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Augmented Reality for Mathematics Learning: A Study for Enhancing Mathematical Comprehension in High School Students

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ABSTRACT

Numerous initiatives have sought to incorporate novel learning environments or technology, including Augmented Reality, into delivering more comprehensive education. But it's crucial to look at how this technology or settings impact different types of students. Research purposes: the main purposes of this study are the degree to which students are receptive to adopting augmented reality software as a learning tool and the effectiveness of such software in improving students' comprehension of probability and statistics in junior high school. Seventy-seventh graders from Purwokerto City, Indonesia's junior highs bordering urban and rural areas, participated. Research methods: two groups of students could be selected: one for the experiment and another for control purposes. In contrast to the control group, who stuck with tried-and-true teaching techniques, the experimental group conducted additional exploration of probability concepts either alone or in small groups using custom-built augmented reality software. While the control group continued to use more traditional methods of education, the experimental group utilised custom-built augmented reality software to explore probability concepts further, either individually or in small groups. All three courses met for a total of sixty-two days. Research results: The findings from the study showed that students' grasp of mathematical ideas can be improved by around 25.6% with the help of augmented reality learning apps. Furthermore, we analyse the differences in student learning and inquiry behaviours between two experimental conditions that differ in the complexity of augmented reality information. Furthermore, the results of the attitude questionnaire and the open-ended questions (5 items questions) corroborate the students' good opinions towards applications. However, in the future, researchers may look at how augmented reality affects students' more subjective characteristics, such as learning anxiety, and broaden the demographic of those who use these apps.

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A. INTRODUCTION

Virtual learning environments have attracted the attention of many academics due to the unique experience they offer students. Students in well-designed virtual classrooms could learn more with less mental effort than in more traditional classrooms, according to an assessment of many educational applications of 3D technology by Pramuditya et al. (2022). Surgeons who spent three hours a week playing surgical simulation applications were more efficient and made fewer mistakes during procedures than their non-gaming counterparts (Fendi et al., 2021). Second Life and other third-person virtual worlds have been utilised by many schools as a means of online instruction (Salim et al., 2020). It has the ability to pave the way for more people to go to college. It has the potential to help close the "Digital Divide" by providing resources to kids who otherwise would not have access to a good education (Del Cerro & Méndez, 2021).

The ability of augmented reality (AR) technology to enhance student engagement and visualize complicated three-dimensional phenomena is making it known to educators (Richardo et al., 2023). According to Abdullah et al. (2022), the integration of augmented reality into educational environments is thus gaining popularity. This study compares the educational effects of low-complexity and high-complexity AR designs, with a focus on the understudied use of AR for one-on-one remote tutoring. The reason we're concentrating on one-on-one tutoring is that it's a typical educational practice that can take place in a number of settings, including students' use of instructors' office hours to ask specific questions, students' participation in private tutoring outside of class time, and even online videoconferencing. Even though augmented reality has proven to be useful in mathematics classes when students engage with the material on their own.

Meanwhile, in most people's minds, AR is just a more advanced version of Virtual Reality (VR). In computer science, this technique has three main characteristics: real-time interaction, 3D registration, and virtual elements superimposed on top of the natural world (Suzanna & Gaol, 2021). To sum up, AR combines digital and physical components. In these real-life settings, users might interact with digital, three-dimensional things. In a perfect world, an AR learning environment would allow students to see in three dimensions invisible and hard-to-visualize occurrences, make concepts more tangible, and gain insight into subjects they struggle with. Abdullah et al. (2022) suggested that AR might be integrated with various learning styles, such as discovery, cooperative, and collaborative learning. Nevertheless, it is worthwhile to investigate if all educational audiences benefit from modern information technology. There have been a lot of attempts to use new learning settings or technologies to provide richer content. However, it is essential to study how these technologies or environments affect students with varying characteristics (Richardo et al., 2023).

While several research has explored the use of AR in the classroom, only a few have focused on students from various backgrounds. For this research, we created a mobile device suite of AR learning apps to help students better understand statistics and its mathematical applications. The information is based on reality, but it is hard to picture because of its abstract nature. The primary foci of this research are the efficacy of AR software in enhancing students' understanding of statistics and probability in junior high school and the level of openness to using such software as a learning tool.

B. METHODS

1. Participants

The 70 seventh graders came from junior highs bordering urban and rural areas in Purwokerto City, Indonesia. Ages thirteen to fifteen were represented among the participants. The students were all in the same class and had a similar understanding of probability from their previous studies. For group projects, the class was split into four equal parts. A separate experimental group and a control group were then formed from the aforementioned groups.

On the pre-tests, both groups performed similarly. In conclusion, 36 students were in the experimental group and 34 in the control group. We made sure to remind all participants that their participation was entirely optional. We also told them that their responses and answers would be kept completely confidential and would not impact their maths scores in school.

2. Research Design

The probability unit's instructional and learning framework for the two groups is illustrated in Figure 1. For each of these classes, the experimental group used custom-built AR software to delve deeper into probability ideas, either alone or in small groups, while the control group stuck to more conventional methods of instruction. A total of six weeks was devoted to all three classes.

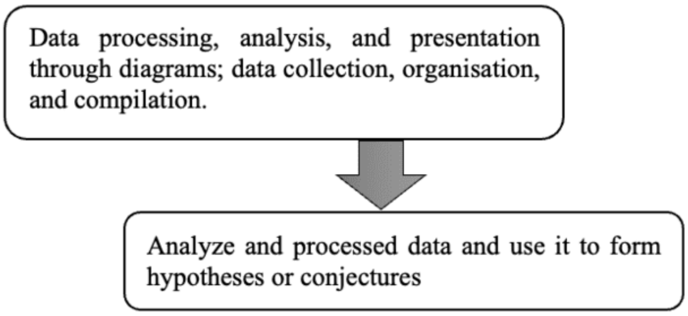

Figure 1. The Mathematics Content View

In Figure 2, we can see the outline of every class. In the first five minutes of class, we had a "Perform the task at hand" activity—a quick task that students could work on the board as soon as they walked in—and we encouraged group conversation during that time. During the subsequent fifteen minutes, the day's topic was presented to the students in both groups. This part of the class was structured like a hybrid lecture/group discussion. The students utilized handphones with AR programs for fifteen minutes to delve into probability concepts.

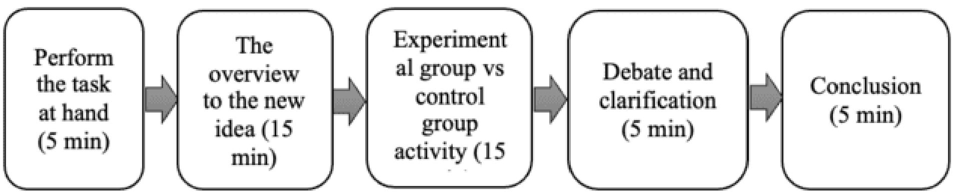

Figure 2. The Classroom Activity

Meanwhile, Figure 3 shows that the students could communicate with one another and the instructor or helper for assistance while recording experimental data. Students had five minutes to share what they had learned from the experiment with one another during the subsequent discussion. The last five minutes of class were devoted to a guided recap. Every one of the three subjects would have this same lesson plan.

Figure 3. The Students' Activity for The Experimental Group

3. AR in Experimental Group Design

Figure 1's "Data presentation through diagram" lesson inspired the first app. Just the two of them could play the game. To activate the software, one student placed the AR card they had created in front of the camera. As soon as the vehicle was in view, the camera rolled dice. A visual representation of the outcome was displayed on the screen. The second student followed suit, and the game proceeded to the second round. Students could roll the dice again during this round or end the game if they thought their numbers were good enough to win. Unless one of the students decided to end the game, it would go on to the following round. The winner was declared after all the students had scored at least seven points or came closest. But the game would end immediately for the student with seven points or more. Using this software, students could feel the likelihood in a real-world setting. By the time they finish the app, they should have a good grasp on when to keep going and stop.

The second app was made just for the "Analyzed and processed data" lesson in Figure 1. This application introduces sample spaces of equally probable probability occurrences to students. The app had the students work in pairs, each accessing a single handphone. The application's four paper types were money, dice, cards, and balls. Every one of the sheets stood in for a separate, equally probable event. As soon as a pupil held a piece of paper up to the camera, the full sample area would be shown on the screen. Students were to confer with their groups on the paper's sample space for the given probability event and then use the handphones to verify their work. The analyzed and processed data would also be a multiple sample space of two probability events if students could hold both papers in front of the camera at the same time, as shown in Figure 4.

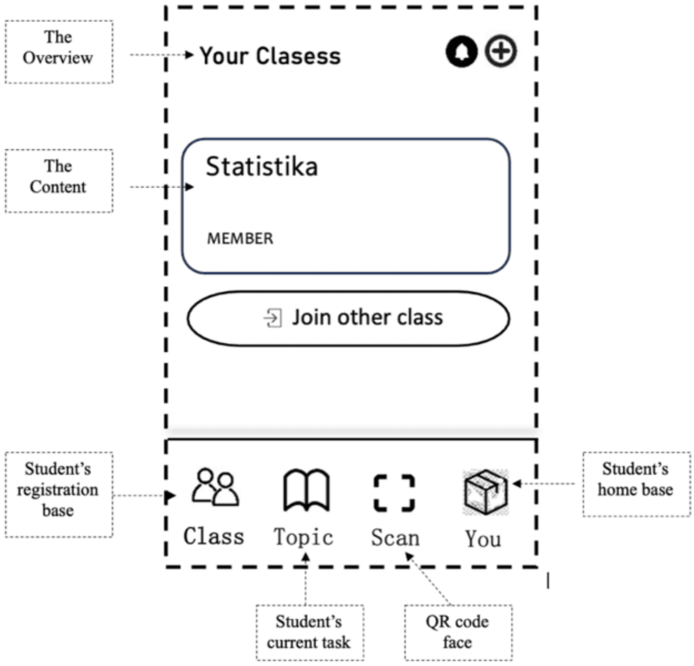

Figure 4. AR System of The Experimental Group

As part of their coursework, students were introduced to three AR programs. Figure 4 shows the framework of the system for AR learning applications. A pixel picture can be taken by contacting the Android handset's camera through the physical device layer. For the application layer to call the interface methods, the software development kit is provided by the development layer. The function module layer provides an interface for interacting with various AR functionalities. In the meantime, the software counts the number of data on the diagram and displays the results on the top left of the screen in real time. As illustrated in Figure 5, the head-side probability curve graph is shown in real time on the screen's bottom left corner.

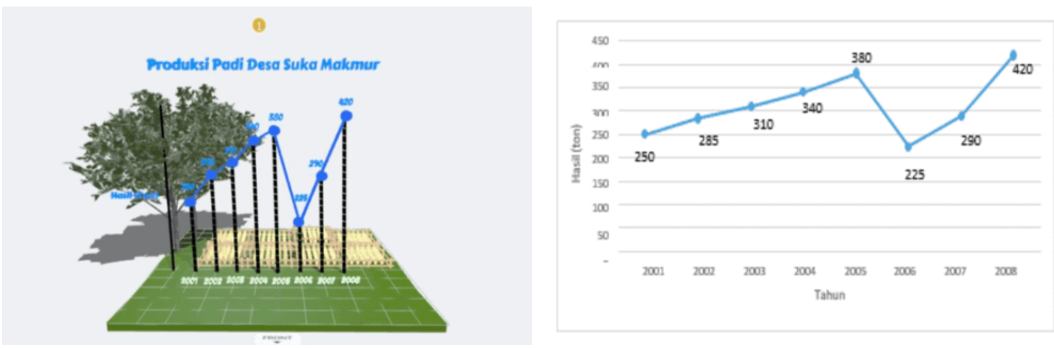

Figure 5. AR Screen of Diagram Data

Students may find the third valuable software because it eliminates the need to manually gather data and create curve graphs in class. This app explores various uses of AR in the classroom, not for presenting anything but to assist students in their exploration of subjects, which could lead to an increase in class time consumption in many instances (Akçayır & Akçayır, 2017). Figure 4 shows how teachers may view all of their students' data through a QR code when they upload it to the server and how the application saves previous data in a local database that users can access when they quit. The feature was added at the recommendation of the teachers because it enhanced their ability to communicate the lesson's topic and allowed students to comprehend the link between two probability categories better using classroom data. These findings may assist students in visualizing how the actual probability approaches the theoretical probability of 0.5.

4. Experimental Tools and Hypotheses

This study utilized experimental research methods. We used surveys, exams, open-ended questions, and in-depth interviews to examine how AR affected students' knowledge and outlook. Here is the research hypothesis: H1 is compared to the control group, students who used AR to supplement their learning may have succeeded more; and H2 is the students had a positive outlook on the AR software and were willing to incorporate it into their study.

5. Research Instruments

a. Pre- and Post-Test

   We utilized the standard test distributed to all local schools by the local Education in Purwokerto, Indonesia, to evaluate the students' understanding of probability. This study would have more practical and relevant implications if students could do better on the local exams. Thus, we used this standard test instead of making a new one. However, for students who might have yet to study them, we changed a few technical words to more layman's ones in the practice test. There were a total of sixteen probability problems on both exams. There was a 100 maximum score on all of the tests.

b. AR Apps Utilization Questionnaire

   The original survey instrument was created by Chao and Chang (2018) and used as a basis for this questionnaire. The questionnaire was adjusted by Thamrongrat (2021) to assess the level of technology acceptability for AR technologies. The survey used in this research has three parts: contentment construct, cognitive processes, and cognitive access thoughts. We used this survey to find out how the students felt about the AR apps for mobile devices and how satisfied they were with them. Only the post-test included this questionnaire. Those in the experimental group were the only ones who completed the survey. With Cronbach's Alpha values of 0.98 for the questionnaire and 0.95, 0.94, and 0.91 for the three constructs, respectively, we can say that the reliability of the results is high. The findings provided evidence that the questionnaire can be trusted.

c. Semi-Interview Questions

   As an additional component to the post-test, some students were asked to complete a few open-ended questions in addition to the quantitative research tools. Students who participated in the study were also interviewed in person by researchers following class. The experimental group's post-test consisted of five free-form questions.

   1) For you, what was the most enjoyable part of the lesson?
   2) How do you think these AR features would benefit this unit?
   3) What are the drawbacks of the unit's AR apps?
   4) What are the benefits of using a tablet and AR instead of the more conventional methods of instruction and learning in a math lesson?

5) How does the traditional method of teaching and learning mathematics (without using tablets and AR) benefit students?

These questions enhanced the questionnaire that sought to understand students' perspectives on using AR in the classroom. Additionally, following the lesson, four students were randomly chosen to participate in in-person interviews regarding their thoughts and feelings regarding AR instructions. Among the many topics covered by the inquiries were:
1) How does using AR in the classroom compare to more conventional approaches?
2) What mathematical knowledge did you acquire from the first mobile AR probability application (Experience the data presentation)?
3) What mathematical understanding did you acquire from the second mobile AR probability application (Data Analyze)?

This study aimed to compare standard mathematics training with instruction that included learning activities with AR applications. Hence, the first question was chosen accordingly. Questions two, three, and four are crucial because students' grades matter for the study's efficacy.

C. RESULT AND DISCUSSION

1. Examining Learning Gains of Experimental and Control Group – RQ1

The experimental group had test results of 36*2 (36 before and 36 after the intervention), while the control group had results of 34*2. At most, you could get a 100 on the exam. The pre- and post-test primary group descriptive data are displayed in Table 1. Subsequently, the experimental and control groups' pre-and post-test scores were analyzed using paired t-tests. The outcomes can be seen in Table 2. Both the experimental group ($t = 12.56$, $p < 0.01$) and the control group ($t = 4.52$, $p < 0.01$) students performed better on the post-test compared to the pre-test, as shown in Table 2.

Table 1. The Pre- and Post-Test Score

Experimental Test	**Group**	**N**	**Mean**
Pre-test	Experimental group	36	81.04
	Control group	34	80.70
Post-test	Experimental group	36	85.36
	Control group	34	83.63

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

Group		**Mean**	**S.D.**	**t**
The range for Pre- and Post-test	Experimental group	8.52	4.56	12.56*
	Control group	3.42	5.63	4.52*

Table 3. The ANCOVA Value for Pre- and Post-Test of the Experimental Design

		Prior Experiment		After Experiment		Univariate ANCOVA			
Group	N	Mean	S.D.	Mean	S.D.	Adjusted Mean	Standard Error	F	eta^2
Experimental Group	36	81.04	12.43	85.36	11.34	89.45	.73	31.94*	.33
Control Group	34	80.70	11.45	83.63	10.44	84.23	.69		

We used an analysis of covariance (ANCOVA) with post-test scores from both groups to see whether AR had any effect. Student performance on the pre-and post-tests is defined as the independent variables and covariances' performance before and after AR treatment. Table 3 displays the outcomes. According to the results of the analysis of covariance (ANCOVA), the experimental group achieved noticeably better scores on the post-test ($F = 31.94$, $p < 0.01$, $\eta 2 = 0.33$). Finally, it is worth mentioning that using AR learning aids significantly boosted the students' learning gains in likelihood following the courses. Additionally, following the classes, there is a wider gap between the two groups; the experimental group outperforms the control group. Such findings are consistent with hypothesis 1.

2. Statistical Examination Results for AR-based Questionnaire – RQ2

The descriptive statistics of "Satisfaction" are shown in Table 4, and all 36 students in the experimental group completed the questionnaire. With a mean score of 4.05, " Mathematical learning with AR is fun for me " is the most popular, suggesting that students would thrive utilizing AR techniques in subjects other than mathematics. The high average score of "Probability is an intriguing subject, and I find that it is directly tied to the substance of these applications" lends credence to this idea. Regarding mathematics education, the high mean score for the item "These AR-based applications can help me discover new problems and questions" indicates that students benefit from using this AR-based application to find new issues to study. AR is an excellent tool for maths schools since it complements lessons that focus on problem-solving. Students seem generally pleased with these AR programs since the mean score for all claims is more significant than 3.00, as shown in Table 4.

Table 4. The Mean Statistics for the ”Contentment” Construct in the Questionnaire

The Item	Mean	S.D.
We used to learn in a boring old classroom, but AR learning apps are way cooler.	3.92	.94
I can find fresh difficulties and queries with the help of these AR apps.	3.82	.98
By utilising AR apps, I am able to visualise mathematical ideas like probability.	3.93	.94
Mathematical learning with AR is fun for me.	4.05	.92
Using AR to learn is fun for me.	3.89	.94
It would be great if other subjects, like chemistry and physics, could also benefit from AR apps for education.	3.94	.94
One day, I'd like to be able to use AR apps to study mathematics.	3.93	1.01
To my friends and fellow students, I wholeheartedly endorse the use of AR for educational purposes.	3.92	1.01
AR learning apps pique my attention.	3.89	.93
"Probability" is an intriguing subject, and I find that it is directly tied to the substance of these applications.	3.99	.94

The Item	Mean	S.D.
With the help of AR learning technology, I can study both independently and in groups with my peers.	3.89	.93
These apps have a nice, genuine look to them.	3.91	.94
The colours used in the applications are suitable; they are both visually appealing and unobtrusive.	3.94	1.01
Using AR to study statistics and probability is essential, in my opinion.	3.94	.93

Meanwhile, items that measured the "Cognitive Processes" are displayed in Table 5 with their descriptive statistics.

Table 5. The Mean Statistics for the "Cognitive Processes" Construct in The Questionnaire

The Item	Mean	S.D.
In my opinion, AR makes course materials more comprehensive and easy to grasp.	3.82	.94
When it comes to maths, I think AR is a game-changer.	3.84	.98
By utilising AR, I am able to fully grasp crucial concepts that were before a mystery to me.	3.94	.95
When I use AR, I am able to think and experiment freely, which greatly aids my problem-solving abilities.	4.06	.98

With a maximum score of 4.10, the statement "It is not hard to operate AR applications" indicates that these applications positively impact students' ability to study and comprehend the material. According to Cabero et al. (2021), this finding shows that AR positively impacts learning.

Table 6. The Mean Statistics for the "Cognitive Access Thoughts" Construct in The Questionnaire

The Item	Mean	S.D.
It is not hard to operate AR applications.	4.10	.94
It has not taken me too much effort to learn how to use AR.	4.13	.95
Both the material and the methods used in the educational exercise are straightforward and easy to grasp.	4.01	.95
It doesn't take me long to figure out how to use AR.	4.05	.84

Table 6 concludes with descriptive statistics for items that score high on the "Cognitive Access Thoughts" scale. With a mean score of more than 4.00, all four assertions in this table indicate that the AR applications are user-friendly for students in junior high. The results of three constructs show students' positive attitudes and willingness to use AR in the classroom, which support hypothesis 2.

3. Semi-Structured Interviews Results

A total of 36 students in the experimental group were asked five free-form questions, and every single one gave an honest opinion. Students were asked to identify the most enjoyable part of the unit in the first open-ended question. The entire class participated in Do Now activities using three different AR apps. All students, except one who refused to participate, rated the AR applications as their favorite portion of the course. Of the three AR apps, students found the third one to be the most engaging and well-liked. In the second and third free-form questions, we had students consider the pros and cons of using AR in the lecture. When asked about the benefits of AR in the classroom, 84% of students said it made the class more engaging and fascinating, 68% said it made teaching and learning more efficient, and 52% said it strengthened their desire to study. Still, 40% of teachers felt that some students were too preoccupied with their tablets to pay attention at some points in class.

In the fifth and fourth free-form questions, we wanted students to weigh the pros and cons of the conventional approach to teaching mathematics. The percentage of students who said that traditional methods of instruction enhanced their performance on tests was 38%. Some students may have felt that the more conventional methods of instruction would benefit them more on the exams, given that mainland Chinese schooling is mostly focused on test prep. Meanwhile, Traditional maths classes were deemed dull and rigid by every student.

4. Students' Opinion of AR Apps Based

For this study, we randomly polled four students from the experimental group on their thoughts and feelings toward AR teachings. "How do you perceive the difference between the traditional maths courses and the AR technology in today's instruction?" was asked of one student, and his response was: "Using AR in the classroom allows students to actively engage with the material, rather than passively watching a teacher perform a task or spending more time on data recording and curve graphing, which helps students retain more abstract mathematical concepts." Just one more student chipped in: "The program's automatic creation of an empirical probability graph made the research results more understandable. Unlike traditional methods that take a long time to draw diagrams, the AR app allowed students to get the desired graph quickly."

The students also agreed that the practical use of sample spaces helped them better conceptualize and grasp the mathematically abstract idea of sample space. When asked about the mathematical understanding they obtained from the AR probability apps for mobile devices, one student said that the first app, "Experience the likelihood," helped him grasp the notion of probability in its abstract form. He was able to understand better the connection between theoretical and empirical probability through the process. He was able to present fresh and striking examples of the abstract notion of sample spaces through their application. The researchers interviewed the original math instructor of the class. In her response, she said: "Instantaneous data collection from all students and graphing of empirical probability on the instructional screen makes the results more impressive and understandable for all students, leading to increased enthusiasm and curiosity about the class materials in AR compared to regular math class."

Students in the control group may have had trouble filling or going beyond fundamental knowledge gaps if they were asked the same type of question over and over again, particularly if the questions were about obtaining basic information. Further, students who saw AR visualisations may have been building a deeper comprehension of the ideas after acquiring the basic knowledge, since the likelihood of asking exploration questions in experimental group was higher. A greater number of augmented reality graphics may have prompted students to use what they already knew and try new things, as well as helped them fill in holes in their foundational knowledge.

Based on these findings, AR graphics have the potential to help students acquire foundational knowledge, reduce knowledge gaps, and even spark new lines of inquiry when they delve further into a subject area. The incorporation of augmented reality visuals into the learning experience has the ability to spark new ideas in students' minds and challenge them to apply what they've learned in novel contexts. This could lead to improved comprehension and a broader range of ideas being considered in class. Another possible explanation for the Full-AR group's lower Integration question count is that they used more AR visualisations, which may aid in making connections between different concepts.

5. Discussion

There was no significant difference in scores between the two groups before this unit of teachings, according to the examination of pre- and post-tests. Following these classes, ANCOVA results showed that students in the AR group who used the app for probability learning learned more than those in the control group. According to prior research (Elsayed & Al-Najrani, 2021; Kazanidis & Pellas, 2019; Talan et al., 2022), the same finding was made. Results from the quantitative study showed that students learned significantly more. In contrast, the qualitative research, which included students' responses to the questionnaire's open-ended questions, showed that using AR in the classroom significantly increased students' interest in and participation in mathematics. Most students were entirely complimentary of the AR apps. In terms of the benefits of AR, several participants cited increased motivation, more efficient learning, and exciting experiences, which corroborated the positive survey results.

One of the students who participated in the in-person interview said that AR allows him to investigate mathematical links actively. That demonstrated how AR may boost student involvement in the classroom. During the interview, more than one student mentioned the need to grasp abstract notions like sample space. Students were able to build their understanding of statistics using AR, according to a constructivist viewpoint (Del Cerro & Méndez, 2021). According to the mathematics teacher, it's evident that the use of AR technology significantly improved the kids' arithmetic understanding. Using AR software, students could see the three-dimensional cartoon characters with motions superimposed on top of the image. Students in high school found this function to be an engaging addition to the monotonous routine of AR activity.

In addition, students seemed more motivated to investigate and engage with the learning activity when complicated AR information was included (Elsayed & Al-Najrani, 2021). This could be because students are more engaged and enthusiastic when they view interactive visualizations, or it could be because they are naturally curious about the greater amount of information available to them. Students may develop increased mathematical comprehension and confidence as a result of AR-enhanced teacher-student interactions, which may boost engagement, and promote tutoring that is student-driven. The concept that AR-enabled tutoring increases student agency and interaction has to be tested in future studies.

6. Limitations

Several limitations are associated with the present study. Because the study was designed with only two conditions, we don't know how the specific changes in complexity between them affected the students' learning and curiosity. The conditions differed in terms of the quantity of AR representations, the sorts of AR representations, and how they were anchored. To better understand how AR application designs vary along these particular dimensions, future research is required to examine more controlled variation. Both the findings and the discussion are very conjectural and point to potential avenues for further investigation due to the small sample size, which diminished the statistical ability to identify conditional differences. Furthermore, there were not many question prompts in the instructional exercise, which may have contributed to a low question volume.

Additional methods for gauging students' internal processes can be included in future research, such as cognitive load measurements and more targeted pre- and post-test inquiries. Lastly, we recognise that the activity has an impact on the sorts of inquiry that students engage in. Alternative learning content and tutoring activities that are less focused on instruction may cause students to display various patterns of inquiry.

7. Practical Implications

Based on our study, where the instructor wore an AR headset and the student remotely observed, we predict augmented reality to see more use in future 1-1 remote tutoring applications. Students won't need their own augmented reality devices for this kind of tutoring, which might lead to its widespread adoption as a means of incorporating AR into classroom instruction. Additionally, this form of AR remote tutoring could increase educational accessibility, allowing students from rural areas to connect to high-quality training and, in turn, boosting educational outcomes for disadvantaged populations. The effects of this tutoring method on one-on-one interactions between teachers and their classes can be the subject of future studies. These findings suggest that students who were exposed to more AR visualizations desired to participate in more active learning. How do these results stack up against other AR-aided tutoring setups, such as a single AR-aided teacher instructing a class of students in a co-located environment, or setups where students use their own devices to access the AR material, or where it is projected onto a shared screen, can be explored in future studies.

D. CONCLUSION AND SUGGESTIONS

This research examines how mobile AR learning apps impact junior high school student's mathematical understanding, focusing on probability. Two AR apps were developed to aid students in comprehending and mastering statistical and probability-related abstract ideas to supplement classroom exploration activities. Our use of AR differs primarily from others in that we incorporate it into the exploration process instead of merely displaying visual items. The findings of the experiments showed that these AR learning apps can improve students' mathematical comprehension (25.6%). In addition, the students' positive attitude towards apps is supported by the results of the attitude questionnaire and the open-ended questions. The researchers also consulted the mathematics teacher from the junior high school. In addition to studying the impact of AR on learning outcomes and attitudes, future research might expand the target demographic for these kinds of AR apps and investigate how AR influences students' more subjective traits, such as learning anxiety. One possibility is to compare several AR pedagogical approaches.

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