ScholAR: a collaborative learning experience for rural schools using Augmented Reality application

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***Abstract*— Collaborative learning involves working in groups to solve a problem or perform a task. Collaborative learning is often encouraged in rural schools as due to lack of space and infrastructure, students are made to sit on floors and taught together within and between groups. Evidently, in rural schools, technologies have been introduced to support the existing teaching methods. Augmented Reality is one such technology that can provide a collaborative interactive experience. In our study, we provided an AR based application named 'ScholAR' to experimental group of 16 students of 7th grade as at that age they cultivate the ability to reason logically and develop conceptualizing skills. The application involved six tasks on the Mathematics topic of Introduction to 3D Solids targeted to enhance the spatial visualization skills of the students. We did a comparative study with the control group of 16 students who were taught the same topic using physical 3D models and the usual teaching method followed in their school. We report the results of this study, observations and analysis of the use of this AR application in a collaborative environment and the effect of collaboratively using the AR application on the students' performance.**

Keywords—Augmented Reality, collaborative learning, rural education, ARCore

I. Introduction

Over the years, the evolution of technology has witnessed its adoption in various fields including education which has impacted the current ways of teaching and learning. In K-12 education, the traditional method of teaching like using blackboards is now being supported by various technological means, targeting to enhance the learning experience of the students and develop their intellectual skills. Use of projector screens, interactive whiteboards, online learning systems, interactive mobile and desktop applications and virtual learning environments are some of the technologies that are being explored inside and outside classrooms. These are also helping teachers and/or parents to monitor the regular progress of every individual student.

Among the various technologies, Augmented Reality (AR) is one such emerging technology in the field of education. AR enables superimposing virtual graphics on to current existing environment in real time. Various advantages of AR like projecting vector graphics on real world, annotations, visualization of concepts, virtual instructions, collaborative learning have been previously reported [1]. Thus, incorporating AR in classrooms has a huge scope in the domain of education [2].

The use of technology is not limited to only urban schools. Our primary research led us in knowing that the rural schools are not far behind in using the support of technology along with its usual teaching methods. Use of mobile applications by teachers and/or use of projector screens to project some modules or experiments are some of the ways in which technology use is encouraged in rural schools. Due to lack of space and infrastructure, the students are made to study and use the technology in collaboration, the details of which have been discussed in the next section. Thus, benefits of collaborative learning where tasks or problems are made to be solved in groups, can be incorporated with other technologies to be easily adopted and used in rural schools along with its regular curriculum.

In this paper, we present the design of an AR based application used to learn collaboratively. The observations and results of the study conducted with 32 students in two groups of 16 each (experimental and control group) have been reported. The broad goal of the study was to observe the interactions of the students with the AR application and the effect of using it on their performance.

II. Background Work

The broad goal of the study was to understand the role and scope of technology in Indian education.

A. Primary Research

The primary research was done through field survey in three Indian rural schools to understand their existing method of teaching and the role of technology in that. In all the surveyed schools, there were very less number of students in each grade, ranging from around 8 to 35 students. These schools followed the state board syllabi. The teaching methods varied slightly in all three cases.

In first school, the classrooms were segregated subject wise rather than grade wise, where instead of the teachers, the students would go to different classes as per their subject in the timetable. Moreover, activity based learning was encouraged till middle school where they were taught concepts using some handmade activity kits. Students of secondary classes onwards are then taught using blackboard and given computer classes.

The second school had only 3 classroom spaces available where the students of different grades would sit together in the same classroom and one teacher would teach all the grades simultaneously. The basic method of blackboard

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teaching was used more often. The school had a single projector screen and modules for different classes and subjects were stored in a tablet to project on the screen. The students were made to shuffle across the classrooms to use the projector screen.

The third school used a combination of activity based learning and blackboard method of teaching. The teachers at times used their own smartphones to show examples or applications with short quizzes. This school also had projector screen which was barely used due to maintenance issue.

Two key observations were obtained from primary research. In all these schools, due to lack of space, the students of different grades were made to sit together in a single classroom on the floor. Thus, the students at times were made to have collaborative discussions within and between grades, encouraging fun based learning. Moreover, use of some basic form of technology was involved to support the teaching methods.

B. Secondary Research

1) Technology Trends in Indian Rural Education: The Indian schools are witnessing the flowing trend of adapting technology that complements the traditional teaching method. Interactive whiteboards are replacing many blackboards in schools [4]. For rural areas, studies have been conducted to understand the impact of technology and its acceptance by kids of 10-14 years, with minimal intrusion, which was termed as Minimal Invasive Education [5]. Their natural curiosity and collaboratively sharing knowledge in using technology is what builds up their problem solving skills. Various foundations also try to come up with technological support for the schools [6], thus backing up for the underprivileged students.

2) Augmented Reality (AR) in Education: AR is an emerging technology which helps in augmenting virtual information using computer generated graphics on to the real world environment in real time [1]. Geometry and mathematics [7], science [8], geography [9], history [10], astronomy [11] are a few subjects where studies have been conducted to realize the significance of AR in teaching abstract concepts [12]. AR can be used through varied mediums like books, games training modules, object modelling etc. [13]. In classrooms, an engaging experience can be created using AR where students can be made to visualize the concepts which are otherwise difficult to imagine [14]. Similar advantages of AR enhancing performance and motivating the students [15] have been reported in various studies indicating the significance AR might hold in near future.

These AR systems can be marker or marker-less [16] where the former scans the marker through device's camera and reflects the matched content from database on to the real world. The latter uses device's GPS and compass, internet connection and image recognition techniques to track features defined in prior to superimpose the virtual graphics on the real world.

3) Collaborative Learning: Collaborative learning is a way of learning where a common task or problem is solved in groups. The benefits include increase in team engagement, problem solving ability, critical thinking, social skills development and exchange in knowledge [17]. In few studies, collaborative learning using AR has been experimented in higher education [7],[18,19]. However, there are very few existing studies that have experimented the use of AR in collaborative learning for the middle school students.

Researchers have claimed that students of age 10-14 years begin to have the ability to think logically and that is when they can conceptualize the things that cannot be shown in real [3]. This is the age group to which the concept of 3D and its difference from 2D objects is introduced in their syllabus of Mathematics. Since spatial visualization and interaction with 3D objects are among the few advantages of AR, we were motivated to design an AR application on the topic of 'Introduction to 3D Solids' for the middle school students. We wanted the students to be able to explore and experience the spatial visualization and understanding of depth in 3D objects along with real life examples using AR.

III. Design of Intervention

A. Design Process

To come up with the design of the application, we followed the 5 elements of User Experience suggested by Jesse James Garrett [20]. These 5 elements can be seen as falling into 5 planes namely strategy plane, scope plane, structure plane, skeleton plane and surface plane. These planes build from bottom to top, where each plane is dependent on the planes that are below it. Using this model, we defined that the user need was to be able to collaboratively interact with 3D solids using the AR application, to learn mutually about the forms, gain the ability to visualize the 3D forms and its application in real life. AR feature has been incorporated for interactivity purpose and developing the understanding of depth of 3D solids. Fig. 1 shows the information architecture constructed and followed for developing the application.

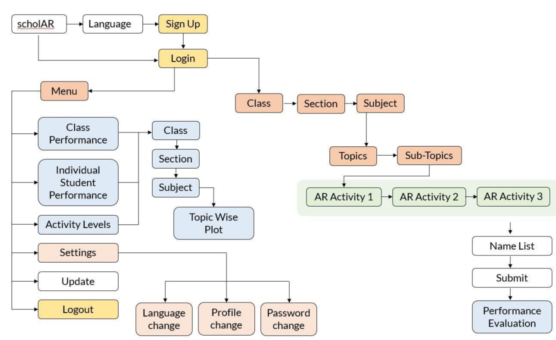


Fig. 1. Information architecture of ScholAR application.

B. Implementation of the AR System

An android based marker-less AR application was built in Unity software using the ARCore software development kit (SDK). With the movement of the phone, ARCore is able to track its position and develops the understanding of the surrounding world and estimates the lighting conditions around [21].

The application starts with the requirement of scanning the surface. Once it scans the ground level, the estimated height of the eye level of the user is calculated in the backend by detecting the height at which the phone is held. The objects are, thus, placed roughly at the eye level for the users to move around and see the object from all possible sides. To experience and explore this ability of moving around the objects using the feature of AR, we preferred not to add the functionality of rotation of the objects. However, the objects can be scaled up and down using two fingers. They can also be moved in x or y plane.

At the end of every activity, there is a submit button. On tapping that, the screenshot of that activity gets saved. This can be viewed later by the researchers or teachers to monitor the students' answers.

C. Activity Design

The topic selected for the study was Introduction to 3D Solids. The activities were further built upon two sub-topics - (1) types of 3D shapes, and (2) vertices, edges and faces of 3D solids. Each of the subtopics had 3 activities where the first activity was an exploratory activity, the second activity was based on the application of the explored content, and the third activity was testing the application skills learned. Following are the details of the activities of the sub topics:

1) Types of 3D Shapes: The learning objective of this section of activities was to make the students understand the different 3D shapes and their existence in the real world.

a) Activity 1: In this activity, the learners are shown five different types of 3D shapes: cube, cuboid, sphere, pyramid and cylinder (Fig. 2). On tapping any of these shapes, a menu appears with three options to choose from: one basic form and two real life examples of that shape. The students can choose to see the objects either on the ground or at eye level. This activity was designed to help the learners explore the features of AR, learn about the different types of 3D shapes and their examples, and creatively develop forms by visualizing and combining different shapes.

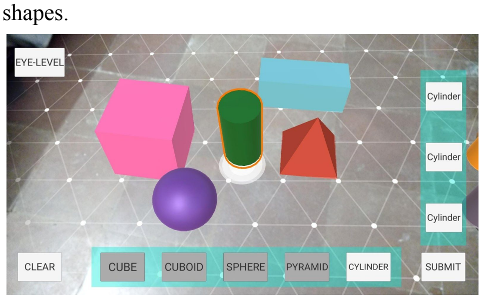


Fig. 2. Sub-topic: Types of 3D Shapes - Activity 1.

b) Activity 2: In this activity, the learners are supposed to choose the shapes matching a given silhouette from a cluster of 3D shapes placed in the surrounding (Fig.3). The button for 'Drop' was given in case they had the realization of picking a wrong shape.

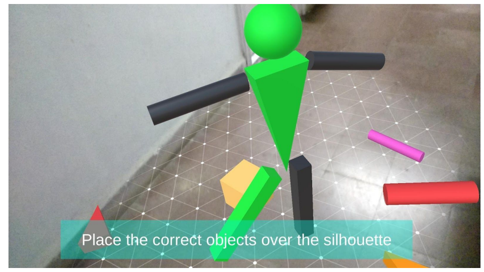


Fig. 3. Sub-topic: Types of 3D Shapes - Activity 2.

c) Activity 3: In this activity, the learners are asked to find 4 shapes of a particular type and color among the other scattered objects in the space around them (Fig.4). Each of the four objects were placed in four different directions. The students are indicated if they submit wrong answer and can correct their answer.

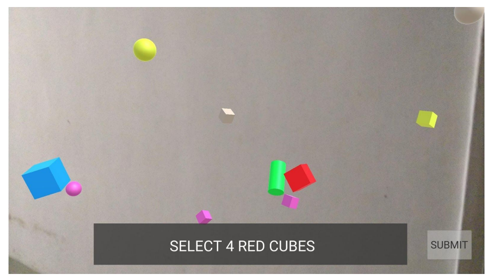


Fig. 4. Sub-topic: Types of 3D Shapes - Activity 3.

2) Vertices, Edges and Faces: The learning objective of this section of activities was to make the students understand the difference between vertices, edges and faces, and be able to count those for a given 3D geometric shape.

a) Activity 1: In this activity, the students are guided to count the number of vertices, edges and/or faces from the given options of 3D shapes. (Fig.5)

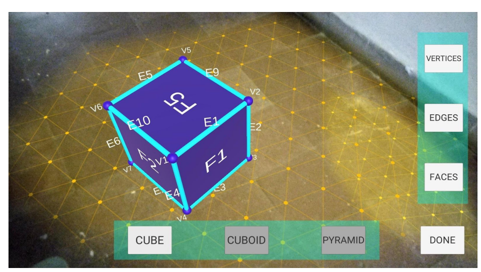


Fig. 5. Sub-topic: Vertices, Edges and Faces - Activity 1.

b) Activity 2: In this activity, the learners are given a combination of two geometric 3D shapes and are asked to count the number of vertices, edges and faces separately in three questions (Fig.6). The right answer gets highlighted in green along with a musical feedback. The wrong answer gets highlighted in red. The next question appears only after marking all three right answers.

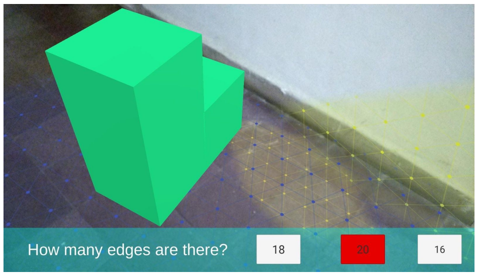
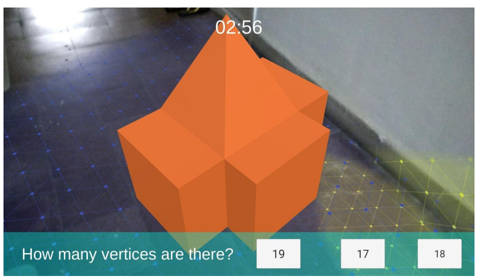


Fig. 6. Sub-topic: Vertices, Edges and Faces - Activity 2.

c) Activity 3: In this activity, a slightly complex 3D shape is given for which the students have to correctly count the vertices, faces and edges asked separately as three questions (Fig. 7). This was a timed activity, to be done in 3 minutes. Score out of 3 is given in the end for the correct answers.



Fig,7. Sub-topic: Vertices, Edges and Faces - Activity 3.

IV. Research Methodology

Our study addresses the following Research Questions:

RQ1: How do students interact with ScholAR application in collaboration?

RQ2: What is the effect of collaboratively using ScholAR in students' performance?

A. Participants

We conducted a two group post-test only study in a school which followed the blackboard method of teaching with occasional use of projector screens. Through convenience sampling, the pilot study was conducted with 32 students of 7th grade belonging to the age group of 12-14 years. These 32 students were randomly divided into two groups of 16 each (by picking chits) where one group was the experiment group, other was the control group.

B. Procedure of Study

The quasi-experiment was conducted in a single day in a classroom of 32 students of 7th grade. This grade was chosen as the topic used for testing was never introduced to the students before. The two groups of students – experiment and control - were made to sit in two different classrooms. A day before the experiment, the teacher had been told what all topics were needed to be covered for the purpose of the experiment.

One video camera each, for the purpose of video recording of the overall event, was placed in both the rooms. An additional video camera was handled by one of the volunteers to closely record the actions that were done by the students during the experiment. The study required the students to move around in the class in groups. Placing static cameras near the group of students was prevented as that could have hindered their movement while doing the activities using the mobile phones.

Experimental Group: Once the two groups settled in the two different classrooms, the students in the experimental group were further divided into four groups of four students each. The teacher was then asked to give a brief introduction about the topic of 3D solids to the students. The teacher took around 8 minutes to give a brief overview of the topic. While the teacher was teaching, all the students were facing the teacher and the blackboard. After the lecture, the students sat facing each other in their respective groups. One mobile phone with the AR application open was then given to each group and kept in the centre on the floor. Once the mobile phones were distributed to each group, the basic use of the buttons and AR feature in the application for the first activity were explained by the researcher. They then explored the rest of the activities in the application on their own. The questions in the application were in English. However, they were translated by the researcher in their regional language. The students were able to complete all the activities in around 45 minutes. In between activities and after the use of the intervention, brief semi-structured interview was conducted in each group. Group interview rather than individual interview was done to encourage interaction among the group members while they answered the questions [22].

Control Group: The control group was made to be taught the usual way using the blackboard. The teacher in addition used some physical models of 3D shapes like cube, cuboid, cone and sphere to explain. During the class, the teacher also explained about the existence and importance of 3D solids in the surrounding environment with several examples. The session was preferred to be kept interactive by the teacher. This session ran parallel to the Experiment group session and were taught for around 40 minutes.

The topic included giving an introduction to 3D solids: difference between 2D and 3D, types of 3D solids and the terms Vertices, Edges and Faces. The same teacher was asked to teach in both the classrooms as all these 32 students were taught Mathematics subject by this teacher. The change in teaching style could have been a confounding variable for our study.

Post-test was then conducted for both the groups after the use of the intervention by the experimental group and the completion of lecture for the control group.

C. Data Source and Instrument

Our aim was to study the way rural students collaboratively interacted with this technology with minimal assistance from the teacher or researchers. We also wanted to analyse the effect on the performance of the students after using the application. The whole study was video recorded so as to capture the actions that the groups of students did while interacting with the application. The detailed documentation of the event activities were noted in the observation log. The immediate observable behaviours, their controlling actions and doubts on using the application were among the few things to be noted down. After the use of the intervention, students were asked questions on their experience of using the application, their learnings from the activities and suggestions if any on the improvement in the application. They were then given the post-test papers to answer few questions related to the topic covered. The question paper was validated by the teacher before the experiment was conducted. Four sets of papers were prepared with the same questions but in jumbled order. The post-test comprised of six questions with sub parts in few questions. The questions tested the first three stages of Bloom's taxonomy [23]. The first question was designed to test the first stage i.e. remembering the facts and concepts, the second and third question was designed to and comprehending them. The rest four questions were testing their ability to visualize and apply the learned concepts.

D. Data Analysis

Data from the mentioned sources and instruments were used to answer the research questions. To answer the first RQ, video data was observed and the recorded interviews were transcribed to obtain the interactive behaviour of the students while using the application and their experience of using it. RQ2 was answered by performing unpaired t-test at $\alpha=0.05$ using the overall marks of the two groups as well as average marks scored in every question of the test by the individuals of the two groups.

V. Results

A. Results related to collaborative interaction using ScholAR

1) Observation based Inferences: While distributing the phones, they were kept in the middle and not handed over to any single person in particular. This was done to observe the way of handling the phones in collaboration on the start of the experiment. In different phases of the experiment, three different ways of handling the phones among the group members of the four groups were thus observed:

a) One participant of the group held and moved the phone while others pressed the buttons on the AR application.

b) One participant of the group held the phone while others held that person's hands to move the phone accordingly to observe the objects.

c) One participant tried exploring the application's features while the others watched and then passed on the phone to the next team member.

To interact with the 3D object(s) displayed in the AR application, it was observed that they explored the two ways of interaction without the help from teacher or researcher:

a) They used their fingers to move the objects back and forth.

b) They moved their whole body back and forth or by bending to observe and move around the 3D objects.

2) Interview Responses: The students were asked few questions during and post the use of the intervention, the responses of which have been categorized as follows:

a) Visualization Skills: In the first activity, while exploring the features of the AR application, the students were prompted by the researchers to try creating some formations. Each of the four group tried to recreate different scenarios or objects using the basic 3D shapes given in the activity such as:

- "Mountain on top of Sun"
- "Making a palace"
- "Toy train crossing a forest"
- "Making a hut"

b) Perception of Learning: The following were some of the responses when asked about the learnings obtained by using the application:.

- "Learned about 3D shapes"
- "We can make any object with shapes"
- "Many things around us are made of these shapes"

c) Usefulness of Application: One participant tried exploring the application's features while the others watched and then passed on the phone to the next team member.

- "The application is very helpful for the beginners"
- "Fun element added with the man activity"
- "It made Mathematics interesting for me"
- "It was easy to learn about shapes using this application because of the examples shown. Teacher would sometimes bring the objects to show in class, sometimes not."
- "The different types of activities makes the application interesting"

d) Challenges in using the Application: Some of the concerns raised by the students when they were asked about the challenges they faced while doing the activities included:

- "Unable to rotate the objects while trying to get a particular orientation"
- "A setting should be there to place one object on top of other"
- "The time away went too soon in the last activity"

e) Collaborative Learning: When asked about their experience in doing activities in collaboration, 2 out of 16 felt that using the application individually would have helped them learn better. The rest of the students liked doing the activities in groups, especially the end activities with questions in both the sub-topics.

B. Results related to student performance using ScholAR

1) Post-test results: To analyze the effect of collaboratively using ScholAR on the students' performance, unpaired t-test was done on the marks obtained in the post-test by the students of experimental and control group. From the analysis it was indicated that at $\alpha=0.05$ ($t=2.18$, $p=0.018$), there was a significant difference in the performance of the students after using ScholAR in collaboration.

2) Post-test responses: To further understand the reason of the difference in student performance, the performance of the two groups in every question of the post-test paper were analysed. Some questions contained sub-parts, thus leading to different marks for each question. Therefore, to obtain uniformity in the results, we normalized the total marks for each question to the range of 0-10. The graph below (Fig. 8) shows the average marks obtained by the students in the experimental and control group in each question.

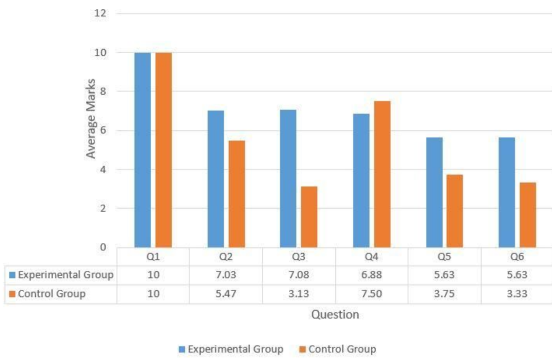


Fig. 8. Results of the post-test questions.

All 32 students correctly answered question 1 that was based on remembering the different types of shapes and their names. Question 2 and 3 tested their understanding from the two sub topics respectively. In one of the sub parts of Question 2, every student of control group wrote the shape of football to be circle or round. Question 3 required them to count the total number of vertices, edges and faces of a triangular prism shown in the question paper. Among the 16 students in control group, only 8 students could correctly answer at least one part of the question, whereas all 16 students gave at least one correct answer for the same question. Question 4, 5 and 6 were application based questions. In question 4 which was a multiple choice question having two correct answers, they were asked to mark the 3D shapes with 6 faces. 10 out of 16 students of control group marked both the correct answers. In case of experimental group, only 6 out of 16 marked both the correct answers. They were awarded marks for each of the correct chosen option. In case of Question 6, only one student of experimental group did not attempt the question and two gave wrong answers to all sub parts. However, 3 students in control group did not attempt the question and three gave wrong answers to the sub parts. Rest of the students in both groups gave at least one correct answer and all right answers were given by 5 and 3 students of experimental and control group respectively.

3) Inferences: From the post test results and the responses to the questions asked in the post test, it is evident that the experimental group performed better as compared to the control group. All the students of both the groups remembered the names of the 3D shapes that were shown to them in class or in the application. However, the understanding of the taught concepts was better in case of experimental group as seen from the answers and scores of question 2 and 3. A probable reason for such result could be that the students of experimental group were able to discuss their doubts and learned concepts with each other using the AR application in collaboration, which the other group could not do. This might have given the experimental group more clarity about the learned concepts.

Question 4 was only one question in which the control group outperformed. In their classroom, the teacher had repeated multiple times the number of vertices, faces and edges of the basic shapes which the students had repeated aloud after her. There is a possibility that the students might have memorized the number of faces, vertices and edges of each of the basic 3D shapes and answered the question on the basis of rote learning. Whereas, the experimental group was made to themselves count the vertices, edges and faces of different 3D structures. So the experimental group performed better in question 5 and 6 when slightly complex 3D shapes were presented and they had to count the number of vertices, faces and/or edges. Overall there was a consistency in the performance of the experimental group which the control group lacked.

VI. Discussion

The first research question looked at the ways in which the students collaboratively interacted with the application. The results obtained from the observation log gave insights on their behaviour of interaction. Since this technology was being introduced to the students for the first time, there was the obvious initial awe-factor related to the use of the application. Therefore, we had designed multiple activities so that the students could get used to the application by the end of second or third activity and the different stages of learning can be attained.

Inspired from the experiment of Minimally Invasive Education [5], we let the students explore the features of the activities of AR application all on their own. After explaining the handling of the application in the first activity (due to time constraints), the researchers intervened only to translate the question and if they faced any technical issue. The students were seen discussing and explaining each other about the features and helping each other to complete the question based tasks correctly and in time. It was observed that sometimes the students even changed the groups to see how the other group members are performing.

The students took on an average 10 minutes in activity 1 as they were exploring the application. When prompted by the researcher to try making some forms out of the shapes, they came up with interesting ideas to design in a short time. They could visualize the object or scenario in its basic form that can be made with the shapes. Thus, we can claim that ScholAR application can help the students in developing their visualization skills. However, while developing the forms, they faced problem in placing one object on top of another as the feature of rotation of a 3D shape to a particular orientation was not added as we wanted the students to move around the objects and see it from all sides in the real environment. The rotation feature can thus be added in the re-design of the application.

Among all the activities, the students liked the second activity of the first sub-topic the most where the shapes matching to the components of the silhouette had to be snapped in. They overall enjoyed using the application as they were using it with each other's help and exchange of knowledge, and could explore multiple varied activities.

The learnings from the application got reflected in their performance in the post test conducted. A significant difference in the performance of the experimental group was observed as compared to that of the control group with a positive gain. From the results obtained for each type of question, we can claim that the collaborative use of ScholAR application was able to enhance their understanding and help them apply the concepts that were briefly introduced by the teacher.

Our study was conducted with 16 students belonging to the experimental group. Thus, we need to investigate further in detail about collaborative use of ScholAR app with a larger sample size. Also, the two group post-test only design has the limitation in not knowing whether the participants in both the groups were of equivalent intelligence. In further studies, this can be worked upon by conducting pre and post tests.

The advantages of the app can be generalized from rural schools by testing the application with the urban schools. In future, we plan to develop more activity modules for ScholAR application. These modules can be explored for other subjects as well like Science, Geography, History etc. to make it an enjoyable collaborative learning experience for the students.

As the tablets have a bigger screen size, a better usability of ScholAR application could have been explored and handled using a tablet. However, as this application has been developed using ARCore SDK, one of the limitations is that this SDK is currently available for very limited high-end mobile devices. It is yet to be available for the tablets and all mobile phones, and is still evolving in its features. Thus, the AR application can only be tested using mobile phones having ARCore.

VII. Conclusion

The aim of our study was to observe and report the interactions of the rural school students in collaboratively using ScholAR application and its effect on their performance. We have addressed two research questions. The results of RQ1 indicated that ScholAR aided in developing the visualization skills of the students and realizing the existence of 3D shapes in the surrounding. Their perception of learning, usefulness of application and the limitations of the application as per the students were reported. The results of RQ2 implied that the collaborative exploration of the application enhanced the performance of these students as compared to those learning by the traditional blackboard and textbook teaching method. The post test results indicated that the first three stages of Bloom's taxonomy [23] i.e. remember, understand and apply were successfully attained by the students using the application.

The study has been conducted in a single school with 32 students of 7th grade. In future, larger sample size of participants from different demographics can be made to test the application along with pre and post tests, for generalizing the results.

Acknowledgment

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