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Gautam Chaudhari
B.Ed., Part 2(Sem IV)
Ashadeep Adhyapak Mahavidyalay Mahesh Park, Tulinj Road, Nallasopara €, Palghar, Maharashtra, India

Deep Murzello
Assistant Professor, Ashadeep Adhyapak Mahavidyalay Mahesh Park, Tulinj Road, Nallasopara €, Palghar, Maharashtra, India

Kamlesh Kumar
Assistant Professor, Ashadeep Adhyapak Mahavidyalay Mahesh Park, Tulinj Road, Nallasopara €, Palghar, Maharashtra, India

Corresponding Author:
Gautam Chaudhari
B.Ed., Part 2(Sem IV)
Ashadeep Adhyapak Mahavidyalay Mahesh Park, Tulinj Road, Nallasopara €, Palghar, Maharashtra, India

Augmented and virtual reality (AR & VR) for mathematics education

Gautam Chaudhari, Deep Murzello and Kamlesh Kumar

Abstract
Study of Mathematics involves concepts that are abstract and hence sometimes difficult and challenging for the students to understand. Students often find them challenging and face difficulty in grasping them. The CPA (Concrete, Pictorial, Abstract) approach of teaching Mathematics many a times is not enough for topics like 3D Geometry, Algebra, Calculus, Symmetry- Rotations and Reflections, Fractals, patterns, to name a few. It can also be due to lack of student engagement, math- phobia, visualising shapes and solids, and low motivation or performance. To address these problems faced, Augmented Reality (AR) and Virtual Reality (VR), commonly known as Extended Reality (XR) can come to our rescue. Integration of these in our regular teaching- learning process can enhance understanding of the subject, visualization of the abstract mathematical concepts and thus improve student engagement. It can help student overcome the phobia and increase their interest in the subject. This Action Research Project aims to explore and assess how the integration of AR and VR can improve Mathematics Education at the School level by transforming abstract mathematical concepts and ideas into immersive learning experiences.

Keywords: Augmented Reality (AR), Virtual Reality (VR), Mathematics Education, Abstract Concepts Immersive Learning, CPA Approach, 3D Geometry, Algebra

Introduction
Mathematics plays a significant role in day- to- day life. It is very important to build mathematical competencies, develop mathematical thinking, logical reasoning, abstract thinking, problem solving abilities in the students in today's digital world. Traditional pedagogical approaches are often not able to engage students in abstract mathematical concepts. Several technologies are available today, which can help create dynamic and engaging mathematics learning experiences that can cater to diverse need of the students and increase their understanding of mathematical concepts. Use of AR/VR along with effective teaching methodologies can lead to improved learning outcomes.

Augmented Reality (AR) and Virtual Reality (VR)
Augmented reality (AR) is an immersive technology that integrates digital information into the real world. Several tools and platforms are already being used to integrate AR and VR into Math education.

AR Tools
- **GeoGebra AR:** For visualizing 3D Geometry and functions.
- **Merge Cube:** A physical cube that interacts with AR apps to teach Mathematical concepts.
- **Microsoft HoloLens:** For advanced AR experiences in education.

According to Biocca and Levy, Virtual Reality (VR) is defined as "the sum of the hardware and software systems that seek to perfect an all-inclusive sensory illusion of being present in another environment."

VR Tools
- **Google Tilt Brush:** For creating 3D mathematical art and models.
- **Z Space:** A VR platform for interactive STEM learning.
- **NeoTrie VR:** A specialized tool for exploring geometric constructions in VR.

AR/VR (XR) benefits learning by helping students grasp complex concepts, improved engagement, equips them with problem solving skills, encourages critical thinking, enhances analytical abilities and their overall learning experience enriching.

Literature Review

A study by Kaufmann and Schmalstieg (2003) [1] on AR for geometry education- They found that AR helped students understand 3D geometry. Another study by Dünser and Hornecker (2007) [12] showed that AR can increase engagement but may have usability issues. A study by Passig, Eden, and Heled (2007) [13] used VR to teach fractions, finding improved conceptual understanding. Another by Lindgren and Johnson-Glenberg (2013) [14] showed that embodied VR experiences enhance learning through motor activity. There's also a meta-analysis by Garzón (2020) [15] that found AR has a positive effect on learning outcomes compared to traditional methods. But they noted variability based on how AR was implemented. A paper by Akçayır and Akçayır (2017) [16] reviewed AR in education and highlighted technical problems and teacher training as major barriers. Similarly, Radianti et al. (2020) [17] did a systematic review on VR in education and found issues like cost and lack of training. In the comparative analysis, reference studies that compare both, like a study by Meyer et al. (2019) [18] comparing AR and VR for STEM education, finding that each has strengths depending on context. For future directions, the need for longitudinal studies, as per Garzón (2020) [15], and collaborative environments as in Chen (2021) [19]. Most studies are short-term, so long-term retention isn't well studied. Also, many studies are in controlled environments, not real classrooms. There's also a need for more research on different age groups and mathematical topics.

Methodology

For this Action Research, data was collected using both Quantitative and Qualitative methods to evaluate the effectiveness. Quantitative Data was collected via pre- and post-tests to measure learning gains and conducting surveys to assess student engagement and motivation. Qualitative Data was collected via Feedbacks of students and teachers.

Students of Std 7th A will be selected with sample size of 40 for the research. They will be administered a pre-test of 10 MCQs of 1 mark each. The AR/VR activities will be aligned with the selected topic for study. The students will then be taught the topic Triangles and its Properties using the AR tool GeoGebra providing clear instructions and guided practice. The students will be allowed to manipulate and visualize the different types of triangles and their properties.

The Learning Outcomes will be measured by conducting a post-test of 10 MCQs of 1 mark each. Student interactions will be observed during class sessions with regards to manipulation, student engagement and motivation. Feedbacks of students and teachers will be conducted via interviews.

Students' Interview Questions

1. What did you like most about learning triangles using GeoGebra?
2. Was there anything you found challenging while using the tool?
3. How did using GeoGebra compare to learning math with textbooks or regular classroom activities?
4. Did using AR/VR features (e.g., rotating 3D triangles) help you understand concepts like congruence or the Pythagorean Theorem better? How?
5. Which GeoGebra activity or tool (e.g., dragging vertices, measuring angles) helped you the most? Why?
6. Do you feel more confident solving problems based on Triangles after using GeoGebra? Why or why not?
7. Would you want to use tools like GeoGebra for learning other topics in Mathematics? Why?

Teachers' Interview Questions

1. How did integrating GeoGebra into your lesson plan help you in teaching triangles?
2. Did you notice any differences in student engagement or participation during GeoGebra activities compared to your regular teaching methods?
3. How do you think GeoGebra affected students' understanding of abstract concepts like congruence or triangle properties?
4. Were there any limitations of the tool that was a bottleneck in student learning?
5. What training or support would help teachers use AR/VR tools like GeoGebra more effectively?
6. Would you recommend this tool to other Mathematics teachers? Why or why not?
7. Do you think AR/VR tools could replace traditional methods for teaching Maths, or should they be supplementary?

Results

Students of Std 7th A were selected with sample size of 40 for the research. They were administered a pre-test of 10 MCQs of 1 mark each.

In the next stage, students were taught the concept using the AR tool GeoGebra.

The Learning Outcomes were measured by conducting a post-test.

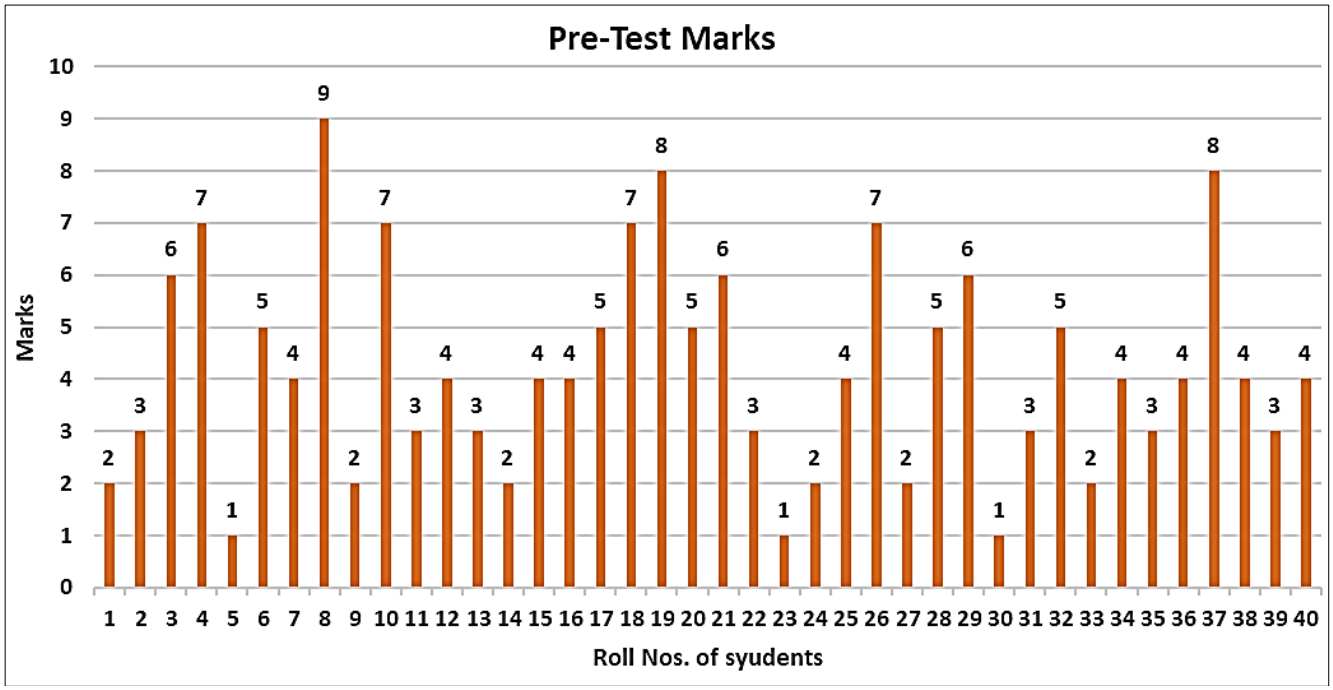

Fig 1: The scores of the pre-test are as follows

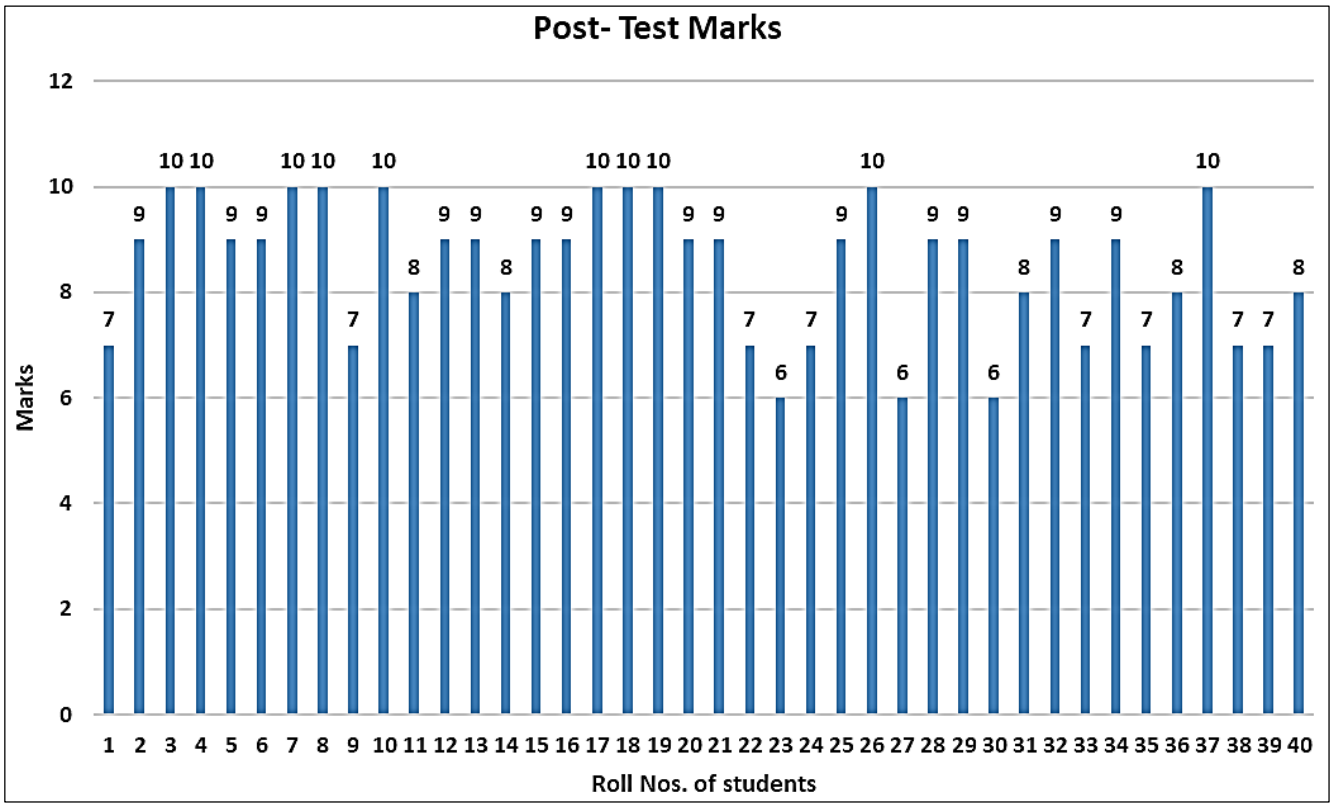

Fig 2: The scores of the post-test are as follows

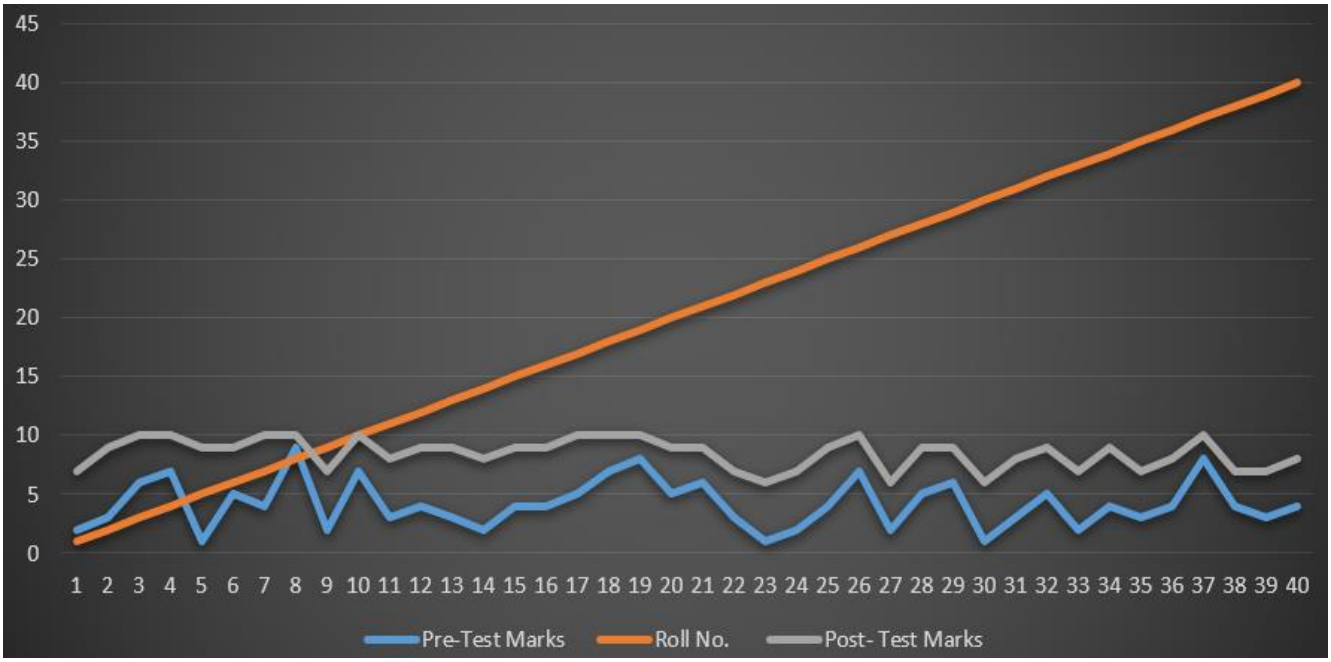

Fig 3: Comparative Scores of Pre-Test and Post- Test

The improvement in scores indicate enhanced learning and understanding of concepts.

Findings from the Observations to measure student engagement and motivation

It was found that the students were highly interested and engrossed while using the tool. They were engaged manipulating, they were using 3D rotation for different measurements of sides and angles. They were also keen on learning the new concepts.

Findings from the Feedbacks of students and teachers

The students found the tool to be very easy to manipulate. According to their feedback, the tool boosted their understanding of concepts beyond the textbook. They found grasping the concept very easy. The students found the use of GeoGebra very helpful and want learn many more topics using such tools.

According to the teachers, integrating GeoGebra in their lesson plan, provided them new opportunities to enhance learning in their class. They noticed a positive change in student engagement and motivation. The teachers felt a need to use such tools for more topics and even can be helpful for conducting formative assessments and revision of the topics. They can use such inputs effectively if they will be provided trainings and follow-up sessions post-training. The teachers would be happy to learn more such tools. They will recommend this to other Mathematics teachers too. According to the teachers the tools will not replace the traditional approaches of teaching- learning but will surely assist the approaches used and make grasping concepts and hence make learning more fun, engaging, motivating and powerful.

Discussion

The Action Research Project was to find the impact of AR/VR in Math Education. The AR/VR tool GeoGebra was used in teaching the topic Triangles and their Properties to Grade 7th students. The post-test conducted shows an improvement in the scores of the students. The results of the post-test indicate that use of the tool GEOGEBRA has contributed to better learning outcomes. The visualization helped students grasp the abstract concepts of triangles and their properties. The interactive features have made the learning more engaging. It lead to better retention**.** Previous studies highlight the efficiency of AR/VR in STEM education (e.g., Huang et al., 2019) [20], particularly in visualizing complex concepts. The pre- and post-test scores support the previous studies, showing that even basic affordable tools like GeoGebra, when integrated into an immersive framework, can have nearly same benefits as of high-end VR setups. Observations when the students were using the tool showed that the students were deeply engrossed in the learning. They found learning interesting and engaging. The motivation level was found very high among the learners. Interviews with students and teachers showed that students understood the concepts more easily and better by rotating 3D models in virtual space than just viewing the diagrams on the board or in their books. The drag and drop feature of GeoGebra helped them understand the properties of triangles for different lengths of sides and measures of angles, the Theorem of Pythagoras. Teachers found the tool to be very user-friendly. GeoGebra can be considered as an affordable and basic tool in addition to the traditional teaching methodologies. The small sample size of just 40 students and for only 1 topic of Geometry was a major limitation of this study. Also, the short time duration of the implementation could not support to find the long-term retention of the concepts in the students. In future, more studies can be undertaken using different AR/VR tools and for a longer duration having more number of participants and for a variety of mathematical concepts.

Conclusion

This action research project helps in understanding the use of integrating AR/VR tools like GeoGebra into mathematics education, specifically for teaching triangle properties to 7th-grade students. The pre- and post-test results show a considerable improvement in students' understanding of important geometric concepts, such as congruence, angle relationships, and the Pythagorean Theorem.

The results point towards better understanding of abstract geometric concepts and meeting of the learning outcomes, and that interactive learning can help in bridging the gap between abstract ideas and students reasoning abilities, thus leading to conceptual clarity.

The limitations like small sample size, less duration and learning of only a single topic do not help in generalisation of the findings, but the improved post-test scores indicate the importance of AR/VR tools in teaching – learning of abstract concepts in Mathematics.

Moving further, future research to understand the retention of learning can be undertaken implementing more AR/VR tools and for various topics in Mathematics, thus leading to better understanding of concepts, making learning real-time, interesting and engaging.

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