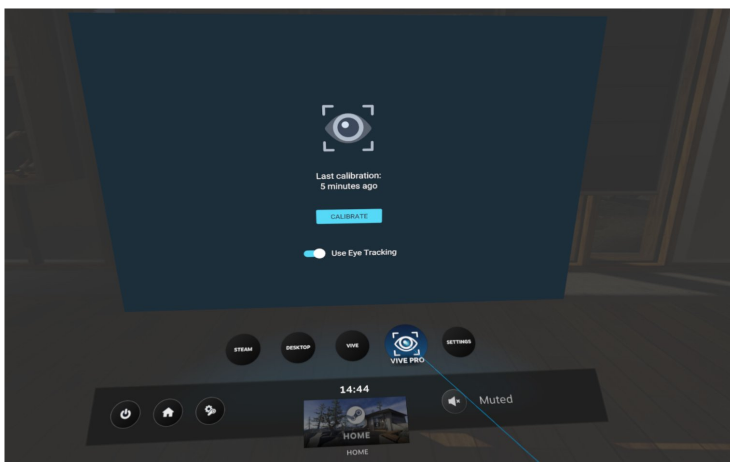

Fig. 4. HTC vive pro eye manual eye tracking calibration

3.2.3 Natural Error. Regarding the second issue, we took into consideration the manufacturer's information indicating that the device's natural accuracy ranges from 0.5° to 1.1°. We record the distance between the players and the object they are looking at, along with other data. Then, we calculate the following equation for each hit point's raw data (x, y) to determine the area of attention with (x,y) as the center and r as the radius.

$$Radius = \tan(1.1^{\circ}) \times distance \tag{1}$$

3.3 Analyzer

To process the raw data, we developed an analyzer using the popular data science library Pandas in Python, as well as Jupyter Notebook to handle large datasets with ease. The analyzer's purpose is to identify intersections between the user's area of interest obtained through eye tracking data and the math symbols in the content. This enables us to determine the user's fixations and calculate their saccade velocity among those fixations.

4 DISCUSSION

4.0.1 NOTE. **As the study needs to receive the IRB approval for running on real participants, a sample data is completely generated randomly using python with some constraints to develop and test correctness of the analyzer. Therefore, the following results are just from a computer generated data. I expect to have similar results by running the experiment on real participants in future.**

The results suggest that individuals with math phobia express their emotions and phobia through their eye movements.

4.1 Differences in Fixations

4.1.1 Longer Fixations. Individuals who seem to suffer from math phobia tend to have extended fixations on equations that feature Sigma or Pi symbols, in contrast to those who do not. Furthermore, These individuals do not continue to follow the teacher's instruction after encountering the symbol, as they tend to pause and disregard the remaining equation.

4.1.2 More Fixations. Their eye movements indicates a higher frequency of returning to symbol positions throughout the class, as opposed to others who tended to return to symbol positions only when the content specifically focused on them.

4.2 Differences in Saccades velocity

4.2.1 Higher Velocity. Individuals experiencing math phobia exhibit a higher rate of view chaining, as demonstrated by their increased average saccade velocity when viewing equations containing symbols such as Sigma and Pi compared to periods without such symbols on the board.

5 CONCLUSION

The results suggest that individuals with math phobia tend to have longer fixations on math symbols, particularly Sigma and Pi, which provides a positive answer to our first research question. Additionally, as they focus on these symbols, they tend to miss the subsequent content, which confirms our second research question.

6 FUTURE WORK

The research suggests that there are many areas within the subject that could be explored by further studies. The author has invested a significant amount of time in developing the system, but there is still a long way to go to develop a robust experimental environment that can effectively analyze a user's learning patterns based on their eye behavior. As indicated by the study, individuals may encounter various challenges during their participation in math learning processes. To optimize their learning outcomes, we need to gain a more comprehensive understanding of their emotional state (which was partially covered in this paper), level of engagement, comprehension, and familiarity with the content. Running a series of experiments with diverse participants is necessary to differentiate these factors and avoid misinterpretation of users' eye behavior during engagement with an immersive virtual learning experiment.

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