Collaborative Approaches to Problem-Solving on Lines and Angles Using Augmented Reality

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Pratiti Sarkar
Indian Institute of Technology Bombay

Jayesh S. Pillai
Indian Institute of Technology Bombay

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Pratiti Sarkar
IDC School of Design
Indian Institute of Technology Bombay
Mumbai, India
pratiti@iitb.ac.in

Kapil Kadam
IDP in Educational Technology
Indian Institute of Technology Bombay
Mumbai, India
kapilkadam@iitb.ac.in

Jayesh S. Pillai
IDC School of Design
Indian Institute of Technology Bombay
Mumbai, India
jay@iitb.ac.in

***Abstract*—The concepts of 2D geometry are often taught in classrooms without the analysis of the learners' understanding and interpretation of the existence of the concepts in natural surroundings. To bring in active participation of the students while they realize the practical application of the taught concepts, we have designed a module on Lines and Angles of an Augmented Reality (AR) intervention named ScholAR. Using ScholAR, the students can interact with an augmented 3D object. They can recall, visualize, identify the type of angle and then mark it by drawing on that 3D object. We performed a comparative study with 21 participants (6 dyads and 9 individuals) of 8th grade. In this paper, we report: 1) the perspectives of the students on their experience of performing the AR learning activities individually and in dyads, 2) the students' approaches while solving the AR learning activities, and 3) their motivation of using ScholAR. We found that 90.4% of the total participants preferred to perform the AR learning activities in collaboration. At α=0.05 (t=2.21, p=0.048), the performance of the dyads was significantly higher after using ScholAR. The usability and motivation level scores, however, were higher for the individuals (70.28; M=4.07) as compared to the dyads (65.23; M=3.94).**

Keywords— augmented reality, lines and angles, 2D geometry, collaborative learning, STEM education

I. INTRODUCTION

The concepts of 2D Geometry like Lines and Angles is introduced in a formal context at the middle school level (6th to 8th grade). One of its major applications in the later years of STEM education lies in learning the basic concepts of Trigonometry [1]. Traditionally, teaching the concepts of Lines and Angles comprise of learning the definitions and diagrams of different types of angles [2]. In classrooms, conventionally an angle is drawn on the blackboard by the teacher, mentioning its measure and verbally explaining the definition and related properties which the students listen to, note down in their notebooks and do some practice exercises [3] . In such a process, the students perceive the learning of such concepts as memorizing the definitions and properties and forgetting them after writing examinations [1],[3]. Thus they lack in understanding the application of lines and angles in a practical world [3]. Some textbooks do provide the 2D images of the examples of 3D objects where such angles can be found. However, as the complexity of concepts increases, the number of examples tend to decrease [2]. This leads the students to often fail to perceive and experience the relations, connections and creativity infused by working on angles [1]. In order to work on these aspects, it is required to help them relate the learned concepts with examples and applications in real life [1],[3].

To provide examples from their surroundings in real-time and help in understanding the application of the different types of angles on those examples, we have explored the use of one of the emerging technologies called Augmented Reality (AR). AR is a technology that superimposes computer-generated graphics on to the real world in real-time, leading to the simultaneous co-existence of virtual and real world [4]. Thus, we have used AR manipulative to help the students apply the learned concepts by active collaborative learning through exploration on their own with examples from outside the classroom while sitting inside the classroom.

In this paper, we present the design, implementation and preliminary evaluation of the Lines and Angles module using tablet-based Augmented Reality (AR) application named as ScholAR. The module comprised of three different AR learning activities with multiple problems targeted towards recalling, visualizing, identifying the example of a type of angle and marking it on an augmented 3D object by the draw enabled feature of AR. The study was conducted with 21 participants of 8th grade who had studied the topic of Lines and Angles in 7th grade. The participants were randomly distributed into 6 dyads and 9 individuals and a comparative study was done between the two groups. Three researchers acted as facilitators, who helped the participants revise the concepts, gave a demo of the ScholAR app, observed the actions of the participants and conducted interviews with them. Learning was evaluated through pre and post-test, along with the evaluation of usability and motivation to use the intervention. The broad goal of the study was to observe and identify the ways that motivated the dyads and individuals to approach towards solving the AR based problems. Analysis of data from transcribed interviews, videos, test results and survey questionnaire responses indicate that the collaborative use of the Lines and Angles module of ScholAR along with the recalling prompts by the facilitator can act as a supplement in the classroom.

II. BACKGROUND WORK

The branch of Geometry is an essential component in Mathematics comprising of 2D and 3D geometry. This is introduced in the curriculum of middle school level (6th to 8th grade) as this is the age (11-15 years) when students begin to gain the ability to think logically and understand abstract concepts, the examples of which are difficult to show in real life [5]. Geometry tends to act as a base for the applications in other fields of mathematics, along with providing the ability of analyse and interpreting the world [6]. While learning Geometry, it is required to realize that it is not only concerned with learning the definitions but also be able to analyse the properties and theorems of 2D and 3D geometry in order to develop geometric relationships to solve problems [7].

With the advent of technology and its ability to provide visual representations, various modes of interactive geometry have been brought forth in research to focus the attention of

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students towards the mathematical concepts and techniques [8]. The broader goal of interactive geometry software is to help students learn and explore geometric concepts through manipulation of geometric objects like points, lines, circles, etc. [9]. GeoGebra is one such software which has been majorly used to explore an object with its possible mathematical representations [10]. Dynamic Geometry Software (DGS) like Cabri-Geometre [11] and SketchPad [12] is another category which allows deeper exploration of geometric objects through dynamic manipulations [13]. This exploration is difficult to do in case of pen and pencil based learning, a comparative study of which has been done earlier with GeoGebra [14]. However, such interactions are still restricted to the use of a desktop with keyboard and mouse used as manipulatives.

Augmented Reality (AR) manipulative is one of the emerging technologies [4]. Its application in education is considered to be valuable due to various characteristics like its ability to engage novice learners by providing rich contextual learning and individual unique discovery path with no real consequences occurring in case mistakes are made during skills training [15]. Beyond these characteristics, through intuitive interactions in AR the learners can easily interact with the educational content in a way they would interact with the physical world [16]. Interactions such as scaling by moving farther or closer to the virtual object, moving around it to see from different perspectives and selecting it by pointing at it tend to provide intuitive navigation and manipulation, thus reducing the effort of learners to learn beyond the acquired skills and knowledge [17]. In earlier times, the process of problem solving required manipulating actual objects while moving around. Similar such physical movements when incorporated in immersive platforms like AR can help in naturally learning the abstract concepts [18]. These benefits of AR have been explored in various studies involving the representation and manipulation of 3D objects to teach 3D solid geometry in AR [19]-[22]. Exploration of 2D geometry has been hardly observed in existing works, where one study exists to develop 3D objects from 2D shapes in AR [14]. Studies have also suggested that collaborative tasks in AR can help in improving visualization skills, critical thinking skills, problem solving skills and communication of the participating students [19],[23]-[26]. Such collaboration is worth when the content and experience of AR is independently controlled along with personalized view for all individuals in a group [16], [26].

In contrast to former studies, through the Lines and Angles module of ScholAR, we explore the application of 2D geometry on 3D virtual examples. Using this module, we expect that the AR learning activities will help middle school students in realizing the application of lines and angles in real world objects and scenarios. Further, these activities when done in collaboration can motivate them towards the approaches of AR based problem-solving.

III. Design and Implementation

A. Technical Design

We developed the Android-based marker-less Augmented Reality (AR) application in the Unity software using Google ARCore SDK version 1.7.0. ARCore enables the tracking of phones' position with its movement and estimates the lighting conditions of the surrounding world accordingly [27]. Plane detection and raycasting were the two ARCore components primarily used in the development of the AR application. The exported android packages from Unity were deployed on Samsung Galaxy S4 Tablets running the Android operating system (version 8.1.0).

B. AR Interactions

On starting the application, a grid appears to indicate the scanning of a textured surface on which a virtual graphic gets augmented. In ScholAR, once the grid appears, a 3D house gets superimposed on the existing surrounding in real-time by tapping on the screen of the tablet with two fingers. By detecting the height and position of the held tablet, the 3D house gets augmented at the eye level of the user, the calculation of which is enabled by ARCore at the backend. In order to provide an immersive experience, the manual rotation of the 3D house is disabled so that the users can themselves move inside and outside the 3D house to explore it from all sides, the way they would do in reality. The house could be scaled down or up by tapping farther or closer respectively with two fingers on the detected grid on the horizontal plane. Using the ARCore draw feature, the users can draw anything on the screen using one finger tap and drag. In order to erase the drawn marks, the users need to tap with three fingers inside the house. The augmented house disappears if the three fingers tap is done outside the detected plane of the house.

C. Activity Design

The activities were designed on the topic of Lines and Angles from the state board syllabus of 7th grade. There were three activities built upon the sub-topics of: 1) types of angles, 2) pairs of angles and 3) interior and exterior angles of a polygon. In order to involve the active participation of students as well as the teachers, each of the activities required a facilitator to explain the problem and the students calling out the facilitator to check their marked answers. The activities were targeted to be solved by recalling the definition of the type of angle, visualizing that angle by forming its mental image, then mapping that mental image of the recalled angle on to the 3D object and finally drawing on top of the identified angle. The AR learning activities designed are further explained below:

1) Activity 1 – Types of Angles: The learning objective was that at the end of this activity, the students will be able to identify and distinguish between acute, obtuse and right angles in their surrounding objects. The activity involved moving around the augmented 3D house on the tablet to identify and mark three acute angles, three obtuse angles, and three right angles. There were multiple possible angles for each type that could be marked. This activity was designed for the students to get familiarized with the 3D house from outside as well as the different AR interactions implemented.

2) Activity 2 – Pairs of Angles: The learning objective was that at the end of this activity, the students will be able to classify the different pair of angles: complementary, supplementary, adjacent and linear pairs of angles in the examples of real-life objects. In this activity, a contextualized way of problem-solving was put forth to the students where they had to find a wood log for the carpenters to repair that formed the common arm of the adjacent angles. This pair of angles also formed supplementary angles where one of the angles are acute. They were supposed to find this answer on the left or right side of the 3D house as both were identical.

There was a unique defined answer to this question as shown in Fig. 1.

3) Activity 3 – Interior and Exterior Angles of a Polygon: The learning objective was that at the end of this activity, the students will be able to locate a polygon in their surroundings and practice calculating its sum of interior angles. The problem was broken down into smaller problems. In order to provide further immersive experience, the students were asked to go inside the house, explore it and count the number of windows. They then had to pick any window, count the number of sides and name the type of polygon it was. This was followed by drawing the minimum number of triangles into which the polygon can be divided and finally calculate and tell the sum of interior angles of that polygon.

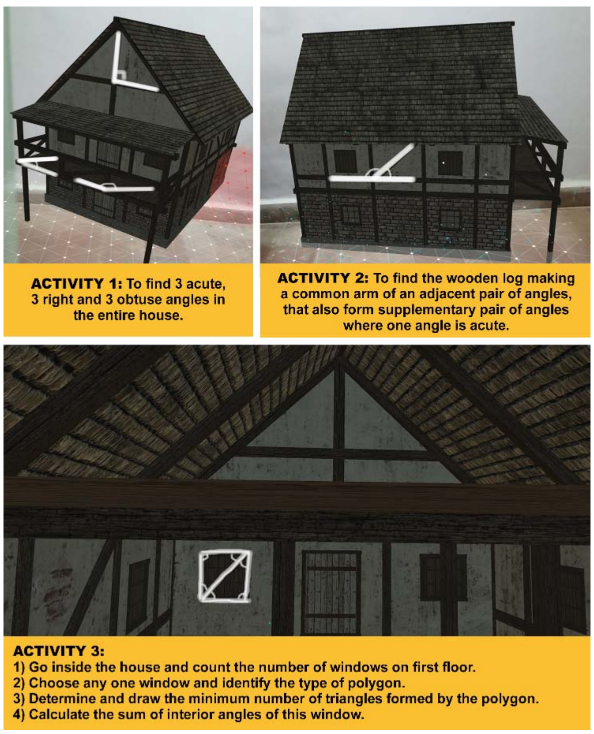

Fig. 1. Types of questions for the AR learning activities designed

IV. METHODOLOGY

The study focused on the following research questions:

RQ1: What are the students' perspectives on the AR learning activities when they perform it in dyads and individually?

RQ2: What are the approaches taken by the students in solving the AR learning activities in dyads as compared to the individuals?

RQ3: What motivated the dyads in performing the AR learning activities as compared to the individuals?

A. Participants

We conducted the study with the students of a suburban school in which the blackboard teaching method is followed with occasional use of projector screens. This school had only one section for each grade with a maximum of 33-40 students in a grade following the state board syllabus. Through convenience sampling, the study involved the participation of 27 students of 8th grade from the age group of 12-13 years, out of which 6 students participated in the pilot study and the remaining 21 in the main study. These students had studied the topic of Lines and Angles in their 7th grade. The language of instruction was a combination of Hindi and English.

B. Pilot

We conducted a pilot test with 6 participants. This was done to check and refine the instruction delivery, time and execution of the designed activities. We were thus, able to verify the estimated time of the study and the use of the data collection instruments.

C. Procedure of Study

The two-group pretest-posttest study was conducted in 3 days over a span of two weeks, where on the first day of week one, the pilot study was conducted. The main study comprised of 21 students of the same class where 12 students worked in dyads and 9 students worked individually, randomly distributed by picking chits. The study was conducted in 2 days of 4 slots where each slot session was of approximately 3 hours.

We conducted the study in an empty classroom with minimal furniture for the students to move around freely while four video recording cameras were placed in each corner of the room. Each session began with 20 minutes of revision for all students to recall the taught concepts. After that, a pre-test of 20 minutes was conducted comprising of 6 questions to test their prior knowledge on the topic. This was followed by AR learning activities on the tablet where initially a demo to use ScholAR was shown. After the completion of the AR learning activities, the students were given post-test papers equivalent to the pre-test paper to observe any improvement in their learning. Questionnaires were then given on the usability of ScholAR developed from System Usability Questionnaire (SUS) [28] and on the motivation level of the learners in the four dimensions of the ARCS (Attention, Relevance, Confidence, Satisfaction) [29] model, developed from Instructional Materials Motivation Survey (IMMS) [30]. Both the questionnaires comprised of questions to be answered in the 5-point Likert scale of Agreement. In the end, semi-structured interviews of around 10 minutes were conducted with all the dyads and individuals separately.

D. Data Sources and Instruments

In order to answer the research questions, the following instruments were used in the study to collect data:

1) Video and Audio Recordings: The study was video recorded to view the actions and interactions of the students while they solved the AR learning activities on the tablet and the post-intervention interviews conducted.

2) Observation Log: During and after the study, the researchers documented the observed behaviour of the dyads and individuals at the various stages of the study.

3) Screen Recordings: The actions performed on the tablet by the students during AR learning activities were recorded using the DU Screen Recorder. It also captured the conversations that the students had with their partners or the researchers.

4) Pre and Post-test: Pen and paper based pre and post-tests were conducted. Both the tests comprised of six questions with subparts in a few questions, which were targeted towards assessing the first three levels of Bloom's taxonomy [32]. The first two questions with three sub-parts in each were designed to evaluate the first stage i.e. remembering and recalling the facts and concepts. The next two questions evaluated their understanding of the concept. The last two questions comprised of applying the concept and designed similar to AR learning activities.

5) Survey Questionnaires: Questionnaires inspired from SUS [29] to measure the usability of ScholAR and IMMS [31] to measure the motivation of the students in the study were given. Both the questionnaires comprised of 10 and 36 questions respectively to be answered in 5-point Likert scale of Agreement. In order to reduce their cognitive load in answering 46 questions altogether, the students were given six sheets, one after the other with 10 questions in first four sheets and 6 questions in the last sheet. Among the 36 questions of IMMS, 12, 9, 9 and 6 items belonged to the scales measuring the attention, relevance, confidence and satisfaction respectively (Fig. 4).

6) Semi-structured Interviews: In order to address the research questions, the interview questions prepared and validated by fellow researchers were asked to dyads and individuals. The responses recorded their perceived preference for collaboration or individual work, their understanding of the concepts, areas of difficulties, challenges faced in using the intervention and suggestions.

E. Data Analysis

In order to answer RQ1, thematic analysis was performed on the data collected from the semi-structured interviews. The pre and post-test scores were also analysed to relate the results with the students' statements. RQ2 has been answered using the logged observations, video data and usability questionnaire. To answer RQ3, the scores of the motivation questionnaire (IMMS) were analysed.

V. Results

A. Students' Perspectives about AR Learning Activities (RQ1)

The transcribed responses obtained from semi-structured interviews were coded in order to do thematic analysis. The main themes obtained from the thematic analysis are further described below:

1) Role of Collaboration in Performing AR Learning Activities: During the interview process, out of the 21 participants, 2 participants mentioned that they would prefer to perform the activities alone. Out of these two, one participant who was part of a dyad, felt confident in quickly finding the answers alone. The other participant who performed the activities individually, thought that doing the same on a single tablet might lead to quarrels. The rest 19 participants preferred to perform the activities collaboratively in groups. For this main theme, a number of sub themes emerged from the statements of the participants which helped us in identifying the key perspectives of the students about the need for performing the AR learning activities in collaboration. Table I denotes these sub-themes with some of the key instances quoted by the participants.

TABLE I. Thematic Analysis to Identify the Role of Collaboration as Perceived by the Participants

Themes	***User Instances***
Explanation of learned concepts to partners	"We explained each other and then marked the answer", "I showed him the answer and explained why that answer has been marked", "one who remembers a concept would explain to the partner"
Encourages discussion	"Before marking the angles, we would discuss with each other", "Discussion helped us to understand a few things on our own", "in case one of us would not remember the definition, we would ask and then discuss with each other"
Correcting mistakes	"If one marked the wrong answer, other erased it and marked the correct one", "we would correct each other's doubts", "we would correct each other's answers"
Guidance of each other for quick actions	"In a group we can solve quickly using both minds", "we can help each other quickly if get stuck", "by helping each other, the activities can be finished quickly"
Alternate turns to solve the AR learning activities using one tablet	"We took alternate turns to mark the answers for equal participation", "In the first activity, we had to mark multiple angles of a type. We took turns to do that.", "We took alternate turns to hold the tab"
Better understanding	"In group we can coordinate and understand with each other's help", "asking partner before the facilitator to understand the problem"

2) Perceived Impact of Performing AR Learning Activities Alone: Among the participants who preferred to use the AR intervention in collaboration, some of the things they perceived of performing AR learning activities alone include:

Nervousness: "Nervousness is there while performing alone without any friend's help."

Lack of Confidence: "I was lacking confidence while performing the AR learning activities alone."

Boredom: "Performing the AR learning activities alone will make it boring, where we silently observe, think and mark the answers without any interaction."

Holding and Drawing on Tablet: "We would have had problems in holding the tablet and marking also. Means it's scary that the tablet might fall down."

Understanding Questions: "It would have made it difficult to understand the questions while performing alone."

More help: "Performing the AR learning activities alone would have required more help from the facilitator."

3) Experience of Using Augmented Reality (AR): Some of the experiences reported by the participants included:

a) Use of Tablet: The participants perceived that the use of AR technology on the tablet was able to draw their attention. As they were all familiar with the use of mobile phones, it helped them in focusing and concentrating on the activities on the tablet aligning with their course syllabus.

b) Relevance of AR: Some of them were able to realize the relevance of AR. They stated that they could see a 3D object in the form of a house in real-time and could move around it, which is otherwise not possible to do on seeing a

2D image of a 3D object. They were able to go inside and outside the house to explore from all sides which made it an engaging experience for them.

c) Interaction with AR: The immersive nature of ScholAR helped them in staying engaged with the AR learning activities. Moving around and going inside the 3D house with the ability to draw on it were the interesting aspects.

d) Learning by Doing: 20 out of 21 participants preferred AR learning activities instead of the usual classroom teaching as they were able to "watch, do and learn the concepts" themselves instead of copying the taught concepts in the notebook from the blackboard. This made it an overall fun and interesting way of learning for them.

4) Prompts from Facilitators: From thematic analysis and logged observations, it was noted that during the study the participants required prompting from the facilitator(s) majorly in three cases. Few participants were finding it difficult to recall the definitions and needed the help of the facilitators in order to be able to solve the AR learning activities. At times in order to remove the confusion due to lack of recalling ability, the facilitator had to break down the question into smaller basic problems to help them build upon those. The facilitator had to prompt in when due to some confusion, the participants would begin to mark random things on the tablet.

5) Learning Impact from AR Learning Activities: Along with the thematic analysis, pre and post-test results were observed to establish its relation with the statements of the participants. To analyze the effect of ScholAR on their learning, paired sample t-test was done on the marks obtained by the dyads and the individuals in the pre and post-test papers. From the analysis, it was indicated that at $\alpha=0.05$ ($t=2.21$, $p=0.048$), the performance of the dyads was significantly higher after using the AR intervention. However, for the individuals, at $\alpha=0.05$ ($t=0.86$, $p=0.41$), there was no significant difference in the performance.

As can be seen in Fig. 2, the scores of dyads and individuals increased in the two application-based questions in the post-test and dyads score more than individuals. One question was similar to the AR learning activities where the participants had to identify and mark angles as per the question on the 2D image of a 3D scenario. In pre-test only one participant could identify and mark the required number of types of pairs of angles whereas three participants could do so in the post-test. The number of students correctly finding and marking at least one angle increased from 7 in the pre-test to 12 in the post-test. However, all participants attempted the question in the post-test. During the interview, the reason for this stated by the participants was that visualizing and finding angles in the objects were easier for them after the AR learning activities, making it easier to understand and attempt the questions. They could relate the scenario given in the test paper with the AR learning activities and answered the questions accordingly.

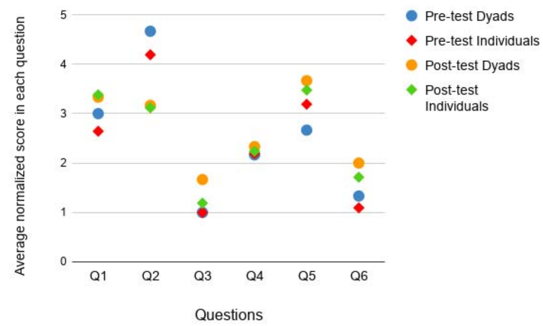

Fig. 2. Pre-test and post-test performance of dyads and individuals

B. Students' Approaches to Solving AR Learning Activities (RQ2)

The observations and usability questionnaire were evaluated to understand the approaches adopted:

1) Observations while Solving AR Learning Activities: From the logged observations, interview transcripts and video data the following findings were noted:

a) Learnability: On an average, the dyads took 15, 20 and 5 minutes to solve Activity 1, 2 and 3. The individuals on an average took 2 and 5 minutes more as compared to the dyads in solving Activity 1 and 2 respectively. A major reason for the increase in time was the inability to recall the definitions of the types of angles asked in the activity to identify and mark. It was also observed that while the individuals were performing the activities, they tried to discuss with another participant by either asking the way to solve an activity or to help after being able to find the answer.

b) Holding the Tablet and Drawing: It was commonly observed that while performing the activities in dyads, if there was a height difference between the two participants, then both would hold the tablet, where the taller person would hold from behind the shorter person (Fig. 3). Whosoever was able to identify an angle first would mark and tell the partner the reason of marking it. In case there was no height difference, the two participants would stand next to each other and one of them held the tab. The other participant would guide the direction in which to move to find the answer. In this case as well whosoever found the answer first would mark. In the case of the individuals a common pattern of holding the tablet vertically was observed (Fig. 3). However, by the last activity, all individuals held the tablet horizontally. It was easier for them to hold it vertically as it reduced the distance on the screen to mark. Except for one individual, all held the tab in both hands and used their thumbs to mark the angle. The one individual who could manage to hold in one hand used index fingers to mark. Activity 3 was the only activity where all the participants bent towards the floor to observe the house from inside.

c) Likeability:

Activity 1: For 2 participants from dyads and 1 participant from individual this activity was the most liked one as they found it to be the basic and easiest of all. However, for 1 participant from dyad and 2 individuals this was the least liked activity as they were not able to recall the definition of obtuse angle which took time in identifying and marking on the tablet.

Activity 2: For 2 participants from dyads and 2 individuals this activity was the most liked one as they were able to solve this activity quickly. However, 5 individuals least liked this activity as they were not able to recall the definitions of the types of angles that were asked to mark in this question, which further made it confusing for them to solve the activity.

Activity 3: The maximum excitement was observed in this activity. For 7 participants from dyads and 7 individuals this activity was the most liked one as going inside the house was the most fun part of the intervention and it also took them the least time to solve this activity. However, 2 participants from dyads and 1 individual least liked this activity as they were unable to recall the approach to solve this activity, making it time taking to answer.

Fig. 3. Students performing AR activities individually and in dyad.

2) Perceived Usability of ScholAR: The participants were given the SUS usability questionnaire towards the end. The standard average SUS score is considered to be 68. Scoring below 68 requires improvement in the design and usability of the intervention. The overall SUS score for our AR intervention ScholAR was 67.74. The SUS score for the participants in dyads was 65.83 and for individuals was 70.28. The SUS score was higher for individuals as compared to the dyads implicating that the design of ScholAR would require amendments to accommodate the suitability for the dyads.

C. *Students' Motivation in Performing AR Learning Activities (RQ3)*

The reliability of motivation questionnaire data was obtained using Cronbach alpha value [32], and was found to be 0.91 indicating good reliability [33]. The Cronbach value for the items of the scale of Attention (0.71), Relevance (0.75), Confidence (0.70) and Satisfaction (0.88) all indicated to be reliable.

1) Motivation Level of Participants in General: The overall motivation level of all 21 participants was positive with a mean score of 3.99. The minimum overall motivation level score was 2.58 of a participant who performed the AR learning activities in dyad. The maximum overall motivation level score was 4.64 of a student who solved the AR learning activities individually. Based on the score range, the motivation levels are divided into low (<3.00), medium (3.00-3.49), upper-medium (3.50-3.99) and high (4.00-5.00) [34]. Ten participants (47.62%) had high motivation levels, another set of 10 participants (47.62%) had upper-medium motivation levels and only one participant (4.76%) had low motivation level. As can be seen in Fig. 4, Item 3 of Relevance scale i.e. "completing this study successfully was important to me" scored to be of the highest motivation level (M=4.62). Whereas, Item 3 of Confidence scale i.e. "After the revision at the beginning of the study, I felt confident that I knew what I was supposed to learn from this study" scored the least (M=2.71).

2) Motivation Levels of Dyads and Individuals: To compare the motivation levels of the dyads (N=12) and the individuals (N=9), unpaired t-test was conducted. At α=0.05 (t=0.69, p=0.49), there was no significant difference in the motivation levels of the dyads and individuals. However, the average motivation level of the individuals (M=4.07) was 0.13 scores more than the dyads (M=3.94). This means that the individuals were comparatively more motivated in using the ScholAR than the dyads.

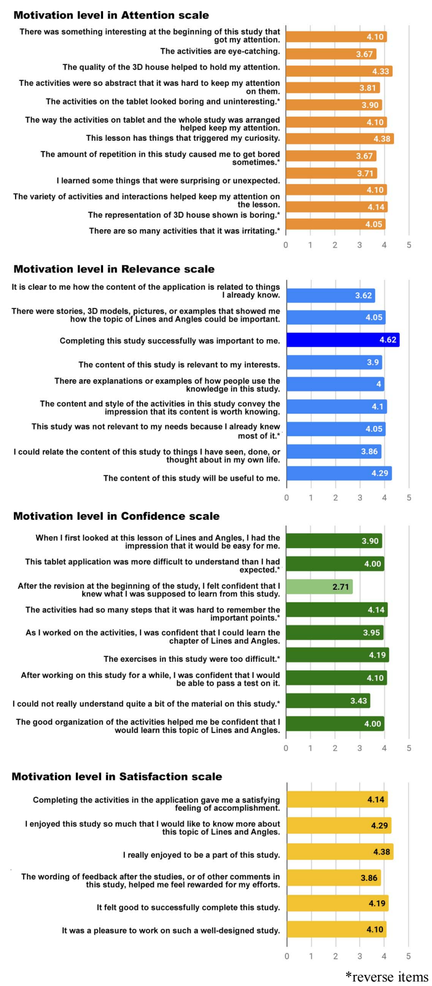

Fig. 4. Mean Motivation level of items from 4 scales of ARCS Model

VI. Discussion

The first research question focused on understanding the student perspectives on the use of AR individually and in dyads. As seen in a previous study [25] and from our results, it was noted that the participants preferred to perform the AR learning activities in collaboration than alone. This was primarily for three reasons: 1) holding the tablet and marking the angles simultaneously can be eased out, 2) partners can help in recalling the definitions and understanding the related concepts through discussion and applying the same with minimal prompts from the facilitator, and 3) they gain confidence with the assurance of the partner's help. However, as opposed to the results in a former comparative study of dyads and individuals [25], the learnings from the AR learning activities got reflected in the performance of dyads in the post-test. A significant difference at $\alpha=0.05$ ($t=2.21$, $p=0.048$) in the performance of the dyads was observed as compared to individuals with a positive gain between the pre and post-test. The participants stated that the AR learning activities helped them in understanding the post-test questions better and could relate the test problems with the activities.

Earlier studies have revealed that the use of AR lessons can help students in learning and investigating progress [26]. With the multiple designed activities, the participants were able to realize the relevance of AR. The majority stated that the immersive experience of interacting with the 3D house shown in real-time was a fun and engaging experience, which cannot be obtained while sitting in the classroom and jotting down the taught concepts in the notebooks from the blackboard. They felt that because of the ability of them watching and performing the AR learning activities themselves, they were able to concentrate more and understand the concepts better. However, it was observed that a number of participants had difficulty in recalling the definitions of the taught concepts. As a result, the researchers had to prompt in to repeat the definitions to help them recall and identify the required angles. It has been reported that with AR content, students are able to retain the content more as compared to non-AR mediums [16]. Many of our participants stated that the repetition along with the practical application through AR learning activities indeed helped them in understanding the concept of Lines and Angles better which they lacked while learning in the classroom.

The second research question focused on the approaches taken in solving the AR learning activities. It has been seen that through physical involvement, the learning experience enhances [18]. We thus provided an immersive experience, by asking the participants to move around and explore the 3D house that was superimposed on their existing surrounding. For this purpose we disabled the feature of rotation of the house. Activity 1 helped them in getting familiarised with the AR interactions. It was observed that one-third of the students had difficulty in recalling the definition of obtuse angle, taking a lot of time to find one. Also, they had difficulty in visualizing and marking the angles in the mirrored reference (i.e. 0° to 360° in the clockwise direction). All the participants took maximum time in solving Activity 2. It was realized that this activity had to be broken into smaller problems by the facilitators to help the participants recall, visualize, identify and mark the answers. Excitement in the 3rd activity was observed to be the highest among all. This is because the participants were unaware that they could go inside the 3D house and explore the multiple floors and roof from within, enhancing their immersive experience. They took the least time in solving this problem as it was already broken into six smaller problems, making this activity the most liked one. The overall usability score of the ScholAR was slightly less than the average score of 68. Moreover, the average usability score of the individuals (70.28) was higher than the dyads (65.23). The possible implication is that with more time in solving the AR learning activities as compared to the dyads, the individuals might have become more satisfied in using ScholAR. Thus, to increase the usability score for the dyads, the AR learning activities need to be redesigned for providing a better user experience to the dyads.

The enhanced motivation to learn Mathematics on using AR application has been reported previously [35]. Similarly, the motivation of using ScholAR was evaluated and reported in the third research question. The overall positive motivation level indicated that the participants were highly satisfied with the immersive experience of AR. Overall, item 3 of relevance scale was scored the highest ($M=4.62$) indicating they believed that the completion of the AR learning activities was of a lot of importance to them. Item 3 of the confidence scale was scored the least ($M=2.71$) i.e. after the revision, they were not confident that they knew what they were supposed to learn from this study. This may be because the activities required recalling some of the definitions of the types of angles at multiple steps. It was difficult for the participant to recall at one go and required the assistance of their partners or the facilitators.

Thus, it implies that the collaborative use of ScholAR's Lines and Angles module along with the recalling prompts can be a worthy supplement for the teachers to bring in active participation through practical exploration. However, there is a minor requirement of redesigning the AR learning activities in order to make it more satisfactory to use and motivating for the participants. Moreover, the redesign must be done in order to facilitate the collaboration of the participating students. Since the preferred mode is in collaboration rather than individual, the further design of the activities as well as the studies will be focused on the use of collaborative AR.

VII. Conclusion

The objective of the study was to identify the ways in which dyads and individuals approach towards solving AR based Mathematics problems. For this, we addressed three research questions. RQ1 captured the perspectives of the participating students about their experience of performing the AR learning activities using ScholAR individually and in dyads. Based on their experience of use of AR on tablets, 90.4% of the total participants preferred collaborative manner of interaction for the purpose of better usability of the intervention, better understanding of the concepts and gaining confidence while solving the AR-based problems. The learning from collaborating using AR got reflected in the pre and post-test results of the dyads showing their performance to be significantly higher at $\alpha=0.05$ ($t=2.21$, $p=0.048$). RQ2 focused on the approaches taken by the participants in solving the AR learning activities. In terms of learnability, dyads took lesser time in completing the AR learning activities as compared to the individuals. In terms of likeability, activity 3 was the most liked one as the problems were broken down into smaller chunks and took comparatively lesser time. In terms of usability of the AR application, the individuals were more satisfied in using the ScholAR. RQ3 focused on evaluating the motivation of using ScholAR. The overall motivation of the participants was highly positive. There was no significant difference at $\alpha=0.05$ ($t=0.69$, $p=0.49$) between the motivation levels of the dyads and individuals. However, the motivation level scores of the individuals ($M=4.07$) was more than the dyads ($M=3.94$) indicating that the more time they invested in the activities kept them more motivated.

The study has been conducted with a sample size ($N=21$) of 8th grade from one school. Moreover, as stated by the participants, the topic of Lines and Angles covered in 7th grade was revised after a gap of more than 6 months which made it difficult for them to recall the definitions immediately. Thus in future studies, we would like to test the AR intervention for larger sample size immediately after the topic gets covered. The current AR learning system lacks real-time annotation of textual data that can be used to provide dynamic information and feedback to the students after they mark answers. Hence, we plan to redesign the AR learning activities for better usability especially during collaboration. We also plan to explore the implementation of other topics of middle school Geometry and Mathematics syllabus as AR learning activities.

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