Pedagogical Research
2024, 9(3), em0210
e-ISSN: 2468-4929
https://www.pedagogicalresearch.com

MODESTUM

Research Article

OPEN ACCESS

A classroom experience for teaching and learning of high school geometry through virtual reality

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Citation: Domínguez Vázquez, B. C., & Díaz Palencia, J. L. (2024). A classroom experience for teaching and learning of high school geometry through virtual reality. *Pedagogical Research, 9*(3), em0210. https://doi.org/10.29333/pr/14634

ARTICLE INFO

Received: 10 Mar. 2024

Accepted: 05 May 2024

ABSTRACT

This study explores the integration of virtual reality (VR) in geometry education and examines the immersive platform's potential to enhance student engagement and understanding through a case report. While students appreciated the interactive and collaborative aspects of VR, they also faced challenges such as VR sickness and technical issues. Recommendations for future sessions include incorporating breaks and providing additional technological guidance. Future research will focus on addressing these challenges, evaluating long-term educational outcomes, and exploring the integration of other immersive technologies like augmented reality. The study contributes to the wide discussion regarding the importance of balancing technological innovation with pedagogical effectiveness for successful VR integration in educational settings.

Keywords: virtual reality, geometry education, student engagement, immersive technologies

INTRODUCTION

The emergence of the metaverse, a collective virtual shared space created by the convergence of virtually enhanced physical reality, augmented reality (AR), and the internet, has opened new horizons in educational methodologies, particularly in the teaching of complex subjects like geometry in high schools. This immersive, digital environment offers innovative, interactive ways to visualize and understand geometric concepts, which have traditionally been challenging for students due to their abstract nature. The utilization of virtual reality (VR) and AR within a metaverse framework for example allows students to engage with three-dimensional geometric shapes, explore spatial relationships, and understand geometric principles through hands-on experiences in a controlled, virtual setting.

Recent research highlights the potential of VR and AR technologies in enhancing spatial reasoning and comprehension of geometric concepts, which are important skills in mathematics education (Bacca et al., 2014). Moreover, studies suggest that the interactive and engaging nature of learning in a virtual environment can lead to higher levels of student motivation and engagement, thus improving learning outcomes.

According to Radu (2014), AR can significantly enhance learning outcomes by merging digital and physical environments, thus providing students a more tangible understanding of abstract geometric concepts. The educational potential of immersive virtual environments, akin to the metaverse, has been explored in various studies. Freina and Ott (2015) provide a comprehensive review of immersive VR in education, noting its ability to engage students and improve their spatial understanding. Moreover, the educational benefits of VR and AR are not limited to increased engagement. Mikropoulos and Natsis (2011) highlight the role of educational virtual environments in enhancing students' spatial visualization skills, a key aspect in understanding geometric principles.

In a meta-analysis provided by Merchant et al. (2014), the effectiveness of VR-based instruction across K-12 and higher education settings was affirmed, suggesting that such technological interventions could lead to significant improvements in learning outcomes. This body of research underpins the potential for metaverse technologies to transform the teaching and learning of geometry in schools by providing immersive, interactive experiences that can lead to a deeper understanding of the subject.

This article aims to explore the current state of metaverse applications in geometry education, examine their benefits and challenges, and discuss practical implications for teachers and students. As educational institutions continue to adapt to digital transformations, understanding and leveraging the capabilities of the metaverse will be relevant in shaping future educational practices and outcomes.

SCOPE & METHODS

Geometry, with its abstract concepts and spatial complexities, often poses challenges to students. Traditional teaching methods, relying heavily on two-dimensional representations, can fall short in conveying the full scope of three-dimensional spatial reasoning required for mastering this branch of mathematics. This is, where the metaverse steps in, providing a three-dimensional, interactive platform for teaching and learning geometry. It enables students to visualize, manipulate, and explore geometric concepts in ways that were previously unimaginable, thus fostering a deeper understanding and retention of knowledge. In a virtual world, the students can interact with geometric shapes and witness the direct consequences of transformations and other geometric operations. Based on this, educators can provide a more intuitive and engaging learning experience. The metaverse's capacity for creating realistic, scalable, and manipulable 3D models provide an unparalleled opportunity to explore geometric relationships and theories in a hands-on manner. However, integrating metaverse technologies into educational settings is not without challenges. It requires access to appropriate technology, such as VR headsets and capable computing hardware, as well as a shift in teaching methodologies to accommodate these new tools effectively. Moreover, educators must ensure that these technologies are used to enhance learning outcomes rather than as mere novelties.

The following text outlines a set of sessions designed to introduce the principles of the metaverse for explaining geometry in high school. Activities are presented with sufficient detail, and later on, the necessary resources required to effectively implement these activities are specified. Let us provide the sessions in a structured way:

Session 1: Understanding 3D Shapes & Volumes in Metaverse

Objective

Students will explore and understand the properties of three-dimensional shapes and their volumes through interactive experiences in the metaverse environment.

Content focus

Three-dimensional shapes (spheres, cones, cylinders, and prisms), volume calculation, and spatial reasoning.

Activities

1. Introduction (10 minutes): Begin with a brief discussion on three-dimensional shapes and volume formulas. Introduce the metaverse platform and explain how the session will proceed.
2. Metaverse exploration (30 minutes): Students enter a pre-designed virtual environment containing various 3D shapes. They will navigate through different stations, each dedicated to a specific shape. At each station, students interact with the shape, resize it, and observe how changes in dimensions affect the volume.
3. Interactive exercise (20 minutes): In small groups, students will complete a scavenger hunt in the metaverse, finding shapes with specific volumes by applying their knowledge of volume formulas. They will document their findings within the virtual platform.

Assessment

Conclude with a reflective session, where students discuss what they learned about the relationship between shapes and volume. Assess their understanding through a virtual quiz on the metaverse platform.

Session 2: Exploring Geometric Transformations in Metaverse

Objective

Students will understand and apply geometric transformations (translation, rotation, reflection, and dilation) in a metaverse environment.

Content focus

Geometric transformations, coordinate geometry, and transformation rules.

Activities

1. Brief recap (10 minutes): Review geometric transformation concepts and rules. Introduce the metaverse activity and its objectives.
2. Virtual geometry lab (35 minutes): Students enter a virtual world designed as a geometric laboratory. They will engage with various stations, each focusing on a different transformation. Students will manipulate objects, observe outcomes of different transformations, and record observations.
3. Transformation challenge (15 minutes): Students will be tasked with completing a series of transformation challenges, such as moving an object from one place to another using a combination of transformations or creating mirror images. They will use virtual tools to execute and visualize these transformations.

Assessment

Wrap up with a group discussion to reflect on how different transformations affect geometric figures. Evaluate understanding through a set of virtual problems that students solve in the metaverse.

Session 3: Navigating Through Geometric Proofs in Metaverse

Objective

Students will explore and construct geometric proofs in an immersive, interactive metaverse environment.

Content focus

Geometric theorems (e.g., Pythagorean theorem and triangle congruence), logical reasoning, and proof construction.

Activities

1. Introduction to proofs (10 minutes): Start with an overview of geometric proofs and their components. Explain how the metaverse session will help visualize and construct proofs.
2. Proof construction arena (40 minutes): In the metaverse, students enter a virtual arena segmented into different proof stations. Each station represents a geometric theorem or property. Students interact with dynamic geometric models to explore theorems and construct proofs, guided by virtual cues and prompts.
3. Collaborative proof building (10 minutes): Pair students to collaboratively build a proof using virtual tools. They choose one theorem explored during the session and construct a proof in the virtual environment, explaining each step.

Assessment

Conclude with a virtual presentation, where pairs present their proofs to the class. Assess students based on their understanding of the geometric concepts and the clarity and logic of their proofs.

To implement the proposed sessions in high school geometry using the metaverse, the following resources have been considered:

1. Virtual reality (VR) headsets and computers
   a. VR headsets: Oculus Quest 2, HTC Vive, or similar devices that support educational VR applications.
   b. Computers: PCs or laptops capable of running VR software, meeting the minimum requirements for the chosen VR headsets (e.g., adequate RAM and graphics card).
   c. Internet connection: High-speed internet for downloading VR content and accessing online platforms.
2. Metaverse platforms and software
   a. AltspaceVR (https://altvr.com/): A social VR platform that allows for the creation of custom environments and can be used for educational purposes.
   b. Mozilla hubs (https://hubs.mozilla.com/): An open-source platform that works on VR headsets and web browsers, suitable for creating and sharing virtual spaces.
   c. Engage VR (https://engagevr.io/): An educational platform designed for virtual meetings, classes, and training sessions in VR.
3. Educational content and tools
   a. GeoGebra 3D calculator (https://www.geogebra.org/3d): For creating and exploring 3D geometric shapes and concepts, which can be integrated into VR environments.
   b. Tinkercad (https://www.tinkercad.com/): An easy-to-use app for 3D design, electronics, and coding, suitable for demonstrating geometric transformations.
   c. CoSpaces Edu (https://cospaces.io/edu/): A platform that allows students and teachers to build their own 3D creations and VR experiences, useful for constructing geometric proofs and exploring shapes.
4. Development tools
   a. Unity (https://unity.com/): A game development platform used to create custom VR content and interactive 3D experiences.
   b. Blender (https://www.blender.org/): An open-source 3D creation suite that can be used to create detailed geometric models for use in VR environments.
5. Additional educational resources
   a. Khan academy (https://www.khanacademy.org/math/geometry): For supplemental educational content and tutorials on geometric concepts.
   b. National council of teachers of mathematics website (https://www.nctm.org/): Provides additional resources and activities for teaching geometry.

Additionally, based on the author's experience with these types of classroom implementations, the following elements were considered key. These points should be kept in mind to ensure a correct implementation of the proposal:

1. Training: Ensure that teachers and students receive adequate training on using VR equipment and software before beginning the sessions.
2. Safety: Follow all safety guidelines for using VR equipment, including break times to prevent VR fatigue.
3. Collaboration: Utilize platforms that allow for multi-user environments to enhance collaborative learning experiences.
4. Feedback: Collect feedback from students and teachers to continuously improve VR learning experience.

Figure 1. Representation of first pictures students watched when immersing into VR, where students can explore & interact with various geometric figures like spheres, cones, cylinders, & prisms (Source: Authors' own elaboration)

Figure 2. Environment incorporates interactive stations for exploring different geometric shapes & integrates elements of nature for a tranquil learning atmosphere (Source: Authors' own elaboration)

By integrating these resources, students can benefit from an immersive and interactive learning environment that enhances their understanding of geometric concepts through hands-on experience in the metaverse.

RESULTS

The author of the work was able to carry out the implementation of session 1 at an educational center located in Madrid, Spain, with students between 13 and 15 years old. Our aim was to understand the complexities of three-dimensional shapes and their volumes, leveraging the immersive capabilities of the metaverse environment. The classroom, typically organized in a traditional seeting, was transformed with the introduction of VR headseats turning the conventional space into a more technologically addapted area.

The session began with a concise overview of three-dimensional shapes and volume calculations. Utilizing the dynamic features of a digital whiteboard, we skillfully illustrated the principles of spheres, cones, cylinders, and prisms, setting the stage for the day's activities. As the foundational concepts were laid down, students donned their Oculus Quest 2 VR headsets, entering a meticulously designed virtual world populated with various geometric shapes (see **Figure 1**).

Under the educator's guidance, they explored this new realm, moving between different stations, each dedicated to exploring the intricacies of a specific three-dimensional form. The heart of the lesson was the metaverse exploration segment (see **Figure 2**), where students, in small groups, delved into the virtual environment provided by a 3D platform representation as Mozilla hubs. They interacted directly with the geometric shapes, manipulating their dimensions and witnessing firsthand the impact on volume. This hands-on experience sparked lively discussions among the students, enhancing their grasp of spatial reasoning and volume calculation.

Figure 3. Details about group activity in which groups shall determine volume of each of cylinders given (Source: Authors' own elaboration)

Figure 4. Setting is similar to a modern classroom in a virtual space, where students interact with quiz content created (Source: Authors' own elaboration)

The climax of the classroom experience was a organized scavenger hunt. Groups engaged in a friendly competition, scouring the virtual landscape to find shapes that matched specific volume criteria derived from their newly acquired knowledge (see **Figure 3** for a picture about the environment). They documented their findings on virtual clipboards, fostering a deeper understanding of geometric principles that enhances their collaborative and problem-solving skills. Following the immersive VR experience, the students gathered for a reflective session, where they shared insights and reflected on their learning journey. This discussion was pivotal, revealing the students' enhanced understanding and newfound appreciation for the relationship between geometric shapes and volume.

To assess the effectiveness of the session, we utilized the metaverse platform to administer a virtual quiz, tapping into the interactive features of educational tools like CoSpaces Edu (**Figure 4**). This approach helped to improve the day's learning outcomes and provided immediate feedback that allows for a real-time assessment of student understanding.

The session concluded with students removing their VR headsets, abuzz with excitement and conversation about their unique educational experience. The once abstract concepts of geometry were now tangible realities, thanks to the integration of metaverse technologies into the learning process.

Collecting Students' Feedback

The students were asked about the advantages and disadvantages they encountered during the session. To do this, an interview process was followed with all the students who had contact with session 1. The interview followed a clear line of general questioning: "Tell me about the advantages and disadvantages you have experienced."

In the context of an open educational setting, students were given the liberty to express their thoughts freely. The discussions were captured using conventional recording devices and later transcribed verbatim into text utilizing a standard text editor equipped with voice recording capabilities. A thematic analysis was carried out according to a well-defined methodology for qualitative research as outlined in Creswell and Poth (2017), which involved identifying frequently mentioned keywords and categorizing them to determine prevalent themes. In the triangulation exercise focused on ensuring the consistency of the transcriptions, the social constructivism theoretical lens played a key role. This approach emphasized understanding the complex realities experienced by participants and how these realities were constructed through their interactions and social contexts. The process involved a detailed comparison of transcriptions with the original audio recordings, paying special attention to the nuances of language and context that could reveal the participants' perspectives and social constructs. Additionally, another team member, made a survey on some of the reviewed transcripts to identify biases or subjective interpretations that could influence the portrayal of the participants' experiences.

Following this process, students shared their insights. One student noted, "VR environment made it easier to grasp geometric shapes." Another mentioned, "the scavenger hunts in the virtual world boosted my motivation to learn geometry." This sentiment was echoed by many, highlighting the immersive and interactive qualities of VR lessons facilitated through platforms like Mozilla hubs.

On the collaborative aspect, a student reflected, "working with classmates in the metaverse was funny and we speak a lot!" The immediate feedback from virtual quizzes was praised for helping students understand intricate concepts swiftly, as one remarked, "the instant quizzes in VR really helped my understanding of the material." However, the approach was not without its criticisms. "I experienced some dizziness from VR headset," one student disclosed, addressing the common issue of VR sickness. Others pointed out, "learning how to navigate the metaverse and use VR equipment was difficult." Technical difficulties were another area of concern, with students reporting, "I encountered several connectivity issues that interrupted the session." Moreover, the intensity of VR environment led to sensory overload for some, as one student said, "at times, VR world was too fast, it was hard to focus on learning."

Despite these obstacles, the collective feedback was positive, with a general agreement that the advantages of immersive and interactive learning in the metaverse outweighed the negatives. Nonetheless, students proposed enhancements for future implementations, suggesting, "incorporating breaks could help alleviate VR sickness," and "more practice with the technology would make things better." They also recommended, "a thorough check of all technical equipment because there were back and forwards". These insights provide valuable feedback for refining and advancing the educational use of VR in academic settings.

DISCUSSION

In the discussion section of our analysis, we delve into the findings from the thematic analysis of student interviews conducted after session 1, which utilized VR to teach geometric concepts in a high school setting. Students expressed a strong appreciation for the immersive nature of VR environment, facilitated by platforms such as Mozilla hubs. This finding aligns with research by Makransky and Lilleholt (2018) who found that immersive VR environments can significantly enhance students' spatial understanding and motivation in scientific subjects, thereby supporting the claim that VR can make abstract concepts more tangible . The positive impact of interactive and engaging aspects of VR on student motivation and interest, as reported by our students, corroborates with the work of Jensen and Konradsen (2018). This study demonstrated that interactive VR learning environments could significantly enhance student engagement and learning outcomes, especially in complex conceptual domains like geometry.

Furthermore, the students valued the collaborative learning opportunities within the metaverse, highlighting the scavenger hunt as an engaging and effective team-building exercise. This observation is supported by studies such as Fowler (2015), where the author suggests that collaborative VR experiences can foster teamwork and improve communication skills among students.

However, the study also revealed certain challenges associated with VR learning, such as VR sickness, a steep learning curve, technical issues, and sensory overload. These drawbacks mirror the findings in the literature, where discomfort and disorientation have been recognized as significant barriers to VR's educational effectiveness (Parong & Mayer, 2018).

As mentioned, this work aims to provide a case study of VR technology applications to contribute to the ongoing debate about its use. Therefore, it is necessary to highlight some aspects related to its potential future applications based on the case experience outlined in this paper. Firstly, personalized learning experiences are a significant future application. VR can be adapted to suit individual learning styles and needs, offering customized scenarios and pacing for each student. This personalized approach, supported by AI-driven analytics, could revolutionize the way subjects are taught and learned, making education more accessible and effective for a wide range of learner populations. As highlighted by Lee et al. (2020), VR's adaptive learning environments can greatly improve understanding and retention by addressing individual preferences and challenges. Secondly, VR holds the potential to expand experiential learning, providing students with practical, hands-on experiences in safe, controlled environments. This is particularly relevant in fields like STEM, where real-world applications of theoretical knowledge are crucial. Future VR platforms could enable students to perform complex procedures as highlighted by Merchant et al. (2014). Another promising area is global classroom integration. VR can connect students and teachers from different geographical locations, fostering global collaboration and cultural exchange. This can break down geographical and socioeconomic barriers to education, providing all students with access to high-quality resources and diverse perspectives. As posited by Wang and Burton (2013). VR's ability to simulate any location or environment opens up unparalleled opportunities for cross-cultural education and global awareness.

Furthermore, VR could play a significant role in special education, providing unique advantages for students with disabilities. Customizable VR environments can be adapted to various needs, providing accessible learning experiences for students with physical, cognitive, or sensory impairments. As suggested by Standen and Brown (2005), VR technologies offer new avenues for engagement and learning for individuals with special educational needs, from simulating social situations for autistic learners to adapting lessons for those with mobility, audio or visual impairments. This aspect was particularly significant for our study, as one of the participants exhibited a hearing impairment, often resulting in difficulties keeping pace with classroom activities. Remarkably, during the trial period, this student reported no issues concerning the auditory elements of VR experience. Furthermore, his feedback did not indicate any adverse effects stemming from his auditory disability. This observation leads us to conclude that the student was able to engage with the session on an equal footing with his peers. This case is interesting to overcome the integration of VR within the Universal Learning Design concept.

However, we emphasize that to realize these future applications, several challenges need to be addressed. These include mitigating VR sickness, improving ease of use, ensuring equitable access, and overcoming technical issues. Moreover, pedagogical strategies must evolve to integrate VR effectively, ensuring it complements traditional teaching methods rather than replacing them.

CONCLUSIONS & FUTURE RESEARCH WORKS

The integration of VR in educational settings, particularly for teaching geometric concepts in high school, has demonstrated significant potential in enhancing student engagement and understanding. This innovative approach, as evidenced by our study in a local educational instution in Madrid, Spain, offers a vivid, interactive platform for students to explore complex mathematical ideas in an immersive environment. The consensus among students indicates a positive reception towards VR's interactive and collaborative features, which have been shown to make abstract concepts more tangible and improve motivation towards learning geometry.

However, the implementation of VR in education is not without its challenges. Issues such as VR sickness, technical glitches, and a steep learning curve can detract from the learning experience. Yet, the overall student response suggests that the educational benefits of VR technology–when properly implemented–significantly outweigh these drawbacks. The practical recommendations provided by students, such as including breaks, enhancing technological guidance, and thorough checks of technical setups, are invaluable for refining VR-based educational practices.

Looking forward, it is essential to continue the exploration and development of VR in educational contexts. Future research should focus on addressing the challenges identified in this study. This includes investigating methods to minimize VR sickness, developing more intuitive and user-friendly navigation controls, and ensuring reliable technical performance to prevent disruptions during lessons. Additionally, research should aim to understand the long-term impacts of VR on learning outcomes and student motivation, comparing traditional teaching methods with VR-enhanced learning across diverse educational settings and student demographics.

Session 2 and session 3, which were proposed but not yet implemented, offer a fertile ground for future exploration. Session 2, focusing on geometric transformations, and session 3, which aims to delve into geometric proofs, represent the next steps in our research and implementation plan. These sessions should be designed to build upon the insights gained from session 1, incorporating student feedback to improve VR learning environment. Conducting systematic studies on these sessions will provide deeper insights into the effectiveness and scalability of VR in teaching complex mathematical concepts.

Furthermore, future work should also explore the integration of additional technologies such as AR and mixed reality to complement VR in teaching geometry. Comparing the educational impacts of these different technologies can offer a more comprehensive understanding of how immersive technologies can best be utilized in educational settings.

Author contributions: Both authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that the study was approved by the institutional ethics committee of Universidad a Distancia de Madrid on 28 July 2020 (Approval code: 07/1920). Written informed consents were obtained from the participants or their legal guardians. Thus, only those consents that have been approved for this study have been considered. The anonymity of the participating institutions as well as the participants in the study has been maintained throughout the work process.

Declaration of interest: No conflict of interest is declared by the author.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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