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Evaluation of memory retention among students using augmented reality based geometry learning assistant

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Abstract

The teaching of Mathematics – in particular, Geometry, through conventional methods has been a challenging task for tutors. Augmented Reality (AR) based applications available in commercial space, have not followed any structured pedagogical approach in the designing process, and also do not ensure that the learning time of students is spent prolifically. In this paper, we explore the use of AR in mathematics for geometry education, to aid visualization of multidimensional objects and long-term retention of concepts by the learners. For designing an appropriate AR application it is necessary to identify some principles which support better memory retention of the students. The application has been specifically designed on the basis of identified principles affecting memory retention. We further explain the development of an AR-based Geometry Learning Assistant (AR-GLA), using a structural approach to pedagogical-design for teaching 3-dimensional geometry to higher school students through improved visualization and enhance their memory retention for related concepts. A sample of 54 K-12 students and 2 teachers with expertise in mathematics were part of the experiment. The students were divided into two different groups; one of the groups was taught with AR-based content whereas the other group was given Interactive Simulation (IS) based learning. The results illustrated that AR-based learning provides better retention of memory as compared to IS-based learning were tested over a period of two months.

Keywords Augmented reality · Visualization · Pedagogical approach · Memory retention · Geometry education

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1 Introduction

Research in the field of education has always been an active topic to explain the necessary actions a tutor must take to enhance the motivation and attention of students and to prepare them for the digital age. According to Richard et al. (Felder & Silverman, 1988), students have many different ways of learning – by hearing and seeing, acting and reflecting, visualizing, interacting, imagining, or remembering the educational content. Not only the students but the teachers also follow different teaching styles; some explain and discuss the concepts, some focus on the application and principles, some include understanding, and others memorization. The conventional way of teaching is completely based on two-dimensional (2D) images and text which is sometimes not enough to provide a real learning experience to the students; especially in STEM education (Science, Technology, Engineering and Mathematics) with topics requiring visualization and abstract understanding. Examples of such topics are chemistry, electronics, architecture and geometry. Augmented Reality (AR) is a visualization technique that combines virtual and real scene-setting (Akçayır et al., 2016), and helps in deep understanding through the visual phenomenon. The research has revealed that AR helps in better engagement while learning which in turn increases knowledge, understanding, motivation and memory retention (Akçayır et al., 2016; Dunleavy et al., 2009; Reyes-Aviles & Aviles-Cruz, 2018). Memory retention is very important for subjects such as Kinematics and Geometry, which require retaining the concepts for a long time. AR can help students learn in a better way as it includes animations and interaction; also, it has the potential to reduce the effort put in by the teachers making it easier to deliver the concepts to the learners (Munoz-Cristobal et al., 2015).Although there has been a lot of research in the field of mathematics, 3D geometry has not been explored to much extent (Silva et al., 2019; Yilmaz & Rabia, 2016).The research shows that the work done in the field of geometry is not properly mapped with the curriculum (Silva et al., 2019). Work done in geometry is limited to shapes, volume or area concepts but the abstract concepts still not much covered.

1.1 Augmented reality and virtual reality in geometry education

Augmented reality (AR) is the multimedia technology that helps in overlaying computer-generated objects into humans' imagination of the real-environment (Saidin et al., 2014). It has been seen many times that AR is allied with many expensive devices that need significant processing ability. But along with fast advancement in mobile phones, a wide range of AR techniques can easily be executed, such as tabletop with a web camera or mobile (Brill & Galloway, 2007; Prensky, 2001).

In the field of education, most of the researchers believe that AR can enhance the technology of interactivity and put an enormous potential implication along with various advantages from virtual augmentation of the teaching and learning process (Chang et al., 2016; Saidin et al., 2014; Ozdemir, 2017a; Turan et al., 2018). As an educational technology, AR is used to enhance the spatial visualization and interest of students in a few subjects with the help of skill training, object modeling applications, and interactive AR books (Saidin et al., 2014). Examples include JonoBox, which is an application developed for learning geometry (Young, 2018) and provides a better understanding of various shapes in geometry. Construct3D is another application that makes use of head-mounted displays (HMDs) and implements an object modeling approach to design the AR-based learning tool for geometry (Ozdemir, 2017b). Also, construct3D supports and promotes discovery-oriented teaching by using geometry construction with the help of a stylus to give input to the AR-based teaching application. It has also helped in increasing students' understanding and visualization of objects in the real environment. Although there are many such applications available, none of the aforementioned applications caters to senior secondary education following a pedagogical approach, involving visualization of abstract concepts.

Virtual reality (VR) is a virtual experience that can be both comparable and dissimilar to the actual world. Entertainment, education, and business are all examples of VR applications (Le & Kim, 2017). In contrast to AR, VR takes place in a virtual environment, and the person becomes an immersive or non-immersive member of that virtual world as discussed in Table 1. With the use of various gadgets such as haptic devices, individuals can interact with and modify computer-generated things in a virtual environment. Implementation of VR in education have highlighted some of issues like high financial cost is required, less realism, and reported physical issues after a certain period of time (Christou, 2010).

1.2 Memory retention

Memory retention is a process of recalling the previously learned content and can be enhanced with the help of AR-based learning, as it gives a better learning experience and visualization. Research indicates that rigorous work needs to be done for verifying the effectiveness of AR for educational purposes and its effect on memory retention (Majuri et al., 2018; Treiblmaier & Putz, 2019). Memory retention in students can be directly improved by enhancing the spatial visualization of the students. Spatial visualization is the ability to develop, manipulate, rotate, and mentally design objects, and is highly required in vector addition of mathematics (Thornton et al., 2012). The spatial visualization helps in concept comprehension by processing the learned information in the working memory (Slijepcevic, 2013), the enhancement of this ability strongly focuses on reasoning skills, critical thinking, and high-level imagination (Camba et al., 2014). So, if the visualization of students is increased memorization can also be increased.

The main aim of the current study is to create such an environment that is capable enough to provide an engaging and interactive experience and then to analyze the effect of the same on the students. To accomplish the objective, the development, and implementation of Geometry Learning Assistant (GLA) has been anticipated for K-12 students. The vector addition has been chosen from 12^{th}-grade mathematics for the execution of AR-GLA. The main objective of the developed application is to assist the students in their learning and long time retention of the concepts related to geometry as this topic requires the concepts which continue for some time (Alloway, 2006). A

Table 1 Difference between AR and VR in geometry

Factors	AR in Education	VR in Education
Immersive	It provides partial immersion. The user is still connected with the real world	No sense of being in the real world. Takes the student away from the reality
Gadgets	While learning geometry through AR there is no requirement of headsets or controllers	In VR one requires headsets and controllers to learn geometry
Cost	As no hardware is required so the cost is less	The inclusion of gadgets increases the cost of VR system
Impact	Enhances both the virtual and real world	Helps in improving only the fictional world

pedagogical approach was followed for the development of this application so that the students can easily relate the content with their textbooks and retain the information.

1.3 Interactive learning and AR

Studies demonstrate that AR — the real-time integration of virtual objects with real-world objects — and Design-Based Learning (DBL) — to make learning more engaging— can help students learn more effectively. The employment of both at the same time is referred to as "Augmented Reality Game-Based Learning" (ARGBL) (Tobar-Muñoz et al., 2016). Due to disparities in how designers and practitioner instructors conceptualize learning and learning objects, there is still a gap between designers and practitioner teachers when building ARGBL experiences. As a result, it's critical to develop ways that incorporate both designers and instructors in order to maximize ARGBL experiences in the classroom (Alloway, 2006).

Section 2 of the paper, discusses about the related studies done in the area of AR and the work done in geometry. Section 3, represents the objectives of the manuscript. Methodology including all the phases of development along with the information of participants is disused in Section 4. Section 5, will be involving the results and discussions of the overall work done.

2 Related studies

Before starting with the implementation and designing of AR-GLA, an extensive literature survey of the available research on AR-based geometry applications has been conducted. Table 2 shows a summary of the existing applications for learning and teaching geometry.

The study in most of the discussed articles has mainly focused on evaluating the student's motivation, learning gain, and efficiency for educational purposes. Additionally, maximum studies emphasize exploring shapes in 3D, area, and volume (Kaufmann & Schmalstieg, 2006; Kirner et al., 2012; Le & Kim, 2017; Radu et al., 2015), and not on the topics for higher grades and memory retention. Also, vector algebra is a topic that has not been implemented using AR in any of the above-reviewed studies (Young, 2018).

3 Methodology

Figure 1 shows the framework of the proposed tabletop environment, AR-GLA, in three phases.

3.1 Phase 1: The exploratory phase

At the initial stage, it is really important to identify the current landscape of ongoing research on AR in education. An extensive literature has been done to identify

Table 2 Summary of the existing application in geometry education

Title	Limitations	Findings
Construct 3D	Weight of hardware, performance, and size technology in early 2000	AR applications using see-through HMD cause several usability problems (Kaufmann & Schmalstieg, 2006)
AR Interactive Book	Only focusing on spatial Visualization	AR-based learning book provides a promising resource and motivation (Kirner et al., 2012)
AR Protector	Target's only angle and line visualization	Using AR increases the motivation and attention of students while learning geometry as compared to traditional learning
Cyberchase Shape Quest	A set of printed flashcards is required	AR games require an iterative method. It requires testing the game often and early. It involves experts from different domains (Radu et al., 2015)
AR Application with Hand Gestures for 3DGeometry	The framework requires extra devices to recognize hand gestures as input	The amalgamation of hand gestures and AR can enhance students' understanding while learning geometry (Le & Kim, 2017)
GeoGebra	It is a purely desktop-based online simulator that does not allow better usability, flexibility, and visualization	Using GeoGebra helps in enhanced learnability as compared to traditional learning

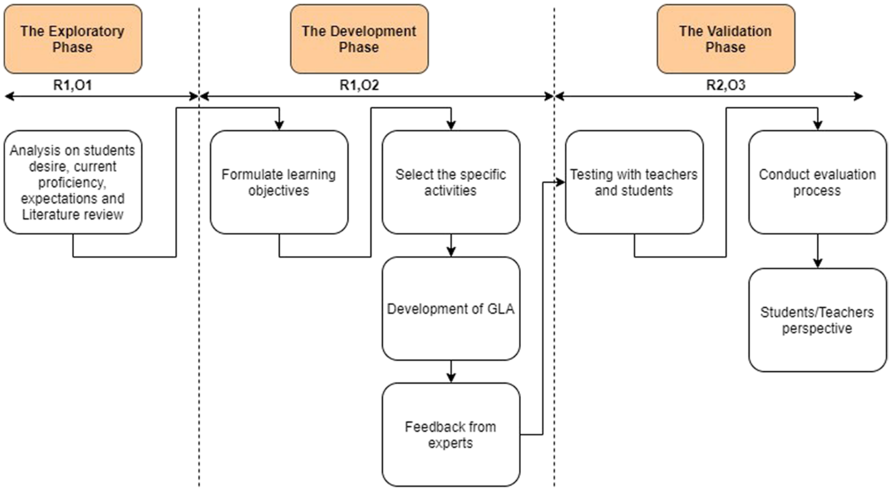


Fig. 1 Framework of AR-GLA

certain factors that affect memory retention as shown in Fig. 2. All the duplicate entries were deleted while selecting the valid factors. The finalized retention factors after discussion and deleting the duplicate entries are motivation (Amin & Malik, 2014), relevance (Boyd et al., 2019), confidence (Amin & Malik, 2014), and satisfaction (Hou & Wang, 2013) as shown in Table 3. So while designing GLA, these four parameters have been kept in mind so that the content is provided in such a way that an enhanced rate of memory retention is achieved. For designing GLA a topic has been selected according to students' and teachers' desires and expectations.

Geometry is considered to be a subject that requires 3D visualization, more flexibility, and usability while learning and performing it on a sheet. It has been noted

Fig. 2 Literature review based on memory retention

Table 3 Constructs assigned after factor analysis

S.No	Memory Retention Principles	Constructs Assigned
1	Rewards, Enjoyment, Association, Environment, Visualization, Satisfaction, Learnability	**Motivation**
2	Relevant Data, UI Design, Real-Time Examples, Context-Based, Consistency	**Relevance**
3	Low Physical Efforts, Organized Data, Appearance, Early-Test	**Confidence**
4	Efficiency, Interactive, Simplicity, Error-Tolerance, Responsiveness, Easy to Use, Skip able Content	**Satisfaction**

that the students face many challenges while learning the course. Many students find it difficult to switch from pictorial to graphical representations in field vector (Bollen et al., 2017). While constructing a vector plot, students usually failed to visualize in 3D that how are the direction and magnitude of the vector changing with respect to the origin. So, it becomes important to present the content of the lecture in such a way that the students can learn of themselves with complete immersion and interaction for better understanding and retention.

3.2 The development phase

3.2.1 Formulating learning objectives

The selection of the topic goes through certain steps:-

1. Discussed with 6 experts and 9 school teachers with a minimum of 5 years of teaching experience.
2. Noted few topics which need visualization in a three-dimensional world, and hard to understand with normal textbooks.
3. Talked with 12 students regarding the difficulty of the topic and the points where they stuck while learning through traditional ways.

3.2.2 Select the specific topic

After discussing with teachers and students a specific topic was selected i.e. **3D vector**. 3D vector includes:

- Depict 3D space mathematically.
- Position points in free space via coordinates.
- Distance formula in 3D.
- Equations for spheres and planes.

This is difficult to imagine and interpret in the real world.

3.2.3 Development of GLA

The developed application follows the Modality Principle (MP) of multimedia learning which supports that the presentation of words through narration in addition to on-screen visuals results in higher retention rates (Moreno & Mayer, 1999) *(Enjoyment)*. An extensive literature supports that the amalgamation of auditory and visual text modalities helps in increasing the capacity of working memory (Penney, 1989). As the MP helps in better memory retention so the principles are followed to achieve better results in the learning *(Satisfaction)*.

Design-based learning (DBL) has also been adopted in the present research paradigm. DBL is a flexible but systematic method aimed to enhance learning practices by design, iterative analysis, development, and validation, based on group efforts among practitioners and researchers in real-environment settings *(Environment)*. The design process is user-specific and is anticipated to be iterative *(Early Test)*. The application intends to put visualization along with interactivity and testing of knowledge after learning *(Visualization)*. The UI of the application is easy to use and understand and also interactive *(UI Design)*. In the testing phase rather than giving the solution the student if unable to solve the problem would first be provided with some clues or hints so that, they can try to retain memory and solve the problem on their own *(Learnability)*. The students are given points for every correct answer *(Rewards)*.

The AR-GLA is a mobile or tablet-based application, the kit provides an adjustable holder for the placement of displaying device so that the student can have a hands-free experience of learning as shown in Fig. 3 (*Low physical efforts*). The content is delivered in such a way that it is easy to understand and correlate with that of the textbook *(Relevant data, Simplicity)*. The developed application can either be used by a group of students or individually as shown in Fig. 4. It is a portable learning kit that can be carried anywhere easily along with the required objects (e.g. markers, graphs, etc.).

For development and scripting Unity 3D engine has been used. ***Unity*** is a game engine that is a commercially accessible cross-platform used not only for constructing 2D and 3D games but also non-game visualizations and interactive simulations. The project created can be extended by writing a script using C# in MonoDevelop. ***Vuforia*** is a software development kit (SDK) for building AR apps. Developers can very easily attach functionalities of computer vision to any application, allowing it to identify objects and images, and interact in the real environment. Vuforia supports the development of AR app for Android, UWP, and iOS devices.

AR-GLA covers a few topics of mathematics: Vector addition, subtraction, cross product, dot product, position vector, and direction ratio, which come under vector algebra of grade 12th. The software development kit (SDK) named Vuforia

Fig. 3 Tabletop setup of AR-GLA

Fig. 4 Delivering the content using AR-GLA

is imported as a package in Unity 3D. This will provide a trackable image in the form of a marker and enable the camera to properly work in Unity 3D. The workflow of AR has three main components named Capturing, Tracking, and Rendering. **Capturing** components include the configuration of an AR camera that captures the marker on the developed tabletop-like environment. **Tracking** components use a machine vision technique that processes the image captured which further matches the vuforia database. **Rendering** components overlay virtual components onto AR marker and therefore AR can display the augmented object or view on the display monitor.

The following are the steps, explaining the process of visualization of vector algebra through AR-GLA.

- Here, the markers are placed on the graph, which is permanently augmented in the application.
- The application includes three interactive buttons learn; test your knowledge and user manual as shown in Fig. 5.
- Then the tablet, which is mounted on the tabletop, is used to scan the markers and images overlaying in the real environment.
- Four makers are used here symbolizing the origin ('O'), vector A ('A'), vector B ('B'), and the resultant vector ('R') as shown in Fig. 6.
- By using image processing directly based upon the vision-based system to target the image is used to find the resultant scalar product of two vectors.
- The movement of all the markers which can be done in any of the three-axis (axis X, Y, Z) will be traced by the algorithm and the results depending upon the position will diverge.
- The outcome can be seen on the display screen of the tabletop which shows the results of the real scene along with some virtual objects.

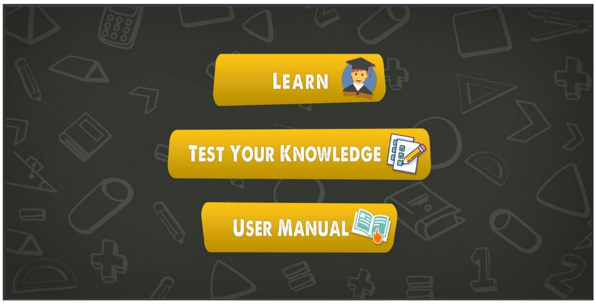


Fig. 5 User interface of the AR-GLA

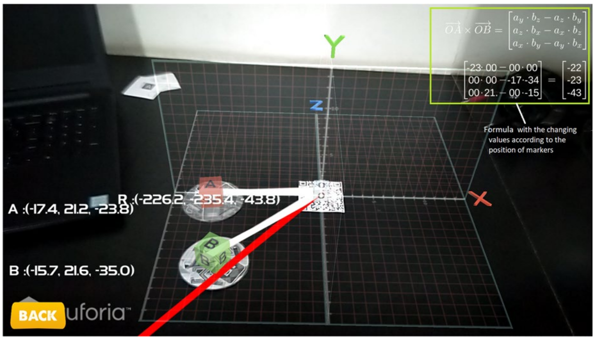


Fig. 6 Scalar vector

Figure 7 demonstrates the UML-Class diagram for GLA created in visual studio which explains the behavior and elements of the game objects. The Main Controller contains the main menu controller which holds different scenes which have been created in unity 3D. In the menu controller, different activities have been attached of which students either can try out an activity or see the real-time example of the activity.

Figure 8 shows the workflow of the application. First of all the kit will be set up and the makers would be placed, after scanning the markers UI of the application will be visible. After that, all the activities of the application will be showed and one can select the desired one to learn and perform.

3.2.4 Feedback from experts

The application was given to the experts of the field including developers, researchers, and teachers of specific subjects for feedback regarding the usability and learnability of the application. Table 4 shows the two-step development of the application which includes an initial phase and then the updated phase. The table discusses the advantages, limitations, types of markers, different designs of UI, augmented information and, design-based issues.

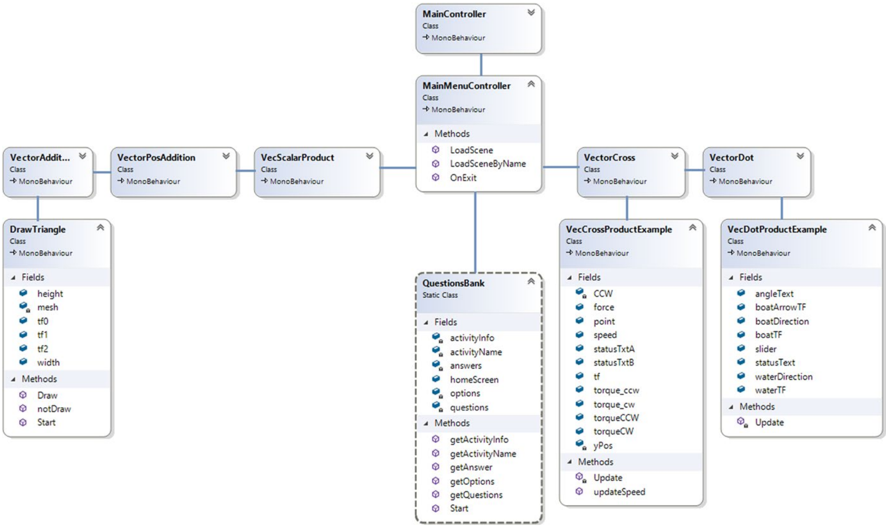


Fig. 7 UML-class diagram of GLA

3.3 The validation phase

3.3.1 Teaching Strategies (TS)

The teaching experience was taken from the students through a questionnaire. The test was being carried out as a quasi-experimental pre-test/post-test in a real teachings scenario (TS). Therefore, two TS would be chosen to carry out the implementation of treatments.

- One will be through Interactive Simulations (IS) which is an open-source application available online. IS provides a 3D visualization along with some digital content to enhance the learning outcome.
- Another will be the proposed application AR-GLA

3.3.2 Participants

A total of 54 students were divided into two groups. The same topics will be delivered in two different styles to check better treatment and its impact on students learning. Students from two different sections were taken as TS1 will other as TS2. The results of both the scenarios will be compared as shown in Fig. 9. A pre-test was conducted among all the students from TS1 as well as TS2 to ensure that they have equal and no knowledge about the topic.

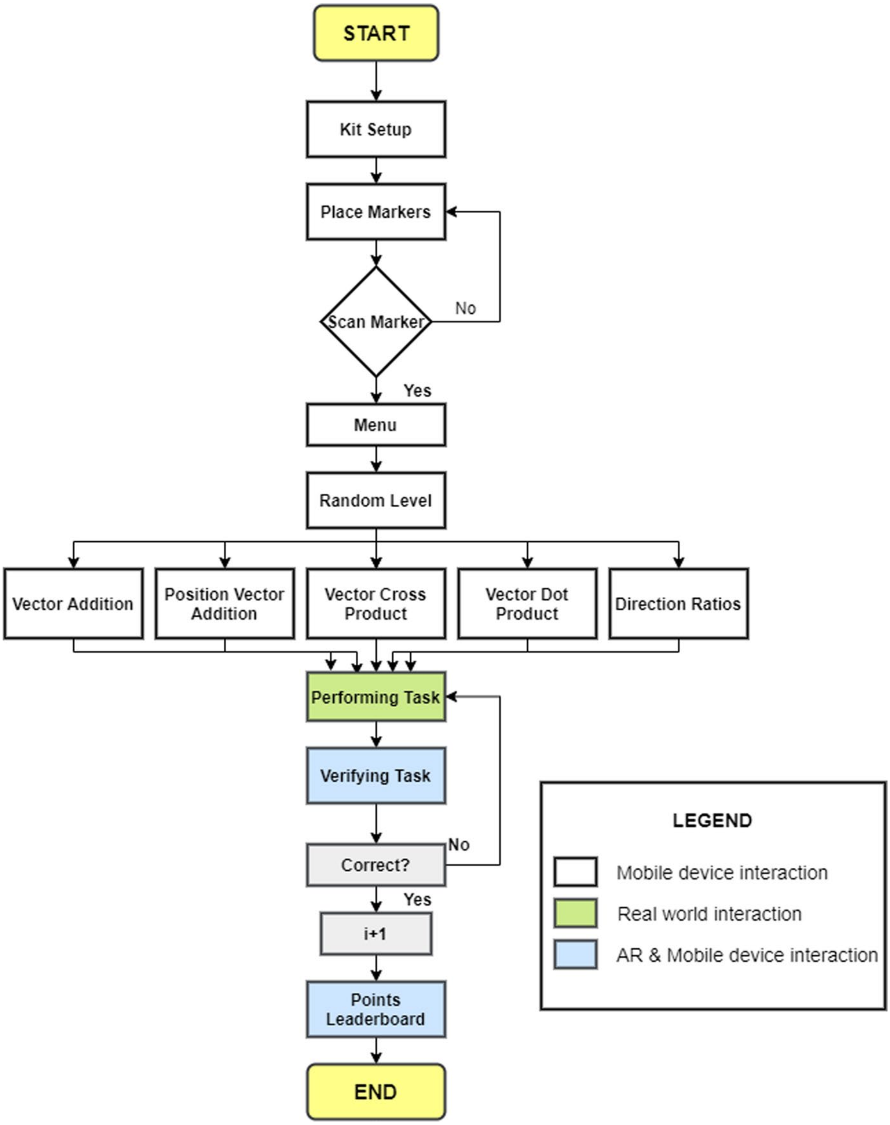


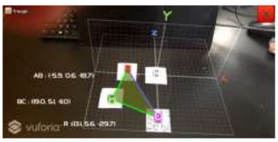
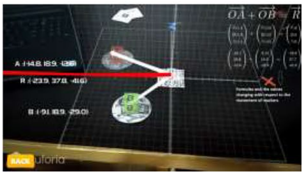
Fig. 8 Workflow of GLA

3.3.3 Research design of AR-GLA and procedure

The learning through both methods was evaluated by conducting a post-test. The following were the steps of the evaluation process:

- A post-test was completely technical and interrelated to the content students have learned using different methods of the learning process. The questionnaire was

Table 4 Different Stages of Development

Factors	Scurry I of AR-GLA	Scurry II of AR-GLA
User Interface (UI)	Simple UI with no pictorial information 	Enhanced UI with pictorial information for better understanding 
Markers	No color and fewer edges 	Colorful and more edges 
Real-Time Examples	In the first stage of AR-GLA, there was no activity related to explaining the usage of the selected topic.	In the second stage of the application, there were supported real-time examples to explain the topic. 
Design	The application included a mobile stand that is not foldable, also not easy to carry and the detecting devices were not completely fixed.	The updated version consisted of a compact, easy to carry, foldable stand which eventually helps in better visualizing.
		
Information Displayed	In the first version of the application, there was no such information displayed which can easily help in relating the activity with the textbook information. 	The second phase of the application was updated with all the relevant formulas and changes according to the changes in vector position. 
Advantages and Limitations	Low detection rate and no information displayed related to the ongoing activity.	Easy detection, scanning of markers and displayed all the relevant information of the activity.

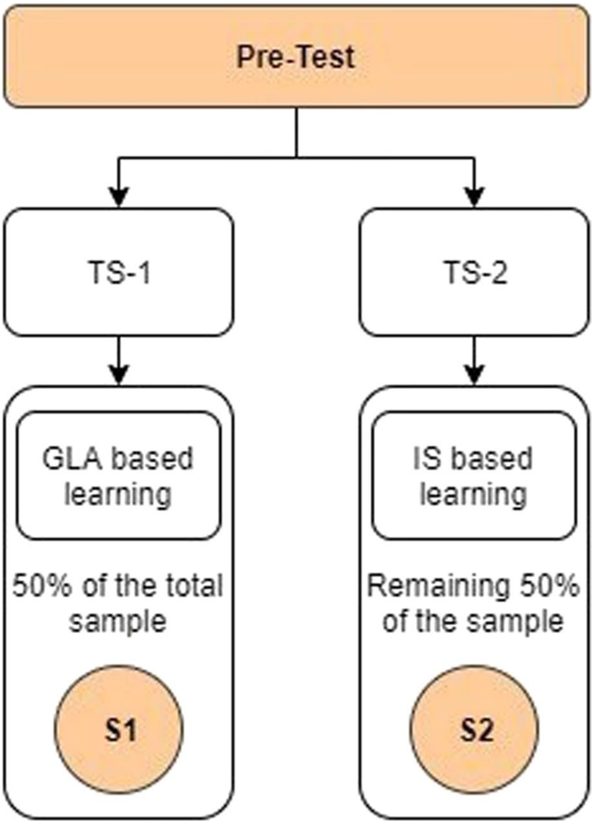


Fig. 9 TS with two different ways of learning

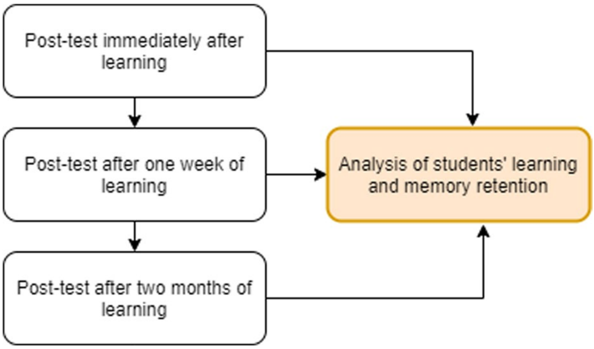
approved by experts and subject teachers. The questionnaire helped in identifying the knowledge attained while learning.

- To evaluate the effect of AR intervention on memory retention capabilities of students, three evaluations were taken for both groups. The first evaluation was conducted immediately after learning the second evaluation was conducted after two weeks without prior notice whereas the third evaluation took place after two months of learning without intimating the students as shown in Fig. 10.

3.3.4 Instrument

The questionnaire was designed consisting of 15 questions and was validated by teachers having 8-10 years of teaching experience in mathematics. Students were given marks ranging from 0 to 15 based on their performance in the evaluation. After checking the normal distribution of the scores, an independent sample t-test was done to find out the difference in scores of both groups for the first evaluation. The questionnaire given to the students was divided into three sub-categories:

Fig. 10 Quasi-experimental setup



i) Remembering – 4 questions (Q1-Q4)
ii) Understanding – 6 questions (Q5-Q10)
iii) Applying – 5 questions (Q11-Q15)

4 Results and discussion

4.1 Results

54 twelfth-grade students of two sections participated in the evaluation process. The whole process continued for a period of two months. The first group consists of 29 students and group two consists of 25 students. Students of the first group were made to teach with AR i.e. TS1 whereas, the second group was given IS-based learning i.e. TS2. Initially, the students of two different sections were provided a pre-test to ensure that the students from both sections have an equal level of knowledge. Table 5 shows that the students from AR-based (2.92) and IS-based learning (3.04) do not have any significant difference in the mean value.

The first evaluation of both the learning process took place immediately after the completion of learning. Considering a normal distribution in primary data, paired sample t-test, with a confidence level of 95% was applied. As shown in Table 6,

Table 5 Pre Evaluation results

Pre-Evaluation	AR-based learning mean (std. dev.)	IS-based learning mean (std. dev.)	ρ-Value
	2.92 (2.253)	3.04 (2.226)	0.802

Table 6 Retention analysis immediate after learning

First Evaluation immediate after learning	AR-based learning mean (std. dev.)	IS-based learning mean (std. dev.)	ρ-Value	Cohen's d
	12.24 (1.920)	9.64 (2.325)	0.00	1.2194

the p-value is significant i.e. it is less than 0.05. A value of 1.2194 was obtained, which shows a large effect according to Cohen, (0.2 shows small effect; 0.5, a modest effect; and 0.8, a large effect).

The second evaluation took place after one week of initial learning and the students were given a test without prior notification. The analysis shows a significant difference between both the mean scores as shown in Table 7 mean for AR is 11.76 whereas, the mean score of IS based learning is 8.00. This means that students of the AR group showed better memory retention than that of IS-based learning.

The third and the last evaluation took place after two months of the initial learning. The p-value comes out to be 0.01 which is less than 0.05 and showed a significant difference as shown in Table 8. The mean score of both the groups clearly shows that students who learned using AR retained the lessons for a longer duration as compared to IS-based learning students who showed less retention rate.

4.2 Comparing learner's perception

The influence of AR and IS based learning on geometry learning motivation, problem-solving skill, and geometry learning achievement was compared and assessed by gender. After excluding the effects of the pre-test on the learning perceived learning, perceived ease of use, and perceived satisfaction was calculated as shown in Tables 9 and 10, the gender variance did not reach significant. As a result, AR-based learning could effectively enhance both the genders' learning motivation, problem-solving skills, and geometry learning achievement. Also the results of IS based learning showed no significant difference between the male and female perceived learning.

5 Discussion

As discussed above to answer the research question first, it is an important and initial step to find out the knowledge retention principles before designing an AR-based application. With the help of a literature review, some of the factors were identified after that factor analysis was done to remove all the duplicate entries. So in the end, final constructs were assigned i.e. motivation, satisfaction, relevance, and confidence which are considered as the most required factors which depend on knowledge retention. In the development phase also these constructs

Table 7 Retention analysis after one week

Second Evaluation one week of learning	AR-based learning mean (std. dev.)	IS-based learning mean (std. dev.)	ρ-Value	Cohen's d
	11.76 (1.899)	8.00 (2.140)	0.001	1.858

Table 8 Retention analysis after two months

	AR-based learning mean (std. dev.)	IS-based learning mean (std. dev.)	ρ-Value	Cohen's d
Third Evaluation after two months of learning	11.32 (1.951)	6.44 (2.88)	0.01	1.983

were kept in mind to achieve better results. These factors proved out to provide enhanced knowledge retention among the students.

The results as analyzed above showed a high rate of knowledge retention when the content is delivered through AR mode to justify the research second research question. A continuous decrease in the level of remembering was noticed in the students from the IS-based learning group. So, it is clear from the observation that interaction, visualization, and real-time examples help in better and enhanced retention of abstract concepts. It becomes necessary to prepare the content in such a way that it helps students in easy and interesting learning with a long-term retention time. In the initial assessment, AR-based learning showed a mean of 12.24 and a standard deviation of 1.920, and the second evaluation which was conducted after two weeks of learning showed a mean of 11.76 and a standard deviation of 1.899 followed up the last evaluation after two months showed mean of 11.32 and standard deviation of 1.951. The results showed that there is not much drop in the retention rate of students during an AR intervention. Whereas, IS-based learning, showed decrease in the retention rate (i.e. from 9.64 to 8.00 and eventually from 8.00 to 6.44). The mean score shows a significant difference between both the interventions and shows that AR provides an improved remembering and retention rate.

6 Conclusion and future scope

The main aim of using the AR-GLA system for learning purpose is following recent researches which show that student's learning improves through visualizing and interactivity (Atwood & Huffman, 2017; Kaur et al., 2018; Singh et al., 2019). The proposed application intends to add both visualization and interaction

Table 9 AR- Analysis of covariance based on gender

Variable	Group	N	Mean	S.D	Adjusted Mean	Std. Error	F	η^2
Perceived Learning	Male	17	4.18	0.52	4.07	0. 07	0.50	0.005
	Female	12	4.04	0.78	4.18	0.11		
Perceived Ease of Use	Male	17	4.25	0.57	4.17	0.07	1.45	0.004
	Female	12	4.24	0.82	4.33	0.010		
Perceived Satisfaction	Male	17	4.35	0.94	4.10	0.09	0.03	0.002
	Female	12	3.99	0.25	4.02	0.08		

Table 10 IS- Analysis of covariance based on gender

Variable	Group	N	Mean	S.D	Adjusted Mean	Std. Error	F	ɳ^2
Perceived Learning	Male	13	2.7	0.29	2.5	0.06	0.42	0.005
	Female	12	2.8	0.37	2.7	0.10		
Perceived Ease of Use	Male	13	2.1	0.3	2.2	0.05	0.99	0.004
	Female	12	1.8	0.1.9	1.7	0.05		
Perceived Satisfaction	Male	13	0.9	0.7	1.3	0.2	0.01	0.003
	Female	12	1.3	0.24	1.1	0.6		

in the learning process which makes learning easy and interesting. For vector algebra of mathematics, a tabletop environment has been created where students can learn and test their knowledge. The present AR application has covered the entire vector algebra; vector addition (triangular law, parallelogram law), dot product, cross product, scalar, and vector product. The application has been build to validate the effectiveness of AR-GLA in mathematics and more precisely to make the students learn better and have better memory retention. It is required to train not only students but also the teachers for effective use of an application. Mobile/ Tablet based AR application is more demanding over PC-based application as mobile/tablet-based AR provides portability, easy availability (Gargrish et al., 2020a, b). However, mobile-based AR had also reported few problems such as screen size, handling issues while learning, etc. All the mentioned issues need to identify for easy and problem-free usage. The proposed AR-GLA (scurry I) was developed and first provided to experts for smooth and easy use. Then scurry II was removed with all the problems like difficulty while tracking the markers, flickering of the device while holding, and difficulty in holding the device from one hand. As a result, students were able to learn using AR-GLA without issues. At last, an interview session was conducted with the educators. According to teachers, the students enjoyed the learning session using AR-GLA. They also suggested that it is an influential and helpful teaching aid that can be used with conventional teaching as it enhances the enthusiasm and level of interest of students during learning. But the technique is not limited to this discussed topic but can be used for other topics of 3D geometry that require visualization and interaction in 3D space.

Declarations

Conflict of interest None

Information regarding the resubmission of previous rejected paper In the beginning the submission was created in a special issue and after few days of the submission I received a feedback to make a submission in Education and Information Technologies as it was not in the scope of that special issue. So, that is the reason on making a new submission. Please consider.

"I, **Shubham Gargrish** the Corresponding Author, declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.
I can confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. I further confirm that the order of authors listed in the manuscript has been approved by all of us.

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