Boosting Junior High School Students' Mathematical Proficiency Utilizing the Integration of AR in the Classroom

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Abstract: Several attempts have been made to enhance education through innovative technologies like Augmented Reality (AR). Examining the effects of these settings or technologies on various student populations is essential. The primary goals of this research are to determine how open students are to using AR applications for educational purposes and how well it helps junior high school students understand geometry. Seventy-seven students from the junior high school in Purwokerto City, Indonesia, which is located on the edge of both urban and rural areas, were selected for this study. We select 34 participants for the experimental group and 32 for the control group. The experimental group used custom-built AR applications to help students better understand geometry concepts, and the control group stuck with more conventional instruction. The findings of the experiment proved that students' grasp of mathematical ideas can be improved with the use of AR learning applications. Results from the survey and the free-form questions further support the students' positive views on applications. Research into the effects of AR on students' more subjective traits, such as learning anxiety, and on a wider range of app users may be undertaken in the future.

Keywords: Augmented Reality, experimental study, high-school students, mathematical proficiency

INTRODUCTION

A multitude of teachers are intrigued by virtual learning due to the unique potential they provide for students. Pramuditya et al. (2022) assessed various educational applications of 3D technology and discovered that students may acquire knowledge more effectively in well-structured virtual classrooms with reduced cognitive strain compared to traditional classrooms. Research by Fendi et al. (2021) indicates that surgeons who consistently engaged with simulation applications for three hours enhanced their efficiency and diminished their error rates during surgeries, in contrast to those who did not utilize such applications. Numerous educational institutions have been utilizing third-person virtual worlds, such as Second Life, for online instruction. Opportunities for higher education may become increasingly available to a broader population. Its assistance for low-income students can substantially reduce the "Digital Divide" (Salim et al., 2020).

The unique opportunity that virtual learning gives to students has sparked the imagination of many teachers. Students in well-designed virtual classrooms could learn more with less mental effort than in more traditional classrooms, according to a study of several educational applications of 3D technology (Pramuditya et al., 2022).

AR is occasionally perceived only as an advanced kind of virtual reality. The three fundamental features of this method in computer science are three-dimensional registration, real-time interaction, and the superimposition of virtual components onto the actual learning (Suzanna & Gaol, 2021). AR incorporates both digital and physical elements. Users may interface with digital, three-dimensional items in these actual spaces. In an ideal scenario, an AR classroom would help students see 3-D concepts that are otherwise impossible to envision, give solid form to abstract ideas, and better understand concepts with which they are struggling. AR has the potential to be used in conjunction with different learning styles (Abdullah et al., 2020).

However, it's still a good idea to find out if all educational audiences get anything from using contemporary technology. There has been a lot of effort to provide richer information to students by employing modern learning settings or technologies. However, research on the effects of these settings or technologies on students with varied qualities is necessary (Richardo et al., 2023). There is some research on AR in the classroom, but not much that especially targets students from various backgrounds. In this project, we designed a collection of AR learning applications for a Chromebook to aid students in mastering the mathematical underpinnings of geometry. Despite its base in reality, the knowledge is abstract, making it difficult to visualize. This study intends to assess the amount of receptivity to employing AR applications as a learning tool and the efficiency of such applications in increasing junior high school students' grasp of geometry.

LITERATURE REVIEW

Constructivism Theory

Constructivist theory emphasises the process of discovering knowledge, ideas, and concepts rather than the outcomes of individual student responses. According to constructivist learning theory, learning is a process that allows pupils to build their knowledge. Knowledge that already exists cannot be communicated, except through the process of imparting knowledge between teachers and students (Vygotsky, 1999). Constructivist learning is also based on the concept that pupils go through a process that is similar to construction. The process of construction is based on learners' experience (Belbase, 2014). In constructivist learning, the teacher serves as a facilitator, allowing students to discover their potential. Thus, pupils become the focal point or play an active role in growing the knowledge they possess. This is consistent with the notion of differentiated learning, which recognises all of students' particular abilities and places them as learning subjects. Students are encouraged to be creative while submitting ideas or thoughts they have. This is done so that students can absorb learning information using their preferred learning style, making it easier to understand (Gold, 1999).

Lev Vygotsky is one of the founders of constructivist learning theory. Lev is an educator who views learning as a social process (Abida & Muhammad, 2012). Students' cognitive and language development occurs in a social context (Belbase, 2014). More than half a century ago, Russian psychologist Lev recognised this fundamental aspect of the child's cognition. Vygotsky's idea attracted increased attention near the end of the twentieth century. Vygotsky believes that every individual develops within a social framework. All intellectual growth, including meaning, memory, thinking, perception, and awareness, shifts from the interpersonal to the intrapersonal domain. The mechanism that underpins high-level mental effort is a replication of social interaction (Gold, 1999). According to Vygotsky, all higher-order cognitive function in humans begins with each individual's social interactions within a specific cultural environment. Cognition refers to the internalisation of social interaction. Vygotsky's theory of social cognition emphasises the need for a new social foundation for comprehending the educational process (Dangel, 2017).

Information Technology for Geometry

Geometry should be highlighted in junior high school courses. The Minister of Education introduces geometry topics to Indonesian high school students as independent sections in the curriculum (Abidin & Herman, 2023). A unit on geometry is also required in the mathematics curriculum of numerous Asian countries' secondary schools. Efforts to strengthen students' reasoning and statistical knowledge have been the focus of various recent examinations in mathematics curriculum in high schools. From a psychological and educational standpoint, Pujiastuti et al. (2020) explored students' knowledge of geometry. Students commonly create subjective and erroneous first ideas of geometry. Students' subjective opinions may contradict the formal assumptions of geometry. Important principles, such as independent occurrences, are comprehended by a considerably smaller percentage of high school students than they were on the National Assessment of Educational Progress. The results showed that the students did not fare well in geometry (Kihwele & Mkomwa, 2023).

Widyasari and Mastura (2020), many students should not rely on their beliefs about geometry but rather on more traditional understandings of the idea. The significance of students' conceptual knowledge and the use of appropriate technology in well-planned learning activities was underlined in Mohammed et al.'s (2022) systematic evaluation of geometry education, which focused on the field as a whole. The study's authors found that this could help students improve their reasoning and comprehension abilities. Sadly, most research on the use of technological tools in geometry lessons has been undertaken in universities rather than high schools. When it came to gathering, analysing, visualising, computing, transforming, and checking data, high school math students relied on graphing calculators (Marrahi & Belda-Medina, 2023). Excel was a typical tool for high school geometry teachers to employ. When compared to the typical group, Excel performed better on the unit tests. Lai and Cheong (2022) used an Excel add-on to help high school teachers and students grasp data modelling. In conclusion, the dynamic statistical tool helped students to arrange enormous data sets and obtain valuable findings effectively (Pramuditya et al., 2022).

Three computer-assisted simulations analyzed using SPSS and Microsoft Excel helped students better grasp sample distributions and associated disciplines (Fernández-Enríquez & Delgado-Martín, 2020; Talan et al., 2022). These simulations were incorporated in some studies that took advantage of relevant technology resources in academic contexts. Preservice teachers can also help students polish their prediction and inference abilities by using simulation geometry tools like Assembler Edu (Fernández & Delgado, 2020). In addition, Elsayed and Al-Najrani (2021) compared the usefulness of numerous technology aids. Technology had a minor effect on boosting students' statistical achievement, according to his examination of 46 studies. Simulation was the most influential of these technologies. In their review of computer-assisted geometry training, Umam and Dwi (2024) synthesised the results of twenty-five distinct empirical studies. The findings reveal that the two most beneficial types of applications are expert systems and drill-and-practice programs. Embedded assessment, students' educational background, and the length of time they spend in class can all change their statistical accomplishments (Somby & Mølstad, 2022).

The Role of AR in the Classroom

Using AR to develop technology could be advantageous for high school students since it provides a more participatory learning experience compared to standard virtual classrooms. Research on AR's usefulness in the classroom has yielded largely positive outcomes. It may act as an excellent teaching tool in elementary school (Ahmad & Junaini, 2020). The possibilities of AR in the classroom have recently drawn the attention of various schools and advocacy groups for better education. The most widely acknowledged advantage of AR was its capacity to lessen students' cognitive load while simultaneously boosting their motivation, understanding, and engagement (Nugraha, 2023).

Students learning attitudes, performance, motivation, and critical thinking abilities could be improved by utilizing an AR system (Guntur et al., 2019). Mathematical attentiveness is better when students employ visual assistance (Suzanna & Gaol, 2021). The researchers opted to implement AR in solid geometry because of its three-dimensional features. A method that was built to help high school students understand solid geometry through AR has been evaluated and proven to be effective (Widyasari & Mastura, 2020). Also, after implementing AR learning tools, low-achieving students' attitudes improved. The open-source, AR-built 3D virtual classroom has enabled geometry and function education and research, analyzing its application in junior high school mathematics use specifically.

On the other hand, studies have also shown that AR can make abstract concepts easier to understand by presenting visual representations of them. Somby and Mølstad (2022) constructed an AR book and examined its usefulness in helping students learn electromagnetism. Narrative results revealed that AR books might benefit in comprehending complicated spatial concepts, as evidenced by the gap in the average proportion of accurate replies given by the two groups of participants. Students may find it simpler to absorb otherwise difficult course material with the usage of AR learning tools (Ahmad & Junaini, 2020).

To study the effect of AR on conceptual understanding, researchers employed a psychological model of AR learning. This paradigm rests on three pillars to characterize the impact of AR on the educational process: physical, cognitive, and environmental. On a cognitive level, AR may help students understand metaphors. According to Nasrudin et al. (2021), this procedure is facilitated by AR scaffolding. Some teachers may choose to employ animated videos generated using Adobe Flash to replicate data presentation as technology progresses. Regardless, some students could conclude the work isn't authentic. Maybe if students cared about the outcome of the experiment, they could finish gathering data much more rapidly. So, we built a course to teach students the basics of geometry, including sample space and more. The objective of this study was to present junior high school students with an introduction to geometry and to suggest an alternative way for them to experience data collecting through AR.

METHOD

Participants

Seventy students from Purwokerto City, Indonesia, reside at the intersection of urban and rural areas. Participants' ages varied from thirteen to fifteen. All students enrolled in the same course possessed a robust understanding of geometry before the classroom learning. The class was partitioned into four equal segments for the group projects. Consequently, two separate groups were formed from the previously mentioned. Both groups of students performed nearly identically on the preliminary examinations. Ultimately, the experimental group was comprised of 34 students, whereas the control group consisted of 32 students. We ensured that all students were informed of the voluntary nature of their participation. Furthermore, we guaranteed that their replies and responses would stay confidential and would not influence their mathematics marks.

Research Design

Figure 1 depicts the instructional and learning framework for the geometry unit for both groups. While the control group continued to use more traditional education methods, the experimental group utilised custom-built AR applications to explore geometry concepts further, individually or in small groups. Each of the three courses ran for a full six weeks.

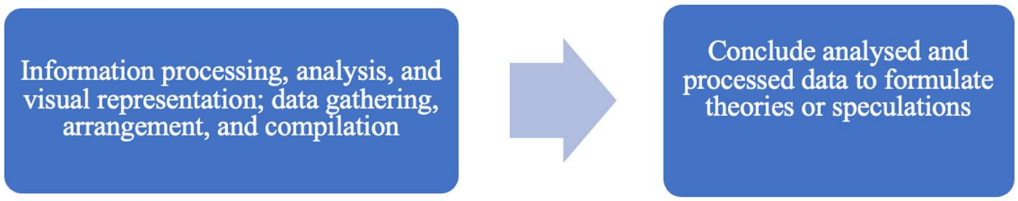


Figure 1. A Review of Mathematical Material

Figure 2 shows the general layout of all the classes. We started class with a "Conclude the current activity", which allowed students to work on a brief assignment on the board as soon as they entered the room. During this time, we also encouraged group discussion. Students in both groups were introduced to the day's topic during the fifteen minutes that followed. The format of this section of the class was somewhere between a lecture and a group project. During a fifteen-minute session, students explored geometry using a Chrome book equipped with AR applications.

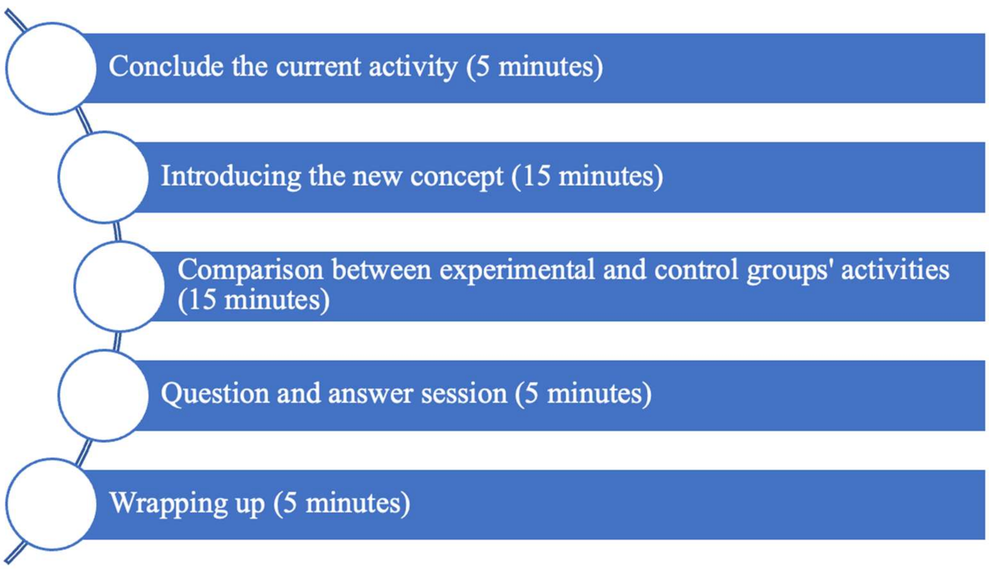


Figure 2. A Classroom Exercise

Students could collaborate with the teacher while keeping track of experimental results (Figure 3). At the end of the experiment, students had five minutes to discuss and share their findings. A guided recap took up the final five minutes of the lesson. This lesson plan would be used for all three subjects.

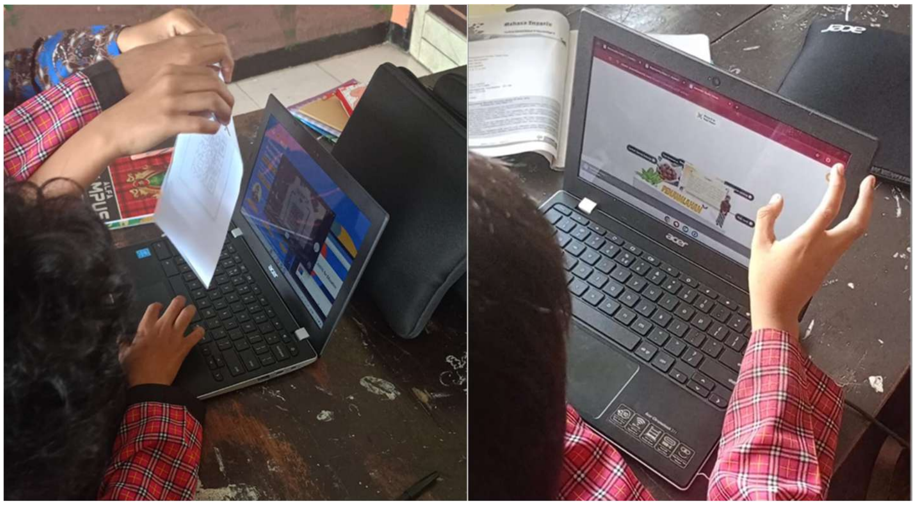


Figure 3. The Student Activity of the Experimental Group

Implementing AR in Experimental Group Design

The initial application was driven by the "Data Presentation through Diagram" instruction in Figure 1. Only the two of them were able to engage in the game. To activate the applications, a student positioned the AR card they had constructed in front of the camera. Upon the vehicle's appearance, the camera triggered. The outcome was visually represented on the screen. The subsequent student emulated the action, and the game advanced to the second round. Students had the option to either re-roll the dice in this round or terminate the game if they judged their numbers sufficient for winning. Unless a student elected to cancel the game, it would progress to the future round. However, the game would terminate quickly for the student to obtain seven points or more. This application enables students to encounter geometry in real-world situations. Upon completion of the program, individuals should possess a firm understanding of when to persist and when to cease.

The second application was specifically built for the "Analysed and Processed Data" lesson represented in Figure 2. This program gives sample spaces of equally probable events to students. The application requires students to collaborate in pairs, each employing a single mobile device. Each page depicted a different, equally geometric occurrence. Upon a student presenting a piece of paper to the camera, the whole sample area would be displayed on the screen. Students had to work with their groups on the sample space of the stated geometric event and thereafter employ their Chrome book to evaluate their findings. The examined and processed data would comprise a multiple sample space of two probability occurrences if students could concurrently show both papers in front of the camera.

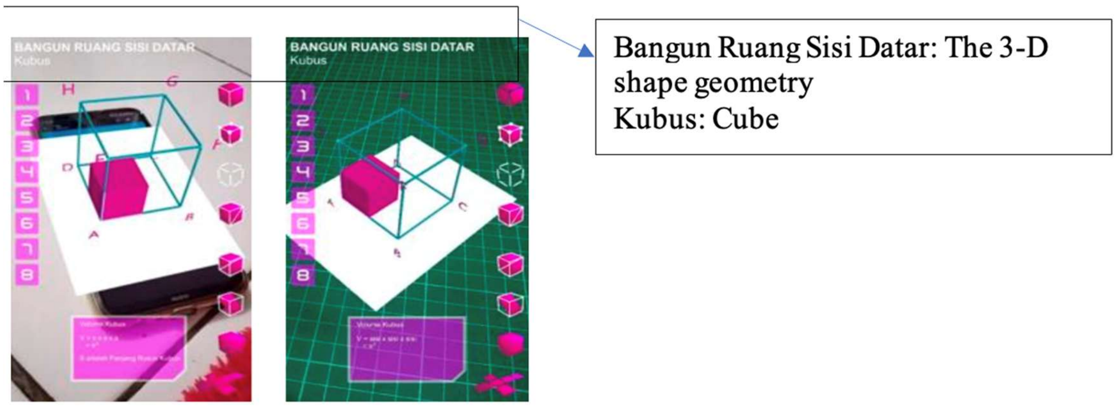
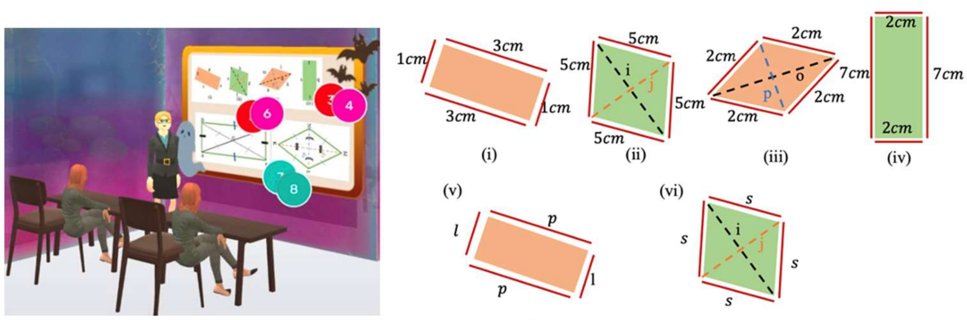


Figure 4. The Sample of AR Applications in the Experimental Group

Students were introduced to three AR programs as part of their coursework as shown in figure 4. Using the physical device layer to connect with an Android phone's camera allows for shooting pixel-perfect photos. The developing layer sends an application development kit to the application layer, allowing the application layer to call the interface methods. An interface for engaging with various AR features is given via the function module layer. Simultaneously, the applications count the data points on the diagram and provide the findings on the upper left of the screen. Figure 5 demonstrates that the bottom left corner of the screen displays the head-side geometry 2-D shape in real time.



Berdasarkan gambar di atas, *berpakah keliling dari pola i sampai iv?Perhatikan penjelasan berikut.*

GAMBAR	KELILING	KETERANGAN
(i)	$8cm$	$K = 3 + 1 + 3 + 1$
(ii)	$20cm$	$K = 5 + 5 + 5 + 5$
(iii)	$8cm$	$K = 2 + 2 + 2 + 2$
(iv)	$18cm$	$K = 2 + 7 + 2 + 7$
(v)		$K = p + l + p + l = 2p + 2l = 2(p + l)$
(vi)		$K = s + s + s + s = 4s$

What is the circumference of patterns *i to vi* as depicted in the figure above? Attend to the subsequent explanation.

Keliling: circumference
K: circumference
Keterangan: The value

Figure 5. Presenting AR Data Visualisations

The third application might be valuable for students since it can do away with the obligation to collect data and construct curve graphs by hand in class. This app dives into numerous AR applications in the classroom, not to transmit knowledge but to aid students in their topic research, which could result in additional class time being spent in many circumstances (Marrahi & Belda, 2023). The procedure of sending a QR code to the server allows teachers to examine all of their students' data (Figure 3). Additionally, the program keeps past data in a local database, which users can retrieve when they exit the app. Teachers recommended the feature for its capability to help students comprehend the connection between two geometry categories using classroom data and for its impact on teachers' ability to explain the lesson's theme. These results could help students visualize how the real chance approaches the theoretical chance of 0.5.

Instruments and Theories for Experimentation

Experimental research methodologies were employed in this study. We investigated the impact of AR on students' understanding and perspective through the use of questionnaires, tests, open-ended questions, and in-depth interviews. The working hypothesis is as follows:

H_1: Students who utilised AR to augment their learning may have achieved better results than those in the control group.

H_2: The students were enthusiastic about using the AR program in their studies.

Research Instruments

Pre- and Post-Test

Our objective was to assess the students' grasp of 2D geometry using the standard test that was administered to all local schools in Purwokerto, Indonesia, by the local Education Department. If students could perform better on the local tests, the consequences of this study would be more practical and meaningful. Therefore, rather than creating a new test, we relied on the current one. On the other hand, we replaced several technical terms in the practice test with more common ones so that students who haven't studied them yet could understand them. On both tests, students would have to solve sixteen geometry problems. All of the exams had a maximum score of 100. The samples of the pre- and post-test are impressive below.

Given the measure of angle A is, 33^0*. find the sum of the measures of the complementary angle, supplementary angle, and vertical angle for angle A.*

a. 257^0 *b.* 237^0 *c.* 279^0 *d.* 227^0 *e. NOTA*

The perimeter of a rectangle is 28 in. if its length is 9 in. Find its area.
a. 6 sq. in. b. 45 sq. in. c. 90 sq. in. d. 2.5 sq. in. e. NOTA

Survey on the Use of AR Applications

This questionnaire is derived from the original survey instrument created by Chao and Chang (2018). Thamrongrat (2021) revised the survey to assess the degree of acceptance of AR applications. The survey for this study comprises three sections: cognitive processes, perceptions of cognitive access, and the notion of contentment. This poll aimed to assess student sentiments and satisfaction with AR applications for Chromebook devices. This survey was conducted retrospectively. No participants from the control group completed the survey; it was only administered to the experimental group. The results can be deemed highly reliable since the questionnaire exhibits a Cronbach's Alpha value of 0.92, with the three constructs demonstrating values of 0.91, 0.97, and 0.93, respectively. The findings indicate that the questionnaire demonstrates reliability.

Semi-Interview Questions

In addition to the post-test, certain students were asked to answer many open-ended questions alongside the quantitative research instruments. Researchers questioned students involved in the study in person after class. The post-test for the experimental group had five open-ended questions.

1. What aspect of the lesson did you find most enjoyable?
2. In what ways do you believe these AR features would enhance this unit?
3. What are the limitations of the unit's AR applications?
4. What advantages does the utilisation of a tablet and AR offer over traditional instructional methods in a mathematics lesson?
5. What advantages does the conventional approach to teaching and learning mathematics (without the use of Chromebook and AR) offer to students?

The questions improved the questionnaire aimed at comprehending students' viewpoints on the utilisation of AR in the classroom. Subsequently, after the class, four students were randomly selected to engage in in-person interviews concerning their perceptions and emotions about AR teachings. The inquiries encompassed numerous topics, including:

1. In what ways does the utilisation of AR in the classroom differ from traditional methodologies?
2. What mathematical information did you gain from the initial mobile AR geometry application (Experience the Data Presentation)?
3. What mathematical insights did you gain from the second mobile AR geometry application (Data Analyse)?

This study sought to compare conventional mathematics training with instruction incorporating learning activities using AR technologies. Therefore, the initial question was selected accordingly. Questions two, three, and four are essential, as students' grades are significant in determining the study's effectiveness.

RESULTS

Learning Gains Analysis in Experimental and Control Groups – RQ1

The control group achieved a score of 32 out of a maximum of 36 points, while the experimental group attained a score of 36 points both before and following the intervention. The maximum attainable score on the test is 100. Table 1 presents the essential descriptive statistics of the primary group prior to and following the test. Subsequently, paired t-tests were employed to compare the pre- and post-test scores of both the control and experimental groups. The results are presented in Table 2. Table 2 indicates that students in both the experimental group ($t = 11.41$, $p < 0.01$) and the control group ($t = 4.24$, $p < 0.01$) performed better on the post-test compared to the pre-test.

Experimental Test	Group	N	Mean
Pre-test	“Experiment” category	34	82.34
	"Control" category	32	81.90
Post-test	“Experiment” category	34	84.66
	“Control” category	32	82.53

Table 1. The Results of Pre-and Post Test

Group		Mean	S.D.	t
The range for Pre-and Post-test	“Experiment” category	8.21	4.62	11.41*
	“Control” category	3.35	5.72	4.24*

Table 2. The t-Test Value for Pre- and Post-Test of The Experimental Design

		Pre-Experiment		Post-Experiment		Univariate ANCOVA			
Group	N	Mean	S.D.	Mean	S.D.	Adjusted Mean	Standard Error	F	eta^2
Experimental Group	34	81.44	12.52	84.66	12.31	86.52	.72	30.81*	.25
Control Group	32	80.50	11.56	82.52	11.56	83.56	.68		

Table 3. Results from the Experimental Design's Pre- and Post-Test ANCOVA Value

To determine the impact of AR, we combined the post-test results of the two groups and performed an analysis of covariance (ANCOVA). Table 3 shows the performance of the independent variables and covariances before and after AR treatment is defined as the student's performance on the pre- and post-tests. The experimental group displayed significantly higher post-test scores compared to the control group, as indicated by the analysis of covariance (ANCOVA) results ($F = 30.81$, $p < 0.01$, $\eta^2 = 0.25$). Lastly, it should be noted that the utilisation of AR learning tools considerably enhanced the students' ability to retain course material. Furthermore, the difference between the two groups becomes even more pronounced after the classes, with the experimental group achieving better results than the control group. The results support hypothesis 1.

Statistical Analysis of the AR-Based Questionnaire - RQ2

All 36 students in the experimental group completed the "Satisfaction" questionnaire, and the descriptive statistics are presented in Table 4. An average score of 4.05 indicates that the predominant response was, "Mathematical learning with AR is enjoyable for me," suggesting that students may significantly benefit from the application of AR principles in areas beyond mathematics. The statement, "Geometry is a captivating discipline, and I believe it is intrinsically linked to the essence of these applications," which received a high average score, supports this perspective. In the context of mathematics education, the elevated mean score for the statement, "These AR-based applications can help me discover new problems and questions," indicates that students gain to identify new topic explanations before using this AR-based application. AR serves as an excellent resource for math classes as it enhances problem-solving instruction. The average score for all claims exceeds 3.00, indicating that students are generally satisfied with these AR applications.

The Item	Mean	S.D.
AR learning applications are significantly more engaging than the monotonous traditional classroom environment of the past.	3.85	.89
These AR applications enable me to explore new difficulties and enquiries.	3.67	.89
I can visualise mathematical concepts like geometry by using AR applications.	3.68	.91
I enjoy learning maths via AR.	4.08	.85
I enjoy using AR to learn.	3.52	.96
If AR applications could improve the teaching of other disciplines as well, such as physics and chemistry, that would be fantastic.	3.84	.93
I envision a future where I can employ AR programs to assist me with my mathematics assignments.	3.81	1.05
I wholeheartedly support the integration of AR in educational settings.	3.73	1.02
I am fascinated with AR educational applications.	3.81	.96
I believe the intriguing discipline of geometry is directly connected to the core of these applications.	3.56	.89
AR technology for education enables me to learn both independently and collaboratively.	3.56	.90
The appearance of these applications is pleasant and authentic.	3.74	.91
The colours employed in the applications are appropriately calibrated; they achieve the intended effect without being excessively conspicuous.	3.78	1.02
In my view, learning geometry and geometry using AR is crucial.	3.58	.97

Table 4. The Mean Form of the Questionnaire's "Content" Construct

The descriptive geometry of the items that measured the "Cognitive Processes" may be found in Table 5.

The Item	Mean	S.D.
AR, in my view, makes course materials more thorough and easier to understand.	3.78	.92
I contend that AR will transform mathematics.	3.89	.89
Utilising AR enables me to thoroughly comprehend fundamental subjects that were previously obscure to me.	3.68	.91
Employing AR allows me to contemplate and experiment without limitations, considerably improving my problem-solving talents.	4.02	.94

Table 5. The Questionnaire's "Cognitive Processes" in Geometry Context

A maximum score of 4.02 for the statement " Employing AR allows me to contemplate and experiment without limitations, considerably improving my problem-solving talents " suggests that students' study and comprehension abilities are positively influenced by these applications. This result demonstrates that AR has a beneficial effect on learning (Cabero et al., 2021).

The Item	Mean	S.D.
Operating AR applications is not difficult.	4.07	.92
Learning to utilise AR has required no effort on my part.	4.06	.94
The materials and procedures employed in the educational exercise are clear and comprehensible.	4.04	.91
I swiftly determine how to employ AR.	4.01	.89

Table 6. "Cognitive Access Learning" Mean Geometry in the Questionnaire

Items with high scores on the "Cognitive Access Learning" scale are described statistically in Table 6. All four claims in this table show that the AR applications are easy for junior high students to use, with a mean score over 4.00. Students' enthusiastic attitudes and readiness to utilise AR in the classroom are demonstrated by the outcomes of three components, lending credence to hypothesis 2.

Semi-Structured Interviews Overview

There were 34 students in the experimental group, and each of them answered the five free-form questions honestly and openly. Students were asked to identify the most interesting component of the unit in the initial open-ended question. All students in the class utilised one of three AR programs to engage in the “Do Now” exercises. The AR applications were the most favoured aspect of the course, as reported by all students, except for one who outright declined to participate. Students exhibited the greatest interest and preference for the third AR application among the three options.

The second and third open-ended questions required students to evaluate the advantages and disadvantages of integrating AR into the classroom. A poll revealed that 82% of students saw AR as an engaging and stimulating educational tool, 65% deemed it an efficient instrument for teaching and learning, and 56% considered it beneficial in enhancing their motivation to study. Forty percent of teachers believed that certain students were daydreaming or otherwise disengaged in class due to their fixation on their phones.

In the fourth and fifth open-ended questions, we prompted students to evaluate the advantages and disadvantages of conventional mathematics instruction. Among the questioned students, 37% said that traditional teaching methods enhanced their examination performance. Given that the predominant emphasis of mainland Chinese education is on test preparation, certain students may have perceived that more conventional pedagogical methods would enhance their examination performance. Simultaneously, all the students perceived traditional mathematics classes as tedious and excessively rigid.

Students View AR Applications

For this study, we randomly surveyed four students from the experimental group regarding their perceptions and sentiments toward AR instruction. A student was asked, "What is your perception of the distinction between traditional mathematics courses and the use of AR technology in contemporary instruction?" His response was as follows:

> "AR in the classroom encourages student participation, rather than sitting back and observing a teacher do a task. This, in turn, helps students retain more abstract mathematical concepts because they spend less time on data recording and curve graphing."

One additional student contributed:

> “The applications improved the readability of the study's findings by automatically drawing an empirical geometry graph. Using the AR app, students were able to get the needed graph in a fraction of the time it takes using traditional methods.”

The students also felt that the real-world applications of sample spaces improved their understanding of the theoretical concept behind them. One student who participated in an interview regarding the mathematical insights gained from AR geometry applications for ChromeBook noted that the initial app, "Experience the likelihood," was significant in helping him understand geometry in its abstract form. As a result, he gained a deeper appreciation for the relationship between theoretical and practical geometry. Applying the abstract concept of sample spaces, he provided new and impressive examples. The researchers spoke with the class's original maths teacher. As part of her reply, she stated:

> "Immediate data collection from all students and the graphical representation of empirical geometry on the instructional screen enhances the results, making them more impressive and comprehensible for all students, thereby fostering greater enthusiasm and curiosity regarding the class materials in AR compared to traditional mathematics classes."

DISCUSSION

The findings indicate that AR can effectively inspire students, aid in the transition between physical and virtual realms, and enhance the manipulation of tangible objects via a tactile interface metaphor. All of these advantages align with the need to instruct mathematics, particularly in mathematical modeling, where students want to understand the application of abstract concepts to real-world scenarios. According to Cabero et al. (2021), mathematical modeling is a sub-competence that helps students understand real-world problems; this program enables students to match 3D objects with their suitable real-world scenarios.

Salim et al. (2020) discovered that students exhibited increased motivation to utilise AR applications for constructing mathematical models derived from real-world instances. This is an element of the educational environment that inspires students to engage in learning within the classroom. The purpose of each task strengthens these two phases of education. Moreover, Elsayed and Al-Najrani (2021), discover that students may utilise the app's suggestion feature to implement previously acquired mathematical principles when encountering difficulties with certain issues.

An analysis of the performance of the two groups on pre- and post-lesson assessments indicated no statistically significant difference. According to ANCOVA statistics, students in the AR group who utilised the app for geometry comprehension outperformed those in the control group following the classes. Previous research arrived at the same conclusion (Elsayed & Al-Najrani, 2021; Talan et al., 2022). The quantitative analysis indicated that students acquired significantly more knowledge. Conversely, the findings of the qualitative study, encompassing students' responses to the open-ended survey questions, indicated that the implementation of AR in the classroom significantly improved students' engagement and excitement for mathematics. According to Somby and Mølstad (2022), the AR applications received unanimous acclaim from the majority of users. The poll results were corroborated by positive feedback from participants, who said that AR might enhance their motivation, learning efficiency, and create more engaging experiences.

During the face-to-face interview, one student stated that AR enables him to actively investigate mathematical relationships that showed how AR has the potential to increase classroom participation. Numerous interviewers from the student body emphasised the necessity of comprehensively grasping sample space and other abstract notions. From a constructivist perspective, students may utilise AR to enhance their statistical understanding (Nasrudin et al., 2021). The mathematics instructor asserts that the student's mathematical understanding significantly improved following the implementation of AR technology. The AR technology enabled students to view animated cartoon characters in three dimensions. The integration of this feature into the otherwise unremarkable AR exercise was well-received by high school students.

Moreover, the results of this study indicate that AR classes influence students' proficiency in geometry. Students who learn geometry via AR exhibit more positive attitudes than those who learn through conventional techniques. The overwhelming majority of respondents demonstrate a keen curiosity and enthusiasm for understanding AR information (Schutera et al., 2021). Despite this, students exhibited a comparatively low level of confidence in the beginning phase due to their unfamiliarity with the concept of AR. Ultimately, they found the learning experience to be entertaining and interactive, which motivated them to further explore geometry. AR-enhanced students' comprehension of the subject matter and heightened their passion for the educational experience within the classroom. The results align with the research of Su et al. (2022), as well as Del and Méndez (2021), which demonstrated that AR aids students in comprehension, enhances learning proficiency, fosters a positive attitude, and increases enjoyment in the educational experience.

In a 2021 study, Moreno et al. (2021) discovered that AR technology serves as an alternative educational tool that enhances students' cognitive by necessitating independent research on their subject matter. Students have the opportunity to explore mathematical concepts instead of receiving rote arithmetic instruction during the AR learning process (Hamzah et al., 2021). In education, the application of any technological tool is not solely confined to novelty and invention but is primarily determined by its efficacy in engaging students, as well as in fostering a conducive learning environment (Schmalstieg et al., 2020). Understanding their students' cognition of geometry will enable educators to recognise those with adverse attitudes and provide appropriate interventions (Vakaliuk et al., 2020).

However, the concept of "active learning" involves both explicit and implicit actions, such as students engaged in critical thinking about the material being taught. Examples of explicit behaviours include asking questions or making requests about the material. The findings suggested that the members of the full-AR group participated in more active learning; nevertheless, this does not imply that all of the students were not involved in the learning process. Despite the fact that they did not participate verbally, the students in the Basic-AR group gave the impression that they were paying attention in class. The cognitive load evaluations and targeted enquiries that are carried out before and after examinations are two alternative approaches that have the potential to be useful in the study that will be undertaken in the future to analyse the cognitive processes of students. Last but not least, we acknowledge that the activity has an impact on the activities that students engage in to investigate. When students are exposed to a wide variety of learning topics and when they take part in less prescriptive tutoring activities, they may exhibit a variety of inquiry patterns.

LIMITATIONS

This study has multiple drawbacks. The precise impact of the complexity variations between the two scenarios on students' learning and engagement remains indeterminate owing to the study's limited sample size. The circumstances regarding the quantity, nature, and anchoring of AR representations varied. Future studies must examine more controlled variations to enhance understanding of the differences in AR application designs for these specific factors. The limited sample size precluded the statistical detection of conditional differences, rendering the results and discussion largely speculative and indicating potential avenues for further research. The instructional exercise may have experienced a low volume of questions due to insufficient question prompts. A bigger sample size engaged in an open-ended tutoring activity for an extended period should yield more detectable statistical impacts.

CONCLUSION

In this study, the impacts of AR learning applications on the comprehension of geometry among students in junior high school are investigated. Students were able to better learn and grasp difficult ideas related to geometry with the use of two AR applications that were developed as a supplement to classroom inquiry activities. Rather than merely displaying visual items, our AR solution incorporates them into the overall experience of exploration. This is the primary distinction between our approach and others. The findings of the experiments revealed that AR learning applications have the potential to improve students' comprehension of mathematical topics. The positive perceptions that the students have of applications are supported by the findings of the attitude survey as well as the free-form questions. Additionally, the researchers had a conversation with the mathematics teacher at the junior high school. The effects of AR on learning outcomes and attitudes may be investigated in the future, but it is also possible that research may investigate how AR influences students' more subjective features, such as learning anxiety. Different teaching approaches to AR could be contrasted.

Moreover, qualitative studies of students' references to AR visuals just utilise data from enquiries that explicitly pertain to the visuals. Nevertheless, students posed numerous enquiries unrelated to the visuals, and this data could provide a clearer understanding of the comparative dynamics among the groups. The statistical implications and reproducibility of descriptive findings should be examined in future studies utilising larger datasets. Moreover, our sample exhibited a pronounced bias towards females, with women constituting around two-thirds of the participants in each condition. Although there seems to be no variation in gender disparity among situations, it remains uncertain whether this influenced the outcomes, as the current study did not do a gender analysis. Subsequent research may ascertain whether the current findings apply to larger populations.

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