Learning Through Visualising Solids with the Arloon Geometry Application
A Quantitative Study

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Abstract

In India, the use of augmented reality technology in the teaching-learning process of mathematics is in its early stages. The present study aimed to utilise the potential of the augmented reality-based android application The Arloon Geometry to improve the achievement of learners in the concept of visualising solids. A total of 500 Grade VIII learners participated in the quasi-experimental study. The results of the study allowed us to reject the null hypothesis and accept the alternate hypothesis that there is a significant difference in learning achievement of visualisation skills of learners when the application Arloon Geometry was used to visualise solids. The study recommends integrating augmented reality technology across various disciplines to improve the achievement level of learners.

INTRODUCTION

Research in mathematics education is required to enhance the teaching-learning process of abstract mathematical concepts. The abstract concept of geometry is problematic for learners in school. Van Hiele's Theory of geometrical understanding suggests ways of teaching geometry based on learning levels. The National Education Policy (NEP 2020) considers the use of digital technology

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in education as important (Ministry of Education, 2020). An initiative of NCERT, the e-Pathshala Augmented Reality Application aims to augment the textbooks and improve child-to-child, teacher-to-teacher, and child-to-adult communication. The optimal use of existing digital platforms and expanding technology-based educational initiatives are suggested by National Curriculum Framework (NCF) guidelines (NCERT, 2022).

Augmented Reality (AR) is the blend of the virtual world with the objects in the real world. With the use of augmented reality, users can overlap virtual images, sounds or texts on real-world objects around them. An experiment was conducted by Rossano and Lanzilotti (2020) using the application Geo+ with primary school students. The concept of solid geometry was taught using the application and the results demonstrated a significant change in the knowledge of solid geometry as a result of the intervention.

Researchers (Hanid et al., 2020) applied an instructional design model to design the GeoAR application and used it for research. The achievement in visualisation skills of geometry and computational thinking was measured using a quasi-experimental approach. The results discovered a significant increase in the achievement of the learners on a post-test based on the concept of geometry.

The use of AR technology for learning the concept of geometry is accepted through various research (Ziden, Ziden and Adu, 2022; Demitriadou, Stavroulia, and Lanitis, 2019; Cahyono, Firdaus, Budiman, and Wati, 2018). In the Indian context, research in this domain is scanty and the present research will be of great help to educators to design online content on their respective platforms on a national level (Kanvaria and Yadav, 2023). The findings of the present study will have important implications for educators to teach basic visualisation skills to learners.

Need and Significance of the Study

The current study aims to investigate the effects of a mobile application based on augmented reality on student achievement in a classroom environment. Because augmented reality facilitates the teaching-learning process, its application in education is important. It facilitates the creation of a blended learning atmosphere. The fourth Sustainable Development Goal (SDG) of UNESCO is to guarantee inclusive, equitable, and high-quality education and to encourage opportunities for lifelong learning for all. With the ability to access educational resources from anywhere at any time, mobile devices are spearheading a revolution in education (Del and Morales, 2018; NCERT, 2020; UNESCO, 2022). As a result, mobile learning plays an important role in bridging the gaps in rural and urban communities, the economy, and functional constraints.

AR is a potent learning tool that according to research, can help students retain resources better than they would have with more conventional teaching techniques. The current study's findings will assist educators in determining whether to implement augmented reality in the classroom and how much of this technology may be used to improve learning conditions. In the field of mathematics education, the study is important since mathematics is regarded as one of the challenging topics. Even if adults are eligible for higher degrees, they occasionally do not even understand the notion of visualisation in geometry. Numerous studies (Ziden, Ziden and Adu, 2022; Demitriadou, Stavroulia, and Lanitis, 2019; Cahyono, Firdaus, Budiman and Wati, 2018) back up the usage of AR technology to teach geometry concepts. There isn't much research in this area in India. Thus, the current study will be very helpful to educators in creating national online content for their platforms. The results of this study will have a significant impact on educators who must tackle the difficult issue of teaching mathematics to children who frequently lack fundamental visualisation abilities.

Review of Related Literature

The quality of mathematics education can be improved by connecting research with practice. Puig et al. (2021) and other team members presented LEGA, an approach to gamification of geometry learning. The results of the quasi-experimental study confirmed that digital game-based activities help in learning of geometry and improved geometrical thinking among learners. In a study conducted about approaches to mathematics teaching, Koskinen and Pitkaniemi (2022) found that conceptual teaching gains better learning results as compared to mechanical teaching. Denizli and Erdogan (2022) compared the achievement of primary grade learners in the concept of geometry before using augmented reality tools and after using it. It was found that the scores on geometry tests improved as a result of augmented reality-based intervention.

The team of researchers, Kondo et al. (2014) designed a framework in line with Van Hiele's levels of geometry learning and found that learning about solid shapes is better when properties of solids are explained with appropriate reasoning. Dynamic geometry environments (DGEs) were used by Ferrara and Mammana (2014) to teach visual geometry. The Cabri3D mobile application was used to engage learners in visual experiences. The results supported that visualising skills of learners were enhanced as an outcome of technology. Most research support that the appropriate use of technology facilitates geometrical thinking among learners of all age groups. Cahyono et al. (2018) compared four different technology-based learning applications to teach the concept of

geometry. One group used *Apple's Measure* application, another used *Google's Measure* application, third group used both applications; and one group was the control group. The performance on the post-test revealed that the groups using technology based mobile applications outperformed those who did not use technology.

The use of mobile application Geo+ was evaluated by Rossano and Lanzilotti (2020) with primary school learners. The results of the intervention using augmented reality-based application confirmed that educational achievement on geometrical concepts improved. The comparative study by Rohendi and Wihardi (2020) was conducted with junior high school students. The researchers designed geometry lessons based on AR for the experimental group. The research results supported that augmented reality-based lessons on geometry helped in increasing the understanding of learners at a significant level. Three-dimensional shapes were taught using augmented reality at the University of Malaysia as a part of the research. The team of researchers Ziden, Ziden and Adu (2022) found that augmented reality is helpful to teach students geometry concepts and the performance of learners on achievement test improved as a result of the intervention. The research team of Schutera et al. (2021) designed application *cleARmaths* to enable learners to visualise solids in a three-dimensional coordinate system. The application was used independently by the learners and spatial understanding of three-dimensional solids improved among them. An augmented reality-based application 3Dmetric was used by Amir (2020) and team, and the results confirmed that the use of application aids in improvement of learner's understanding.

The Arloon Geometry Application: The Intervention

Arloon Geometry is an educational application based on augmented reality. It displayed a fascinating way to discover the world of geometry. The application featured 3D models for geometric shapes that can be manipulated. The content was based on curriculum guidelines and all solid shapes can be visualised from different angles.

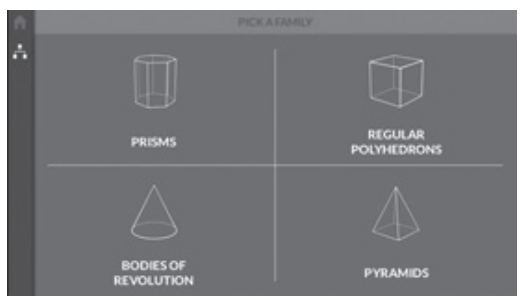

Figure 1: Classification of different 3D solids in Arloon Geometry Application

In this application, the solids can be rotated and moved sideways with a touch. The definitions and characteristic properties of each solid are also displayed.

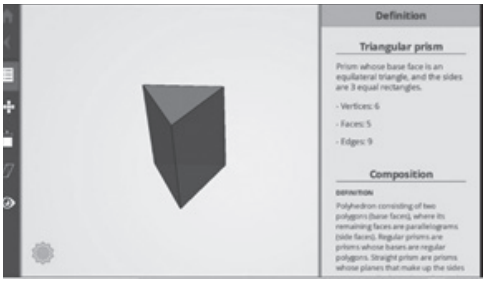

Figure 2: The representation of the definition and visual diagram of the solid

By overlaying virtual information onto the real world, AR technology can create a multi-sensory environment that facilitates the visualisation and exploration of abstract concepts. This can greatly enhance the learners' comprehension, critical thinking, and problem-solving skills. (Kanvaria, Yadav and Monika, 2023).

Research Objectives

The objectives of this quasi-experimental research are:

- To compare the changes in learners' achievement when taught using conventional teaching methods and mobile-based augmented reality application Arloon Geometry.
- To determine whether an augmented reality-based android application contributes in visualisation of three-dimensional solids.

Research Hypothesis

Null hypothesis: There is no significant difference in the achievement of learners when an augmented-reality-based android application Arloon Geometry is used to visualise three-dimensional solids.

Alternate hypothesis: There is a significant difference in the achievement of learners when an augmented-reality-based android application Arloon Geometry is used to visualise three-dimensional solids.

Research Methodology

Research design: A quasi-experimental research approach with a pre-test and post-test design was used to compare changes in the achievement of learners when taught using conventional teaching method and the Arloon Geometry application.

Sample: Using a non-probability purposive sampling technique, a sample of 500 Grade VIII learners from five different public schools in the Rewari district of Haryana was selected. The sample was divided into two groups: experimental group and control group. Each group contained an equal number of participants. We had 250 learners in the experimental group and 250 in the control group. The learners were matched using matching control technique (age, scores on a previous mathematics achievement test by school, same geographical location, same mathematics textbook) to ensure initial equivalence between the groups.

Sampling techniques: The given public schools were selected purposefully by the researcher as they meet the following criteria for selecting schools:

- Availability of learners learning in middle Grade VIII
- Medium of instruction was bilingual.
- Textbooks and Arloon Geometry application used has instructions in the English language.
- Availability of sufficient computer systems
- Access to the internet and network connectivity

Research tools: Learners math skills were assessed through a pre-test and post-test consisting of geometrical problems based on the Arloon Geometry application in alignment with the NCERT curriculum. The same test papers were administered to both groups.

(a) Pre-test: A pre-test was conducted before the intervention based on visualising solid shapes to collect information about the previous knowledge of learners.

(b) Post-test: The same post-test was conducted with both groups to determine the impact of both interventions on learners' achievement.

Controlling the effect of extraneous variables: In this experimental research, using the Arloon Geometry Application, controlling extraneous variables is essential to secure the validity and reliability of the results. Following steps were taken to minimise the effect of extraneous variables:

- Random assignment of participants to experimental and control groups. In each school, half of the learners were taken in the experimental group and the other half in the control group randomly.
- Learners' knowledge of mathematics visualisation was pre-tested using scores on their previous mathematics unit test conducted by the school.
- The group equivalence of experimental and control groups in each school was ensured based on their ages, prior knowledge of mathematics visualisation, mathematics curriculum followed in each school.
- All the schools selected were from the same geographical location to minimise the effect of environment, culture and language.

Tool validation: Face validity was used to validate the pre-test and post-test. They were validated using face validity by 10 elementary mathematics educators. Their observations, comments, and suggestions were incorporated and required modifications were made before administering it. A pilot testing of the tool was also conducted with 10 primary grade learners.

Process of experiment and data collection: The process of data collection in the research study that involves the intervention using the Arloon Geometry Application with the experimental group and having a control group following the regular mathematics curriculum without the

application involved following steps in each school:

- Two different sections of Grade VIII learners were selected.
- One section was assigned as experimental and the other as control group randomly.
- The pre-test was administered to both the experimental and control groups to measure their baseline knowledge of geometry, and visualisation skills. The sample learners were guided to complete the test based on their understanding under the observation of the researchers and another school-teacher in the classroom.
- For the experimental group, the intervention The Arloon Geometry Application was used to teach visualisation of solid shapes using augmented reality. The icons in the application displayed definitions, nets, formulae and features of each solid. The learners experimented with the application for a fixed duration of 30 minutes in each school.
- The control group was taught visualisation of solids using their regular mathematics textbooks. The characteristics of each solid and their identification features were shared with the learners using chalk-and-board teaching strategy.
- The post-test was administered to both the experimental and control groups to measure the changes in achievement of mathematics visualisation skills as a result of the intervention.
- All the collected data was analysed using statistical analysis techniques explained in the next section.

Data analysis techniques: The SPSS software was used to analyse the data employing both descriptive and inferential statistics. The standard deviation, mode and percentage were calculated for descriptive analysis. The paired t-test was used for inferential analysis (Creswell, 2014). The collected data from the pre-test and post-test were compared, and analysed to assess the achievement level of learners' visualisation skills. The t-test assessed the null hypothesis (any change in scores is due to chance) and an alternative hypothesis 95 per cent confidence that the change in scores was not due to change to see if the mean scores of the post-test results were reliably greater than the mean of the pre-test results (Mertler, 2017).

Data Analysis and Interpretations

The present research intended to look for the effectiveness of a mobile-based augmented reality application in the learning of the mathematical concept of visualising solid shapes. The 500 learners who participated in the study ranged from 12–14 years old. Out of the sample, 280 were male and 220 were female.

The following sections will guide the quantitative analysis. Before performing the t-test, we confirmed

that the difference between scores on the pre-test and post-test in both the control, and experimental group was normally distributed. The descriptive statistical analysis of the scores on the pre-test was done for all the participants. From Table 1, the mean score was 5.97, and the variability in the scores was 2.338.

Table 1

Score on Pre-test			
Mean	N	Std. Deviation	Std. Error of Mean
5.97	500	2.338	0.074

Descriptive analysis of scores on Pre-test

Table 2 presents the calculated values. The mean score of the control group is 11.95 and the mean of the experimental group is 16.65. The mean score of experimental groups is larger. We will now conduct the t-test to establish that this difference is statistically significant.

In the next column, the standard deviation of the control group is 2.038 while the experimental group is 2.243. Thus, there is slightly more variability for the experimental group than for the control group. The standard error of the mean for the control group is 0.064 and for the experimental group is 0.071.

The correlation between two variables is a single number that describes how related they are to each other. Table 3 gives out a form of correlation known as a Pearson correlation, and we see that the correlation between the pre-test and post-test for the control group is 0.065, and between the pre-test and post-test scores for the experimental group is 0.178. There is a positive correlation between the two variables. The table also has a p-value that is less than 0.05, and therefore, we can reject the null hypothesis that the correlation is zero.

The results of the statistical analysis suggested that learners'

Table 2
The Descriptive Analysis of Scores on the Post-test of Both Experimental and Control Groups

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Score on Pre-test	5.97	500	2.338	0.074
	Control Group Post-test scores	11.95	500	2.038	0.064
Pair 2	Score on Pre-test	5.97	500	2.338	0.074
	Experimental Group Post-test scores	16.65	500	2.243	0.071

Table 3
Correlation Between Scores of the Control Group and Experimental group

Paired Samples Correlations				
		N	Correlation	Sig
Pair 1	Score on Pre-test and Control Group Post-test scores	500	0.065	0.040
Pair 2	Score on Pre-test and Experimental Group Post- test scores	500	0.178	0.000

spatial abilities were significantly stronger in the experimental group than in the control group. The advantage of a paired research design is that the same people were tested in both domains so that subject-specific variables are all held constant. The paired design helps to isolate only what is different between the two test conditions.

Findings and Results

The findings of the data clearly stated that the mean score of the control group is 11.95 and the mean score of the experimental group is 16.65. The mean score of experimental groups is greater. The t-test established that this difference is statistically significant. The standard deviation of the control group is 2.038 while the experimental group is 2.243. Thus, there is slightly more variability for the experimental group than for the control group. We have interpreted that mean values for two variables with a sample size of 500 were higher for the variable experimental group (M=16.65, SD=2.243) than for the variable control group (M=11.95, SD=2.038). The difference in means (difference = - 10.680) was statistically significant, t (499) = -114.99, p=0.000. The results of the statistical analysis suggested that learners' spatial abilities were significantly stronger in the experimental group than in the control group.

Thus, there is a significant difference in learning achievement when an augmented reality-based android application is used to teach 3D geometry to Grade VIII learners. We can reject the null hypothesis if there is sufficient evidence that the mean of the experimental group is either higher or lower than the mean of the control group. The mean score of the control group is 11.95 and the mean of the experimental group is 16.65. The mean score of experimental groups is larger. The p-value is less than 0.05 and therefore, we can reject the null hypothesis that the two groups have the same means. Finally, we can see the 95 per cent confidence

interval for the difference which runs from −6.166 to −5.794 for the control group and −10.862 to −10.498 for the experimental group. It does not contain the value 0 backing up our rejection of the null hypothesis.

The correlation between the pre-test and post-test for the control group is 0.065 and between the pre-test and post-test scores for the experimental group is 0.178. There is a positive correlation between the two variables. The p-value is less than 0.05 and therefore, we can reject the null hypothesis that the correlation is zero. Thus, the results allow us to reject the null hypothesis and accept the alternate hypothesis that there is a significant difference in learning achievement when an augmented reality-based android application Arloon Geometry is used to teach three-dimensional geometry.

Conclusion and Recommendations

Among the prevailing models of ICT integration in education, the use of augmented reality is one example. The National Curriculum Framework guidelines (NCERT, 2022) suggest optimising and expanding the existing digital platforms, and ongoing ICT-based educational initiatives to meet the current and future challenges of quality education. AR is the fusion of the real and virtual worlds. This technology allows users to see the real world around them with two-dimensional or three-dimensional images overlapped on real-world images. Much research (Ziden, Ziden and Adu, 2022; Demitriadou, Stavroulia and Lanitis, 2019; Cahyono, Firdaus, Budiman and Wati, 2018) supports the use of AR technology for learning the concept of geometry.

The research aimed to find an alternative teaching approach for the concept of spatial visualisation of geometry using a mobile application based on AR. The results suggested that the spatial abilities of learners were significantly stronger in the experimental group than in the control group. The AR application was found beneficial for enhancing the knowledge and skills of the learners. Educators also supported the use of AR technology for teaching-learning of three-dimensional geometry. By integrating the use of AR technology into their pedagogy, educators can improve their learners' comprehension and promote a deeper level of understanding in learners who often lack visualisation skills. AR technology is a promising tool that can be used to help educators and learners reach their full potential in the classroom. AR as an alternative technology has the potential to revolutionise the teaching-learning paradigm in the near future. Learners find augmented reality-based learning content pleasant and helpful. The future applications of AR in education include further integration of simulations and spatial representations (Kanvaria, 2012). The understanding of spatial transformations and other mathematical concepts with the help

of AR will substantially contribute to STEM paradigms of 21st century education.

Scope for Further Research

It is suggested to incorporate augmented reality technology into different subject domains related to abstract concepts that are difficult to teach and difficult to visualise in realtime. The mobile-based applications should be designed keeping in mind the learning levels of learners and should follow the national curriculum, for example, the e-Pathshala application. Future work should determine what concepts are better taught using AR applications so they can be added to the educational application at the national level. In future research, it is important to determine the learning experiences that best fit AR technology. AR applications like Arloon Geometry should also have proper evaluation exercises to monitor and test the progress of the learners. It is suggested to use the latest marker-based AR techniques for a better user experience.

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