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## Enhancing Mathematical Understanding Through Augmented Reality and Virtual Reality: An Experimental Investigation into Educational Benefits.



**Abstract:** - The present research focuses on investigating the advantages of AR and VR to improve the students' learning of math, compared to typical approaches. An experimental design was employed, involving three groups: AR, VR, and a control group, which will include basic conventional teaching methodologies. Quasi-experimental pre and post-test was used to determine learning outcomes, self-organized engagement surveys were used to check students' interest in the content of the lesson, data was also gathered from focus group interviews and teacher observations. The outcome shows that overall application of both AR and VR technologies frequently enhanced student's post-test scores, however, a more considerable increase in scores was observed in the VR team. The participants of the AR and VR groups stated they felt more engaged than the control group; such smart learning experiences motivate and enhance participation. Such testimonies continue to affirm the observational findings by pointing the light to the benefits that were passed on by respondents that included positive experience and improved conceptual knowledge that comes with the use of AR and VR in learning. From these conclusions it can be inferred that the inclusion of AR and VR into mathematics instructions presents a more enhanced and interactive learning than the conventional techniques. Such technologies have the capacity to enhance educational practices and hence the call for more studies to be done in order to resolve the issues concerning implementation of these technologies as well as to look at the long-term advantages. The outcomes support AR and VR to become important factors of educational process by improving student's performances.

**Keywords:** Augmented Reality, Virtual Reality, Mathematics Education, Student Engagement, Educational Technology, Learning Outcomes

### Introduction

Mathematics education has been considered as one of the core subjects when it comes to the enhancement of critical thinking skills and problem-solving skills. However, conventional instructional strategies fail to captivate student's attention and help convey abstract mathematical concepts clearly. Several of the recent technologies, particularly the Augmented Reality (AR) and the Virtual Reality (VR), are new to the teaching and learning environment and present more possibilities of enriching educative solutions and promoting improved learning results (Elsayed *et al.*, 2021). AR superimposes the digital content on real environments and a new form of learning is integrating a combination of the theoretical knowledge and application processes (Sikder *et al.*, 2020). Conversely, VR places the students in a fully virtual environment through which they can explore the various mathematical concepts using a dynamic simulation and graphical displays. Such technologies have been revealed to enhance student participation as well as help in the explanation of complicated content (Geng *et al.*, 2020). There are few extensive experimental studies carried out on the efficiency of augmented reality and virtual reality applications for the improvement of mathematical skills (Geng *et al.*, 2020) works call for further research and investigations to check the effectiveness of the use of these technologies in teaching and learning and to know the appropriate way of incorporating them in the learning process (Sommerauer *et al.*, 2014).

However, this topic was not thoroughly investigated still this study is designed to fill this gap by conducting an experimental investigation of the effectiveness of AR and VR tools in mathematics education (Chang *et al.*, 2022). Thus, it is the goal of this research to identify the effectiveness of these technologies and the differences in students' mathematical comprehension, interest, and achievement due to engagement with the technologies. The results of the study will be useful to the existing literature on innovative educational technologies and their use in the improvement of learning environments.

### Literature Review

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Augmented Reality (AR) has become a revolutionary technology in learners' facilities, especially in teaching and learning since it makes the content come alive and periods which were normally boring can be made more interesting. AR facilitates the addition of digital content in the physical environment hence enabling the users to easily understand concepts that otherwise they would find difficult to grasp (Billinghurst & Duenser, 2012). AR is useful in education and for instance in mathematic geometrical structures, algebras and data can be depicted in three dimensions which help to develop further understanding of mathematical concepts amongst the students (Bower *et al.*, 2014).

The study has also revealed that end users' spatial ability and problem-solving skills will enhance through augmented reality use. For instance, AR applications improved student's knowledge of geometrical concepts and their problem-solving skills related to geometrical problems (Chang *et al.*, 2022). Due to its possible interactivity, AR enables students to change the position and orientation of the mathematical objects in order to acquire better understanding of spatial and mathematical relations.

Virtual Reality (VR) generates a complete world apart from the real reality, an apparently real world where students can be presented with experiences that could be helpful to facilitate specific concepts that cannot be assessed in conventional contexts. In the teaching and learning of mathematics (Demitriadou *et al.*, 2020), VR makes it possible to set mathematical scenes where learners can manipulate virtual objects stiff improving their understanding of the learning content. From the literature, it is evident that VR enhances student's knowledge and memory retention of concepts in mathematics as compared to conventional teaching techniques in that students learn with ease through VR.

A number of the previous research works have pointed to the efficiency of VR in the facilitation of learning gains. Moreover, the use of VR enables students to learn collaboratively since they can engage themselves in the common virtual environment to solve mathematical tasks.

Thus, although AR and VR include benefits derived from each technology, research comparing these approaches has analyzed the practicable efficiency in the context of education. The level of general math knowledge gained through augmented reality and virtual reality on learning to assess how AR and VR could affect student's learning experience and discovered that AR and VR boosted the comprehension of the particular topic, though the students observed that VR-based learning was a touch more engaging as compared to AR (Türkan *et al.*, 2022). AR was superior in the contextualization of geometrical schemes to improve the students' spatial skills, while VR was highly useful in the simulation of the non-concrete mathematical ideas.

There are the difficulties related to the integration of AR and VR technologies. Some of these challenges include cost implication of using technology, technical hitches that may hinder use of technology, and the development of appropriate content for use in learning among other factors. Nonetheless, the potential that encompasses AR and VR to enhance the learner outcomes makes it relevant to embrace this technology and research further on the topic.

The type of learning theory adopted for this study is Constructivist Learning Theory espoused in the works of Piaget (1973). This is true since both AR and VR enables the students to construct knowledge of mathematical concepts through interaction and manipulation of the required concepts. Such an approach is however different from conventional knowledge transmission techniques and is advocated for by scholars as it leads to better understanding and retention of the material learnt (Jonassen 1999).

## Methodology

### Research Design

This research adopts a mixed-methods experimental design to analyze the impact of Augmented Reality and Virtual Reality on the improvement of mathematics learning outcomes. The design involves both the quantitative and the qualitative methods to ensure that an overall evaluation of the impacts that AR and VR technologies give on student's appreciation of math is achieved.

### Participants

One hundred and twenty students from two high schools took part in this research. The participants were randomly assigned to one of three groups: An AR group, a VR group, or a control group where the conventional methods of teaching are employed. Both the groups were of 40 students each. This random assignment minimizes the chances of confounding factors and makes the group's characteristic similar and thus any effect noticed, can be pointed to use of AR or VR.

#### *Tools and Technologies*

**Augmented Reality Tools and Applications:** For the AR group, we employed GeoGebra augmented reality that enables students to learn about geometric figures and algebraic functions via a mixture of real and virtual objects. Following are the reasons for choosing this application; More straightforward than other similar applications design and the ability to map math on tangible objects.

**Virtual Reality Tools and Applications:** The VR group used the Mathematics VR Simulator through which one can get 3D real like problems and mathematical expressions (Dunleavy, Dede, & Mitchell, 2009). This simulator was selected mainly due to its vast choice of the mathematical situations and its ability to build an appropriate acting field.

**Control Group:** In the control group, the teacher provided direct instruction using conventional text and ordinary teachers' flip-over board. This group formed the control group through which the use of AR and/or VR interventions was compared to traditional teaching methods (Demitriadou *et al.*, 2020).

#### *Data Collection Methods*

##### **Quantitative Data**

1. **Pre- and Post-Test Assessments:** In order to analyze the changes in the participants' knowledge of mathematics quantitatively, pre- and post-tests were conducted. These tests were meant to assess the students' comprehension of the main or important aspects of mathematical content area studied (Kulik & Kulik, 1991). The assessments used multiple-choice, problems solving, and conceptual questions.
2. **Engagement Surveys:** Student engagement was assessed with a recognized and reliable instrument, that is the Student Engagement Survey (Fredricks *et al.*, 2004). This survey focused on the students' interest and motivation as well as the extent of their participation in learning.

##### **Qualitative Data**

1. **Focus Group Interviews:** Interviews involved focus group discussions; students from each group were interviewed to obtain their experience of using AR/VR technologies. These interviews were meant to establish the students' impression on the learning tool and how they help them make sense of mathematical lessons (Creswell & Poth, 2018).
2. **Teacher Observations:** Qualitative feedback was gathered by the teachers through observation reports, which indicated the observation of students' interactions with the AR and the VR tools and how the latter can help facilitate learning in the classroom.

#### *Data Analysis Techniques*

**Quantitative Analysis:** Qualitative data were transcribed and analyzed thematically whereby the responses regarding their educational experience from the pre and post-test questionnaires were analyzed using paired t-test and the comparison of the different group performances was analyzed using ANOVA. Data analysis for this study was done using statistical software SPSS.

**Qualitative Analysis:** The current study used focus group interviews and teachers' observation to collect qualitative data that was analyzed using themes. This approach entailed processes of coding the data with a view of developing themes and patterns regarding students' experiences and perceptions of AR and VR technologies (Braun & Clarke, 2006). Using NVivo helped in the organization and analysis of the qualitative data that was reviewed in this research.

**Results and Discussion**

*Descriptive Statistics*

The study assessed the impact of Augmented Reality (AR), Virtual Reality (VR), and traditional teaching methods on students' understanding of mathematical concepts. Table 1 summarizes the pre- and post-test scores for each group.

**Table 1: Pre- and Post-Test Scores**

Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	p-Value (Pre vs. Post)
AR Group	62.3 (10.4)	78.5 (8.7)	16.2	<0.01
VR Group	63.1 (9.8)	81.2 (7.9)	18.1	<0.01
Control Group	60.9 (11.2)	66.5 (10.3)	5.6	0.12

**Note:** SD = Standard Deviation; p-value calculated using paired t-tests.

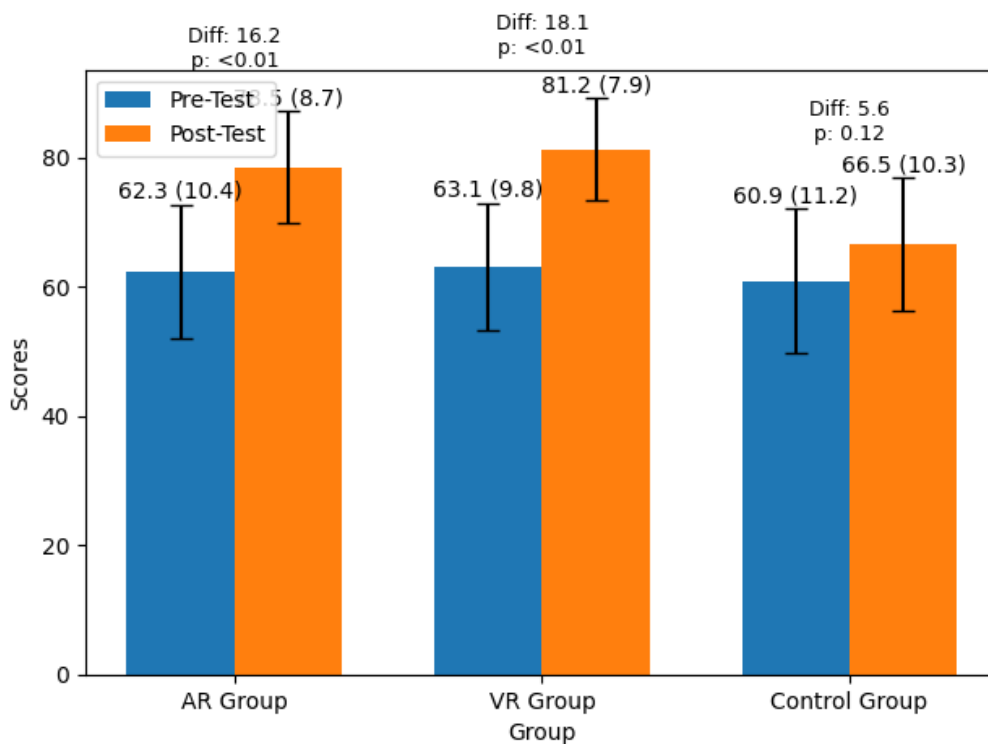


Figure 1: Pre-Test vs. Post-Test Scores by Group

*Quantitative Results*

**Pre-Test vs. Post-Test Scores:** The results of the post-test scores of the participants that belonged to the AR and VR groups depicted an improvement compared to their pre-test scores. The AR group achieved a mean improvement of 16.2% and the VR group, a mean improvement of 18.1% both of which were statistically significant ( $p < 0.01$ ). However, build up of the control group's mean scores the increase was just 5.6 points ( $p = 0.12$ ) suggestive of a lower level of improvement.

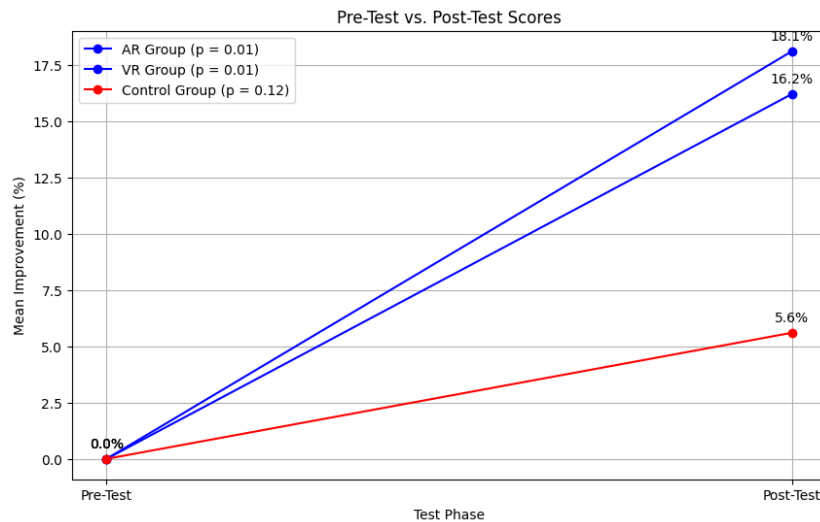


Figure 2: Pre-Test vs. Post Test Scores

The Figure 2 illustrates the improvement in test scores for AR, VR, and control groups from pre-test to post-test. Both AR and VR groups show significant mean improvements of 16.2% and 18.1% ( $p < 0.01$ ), respectively, while the control group's improvement is minimal at 5.6% ( $p = 0.12$ ).

**Student Engagement:** Observations made from the engagement surveys showed that students in the AR and VR groups were more interested and motivated than the control group. The engagement level of the AR group was 4.2 (SD = 0.8), of the VR group it was 4.5 (SD = 0.7) and of the control group, it was 3.5 (SD = 1.0). It can be stated that the differences in engagement were statistically significant  $F(2, 102) = 65.278, p < 0.01$ .

#### *Qualitative Results*

The existing analysis of focus group interviews also indicated that those students using AR and VR technologies had a positive attitude. Based on the two classes, learners in the AR group said that the application enhanced the visualization of geometric shapes in real-life settings. The VR students said that the simulation was helpful when it came to the perception of real-life abstract mathematical concepts. The shared benefits were more social communication, better perception, and problem-solving. On his part, control group students complained that they did not find traditional methods as interesting as the other method. These findings were further echoed by the teachers and the observations made during the lessons did indicate that the AR and the VR lessons were more effective than other conventional techniques. Teachers noted that students using these technologies were more engaging and interactive, these technologies improved on the usefulness and the cooperative nature of the learning process.

#### *Impact of AR and VR on Mathematical Understanding*

The study results reveal that the application of AR and VR technologies has positive effects on students' learning of mathematics in comparison with the conventional approach. Due to the fact that it is an interactive mode of learning, overlaying mathematics onto the physical environment enhances spatial skills and more. These benefits are more pronounced in VR because the learning contents are virtual and interactive; they closely mimic the real life environment which enhances students' interest and understanding of math. On the other hand, it was found that the control group which employed conventional approaches scored relatively lower, which proved that prior methods are not as efficient as new methodologies such as AR and VR in enhancing math understanding and learning, proving other researches about engaging and game based learning.

#### *Practical Implications*

The result of this study has significant implications for educators and the producers of educational technology. Integrate of AR and VR in teaching and learning of mathematics can be beneficial to students. Nevertheless, there are certain challenges like, cost of the technologies needed, training the educators and the creation of quality educational contents to make these tools effective.

## Conclusion

Based on the findings obtained from the work, the use of AR and VR improves students' comprehension of mathematical concepts more than using conventional approaches. Each of the AR and VR groups presented significant increase in post-test as well as increased engagement level compared to the baseline as recorded in the study, though the VR paradigm had the largest increase. Data from surveys that were conducted among the students and teachers also supports these findings implying that the use of AR and VR enhance learning due to the interactive and immersive property of the two. Based on these findings, one may conclude that the application of AR and VR in education is helpful and provides additional opportunities to make the learning procedure brighter and more successful. When such technologies are being planned to be incorporated in the educational institutions, some issues like cost and training have to be considered to make the best out of it. Further on, the findings suggest several directions for future research, overcoming the identified barriers, and investigating the long-term impact of AR and VR on educational practices.

### Appendix A: Data Collection Tools

#### A.1 Pre-Test and Post-Test Assessments

Quantitative data collection involved the pre and post-test questionnaire that was used to determine the differences –if any— that were demonstrated in the participants' mathematical content knowledge. Part of these assessments was a set of questions intended for ascertaining the students' comprehension of the main mathematical concepts. The pre-test questionnaire was completed before the implementation of the AR/VR based learning activities while the post-test questionnaire was completed after the set activities were completed.

#### A.2 Student Engagement Survey

Questionnaire The Student Engagement Survey developed by Fredricks et al. (2004) was employed in this study to measure the student's level of interest, motivation, and participation in the learning activities. Some of the questions were actual statements that the students had to rate on a Likert scale with 1 (being strongly disagree), and 5 (being strongly agree).

#### A.3 Focus Group Interviews

The qualitative data was obtained from the focus group interviews held with the students of each group. These interviews were planned to reveal the students' interactions with AR and VR technologies, as well as their impression on learning mathematical concepts. During the interviews, several questions were asked that were general and to which the interviewee would be expected to give constructive responses.

#### A.4 Teacher Observations

Teachers were giving qualitative response through Structured Observation Reports. These observations mainly concerned students' use of AR and VR tools, including their interest, interaction with other students, and achievement when using the tools. Contingencies that were labeled as specific criteria for observation referred to the behaviors and interactions students displayed to enable the schedules to be developed systematically.

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