The Effect of Using Augmented Reality Module in Learning Geometry on Mathematics Performance among Primary Students

Ainur Yusra Nabila Mohd Nadzri*, Ahmad Fauzi Mohd Ayub, and Nurul Nadwa Zulkifli

***Abstract*—There are many Augmented Reality (AR) applications in smart devices, but their use in education is less focused and does not meet the current syllabus. AR has a great potential to be used in education, especially in introducing abstract concepts. To use augmented reality in education, students and teachers must follow teaching and learning guidelines. Therefore, this study implied the development of an educational module with augmented reality in Geometry, specifically under Space, following the standards-based curriculum for primary school (KSSR) Year 4 lessons. This study aims to determine the effects of using a module with AR (GeomAR3) on student performance in learning Geometry compared to a traditional module (Geom3). This study was conducted quantitatively following a quasi-experimental design with a pre- and post-test. Fifty-nine (59) Year 4 students were involved in the study from a school selected through purposive sampling, with 29 of them as an experimental group and the remaining 30 as a control group. The point of assessing student performance is seen through the implementation instrument, such as a pre-test, a post-test, and a delayed post-test. The study data were analysed using Multivariate Analysis of Covariance (MANCOVA) with the pre-test score as a covariate. The results show a significant difference in student performance on the overall mean score for the post-test ($F(1,59) = 33.848$, $p = 0.000$; eta squared = 0.377) and the delayed post-test ($F(1,59) = 14.740$, $p = 0.000$; eta squared = 0.208), with the experimental group significantly better than the control group. In conclusion, the use of modules with AR was found to improve students' achievement in learning Geometry due to the factor of the ability to visualize clearly, strengthen students' long-term memory, and gain conceptual understanding through the experience shown by AR.**

***Index Terms*—Augmented reality, experimental design module, Geometry**

I. Introduction

Industrial Revolution 4.0 (IR4.0) is an industrial transformation towards continuous automation in the manufacturing sector using smart and advanced technology. It optimises the use of computers and current technologies in producing industrial products based on machine-to-machine interaction. One of the components of IR4.0 is AR technology. This technology is used by incorporating layers of virtual reality into the natural environment to allow users to experience the activity themselves [1, 2]. The augmented virtual reality or artificial reality layer uses computer graphics to incorporate text, audio, or video into the expected environment [3, 4].

Augmented reality or virtual reality in education has proven the efficacy of learning in achieving designed objectives from preschool, lower school, and secondary school to higher studies [5]. According to Papanastasiou *et al.* [5], AR is reported to support the use of 21st century technologies and 4 C's of 21st century skills. These skills are collaboration, communication, creativity, critical thinking, and cooperation, as outlined in the Malaysia Education Blueprint (PPPM) 2013–2025 [6, 7].

The use of AR in education promotes students' engagement in the classroom, enhances understanding of subject content, strengthens spatial skills, improves long-term memory, and increases students' motivation [8–11]. According to a previous study [12], augmented reality can improve the quality of learning, strengthen understanding of challenging concepts, promote self-learning, manipulate virtual materials as actual learning aids, and enhance students' spatial perception. In line with study [13], it was noted that using reality-based kits in learning could attract students' interest, help deliver precise information, and allow students to answer questions 75% faster.

To rebalance the function of AR, teachers must have sufficient knowledge of running the designed teaching and learning with the help of AR. However, the availability of devices in schools will further promote the use of this technology in education [11]. Several independent studies stated that AR is beneficial in increasing students' interest and engagement in the classroom, as well as enabling mastery of difficult mathematics complex concepts compared to traditional learning [14, 15]. Mathematics teachers, in particular, can use augmented reality technology in selected subjects, especially when introducing abstract concepts to students, such as Geometry, algebra, and coordinates. Augmented reality with manipulative materials has a more positive impact on achieving learning objectives. At the same time, teachers can focus on learning without the need to contemplate on appropriate and sufficient teaching aid to be used in teaching and learning [16].

Moreover, a different study [9] established a connection between augmented reality and mathematics performance, motivation, and anxiety, further stating that the degree of students' motivation and anxiety toward the subject affects mathematics performance. According to the study's findings,

Manuscript received March 31, 2023; revised May 6, 2023, accepted June 7, 2023.

Ainur Yusra Nabila Mohd Nadzri is with the Faculty of Educational Studies, Universiti Putra Malaysia, Selangor, Malaysia.

Ahmad Fauzi Mohd Ayub is with Faculty of Educational Studies and Institute of Mathematics Research, Universiti Putra Malaysia, Selangor, Malaysia. E-mail: afmy@upm.edu.my (A.F.M.A.)

Nurul Nadwa Zulkifli is with Faculty of Humanities, Management and Science, Bintulu Campus, Universiti Putra Malaysia, Selangor, Malaysia. E-mail: nurulnadwa@upm.edu.my (N.N.Z.)

*Correspondence: gs61246@student.upm.edu.my (A.Y.N.M.N.)

doi: 10.18178/ijiet.2023.13.9.1952

students who learnt using augmented reality demonstrated higher levels of motivation when using the Attention, Relevance, Confidence, and Satisfaction (ARCS) model. Students with high levels of mathematical anxiety were initially found to be able to offer encouraging performance in algebra and Geometry with the imposed augmented reality intervention. The study by Hanid *et al.* [17] showed similar findings: the effectiveness of augmented reality in improving student performance in Geometry, visualisation skills, and computational thinking as a problem-solving approach. A previous work also conducted a study on the effectiveness of augmented reality in raising student performance in Geometry and visualisation skills, allowing teachers to use a variety of methods when instructing the subject [18].

In previous research on module development with AR, Maulana *et al.* [19] conducted a study among vocational school students on computer installation. They developed the ARRAKOM module to provide students with unlimited learning freedom (ubiquitous learning). Students can explore learning quickly anywhere using devices following Android-based AR. In addition, AR is applied in the module due to the shortage of actual media for this subject. Augmented reality is the technology chosen to overcome this media scarcity while promoting effective learning. The results of expert validity for the ARRAKOM module's media development show excellent (75%) and good (25%) percentages, while the results of material validity show perfect (57%) and sound (43%) percentages.

Meanwhile, Ibrahim *et al.* [20] conducted a study on Year 5 students regarding the use of High-Order Thinking Skills (HOTS) mathematics modules in primary school. The quasi-experimental study was conducted with a sample of urban and rural school students in Kota Bharu, Kelantan. The study's results, which had undergone Analysis of Covariance (ANCOVA) analysis, showed a significant difference in the students of the experimental group compared to the control group for schools in an urban area. However, students in rural schools showed no significant difference between the experimental group and the control group.

Sari Dewi and Kuswanto's [21] study aims to reveal the effectiveness of an AR-assisted physics e-module in improving mathematical communication and critical thinking abilities. The experimental study showed that the AR-assisted physics e-module improved mathematical and critical thinking abilities. Meanwhile, Su *et al.* [22] developed a virtual reality immersive learning mathematics' geometric system to enhance students' sensory experiences about mathematical geometry concepts. The study's findings showed that using the virtual reality immersive learning mathematics' geometric system can improve learning performance after completing the learning tasks of three geometric units of students compared to the control group. Meanwhile, a work by Arifuddin *et al.* [23] developed an AR module to improve students' mathematical creativity, where the results demonstrated effective improvement on students' mathematical creativity in the use of augmented reality module. Aspari and Hartono [24] developed a media module integrating GeoGebra to improve mathematics performance among students in Grade 4. The module was tested using an experimental design, indicating that GeoGebra media and modules have proven to be more effective. Meanwhile, another study [25] conducted a quasi-experimental design to determine the effects of modular instruction on third-year of Bachelor of Elementary Education (BEED) students at Eastern Samar State University (ESSU) in teaching word problem-solving. The findings of the study indicated that students exposed to modular instruction performed significantly better than the control group. Therefore, using modular instruction in teaching mathematics, specifically word problem solving is an effective teaching approach.

The effectiveness of learning with augmented reality technology on performance is discussed in the study [26]. The study concerned the development and validation of an augmented reality-based programming teaching system for 42 Grade 5 and Grade 6 students in Taiwan. The study carried out experimentally and by observation stated that the experimental group of students who learnt with the augmented reality method showed significantly higher post-test score performance than the traditional method. The performance of post-test scores shows that learning with the help of augmented reality applications promotes effective teaching and learning for students. In addition, a study of the effectiveness of WebAR on the English language performance of elementary school students in Iraq was conducted with the implementation of a pre-test and a repeated post-test [27]. The second and third post-test results showed significant results, with a better mean score for the experimental group students than the control group students. The significant results of the post-test with the experimental group being better than the control group were also discussed in the study by Prabakaran and Saravanakumar [28] through ANCOVA analysis to determine the effectiveness of e-content of mathematics interactive modules on mathematics performance.

In addition, an intervention using augmented reality applications to identify student performance in identifying geometric shapes showed that the experimental group was better than the group that traditionally learnt from Arvanitaki and Zaranis [29]. Meanwhile, the use of augmented reality in Content and Language Integrated Learning (CLIL) for learning the English language positively impacted the experimental group, which showed improvement in performance compared to traditional learning [30]. A previous study [31] also discussed similar findings from a study on basic programming conducted on 94 second-year students at a higher education level. An animation-based software was developed with AR technology and was used as an intervention for the experimental group. The study was conducted as a quasi-experiment with a non-equivalent control group model to assess effectiveness by pre- and post-test.

To determine the efficacy of using augmented reality in a delayed post-test, a study discussing the use of Geometry Teaching Assistive Materials (GLA) on an experimental group provided significant effects with an interval of two to four weeks after the intervention was implemented [32]. The study was conducted on 80 first-year students at a polytechnic. Studies that showed significant gains in post-testing for groups using augmented reality in Physics were also evidenced in a study by Dünser *et al.* [33]. This study utilised an interactive augmented reality book for teaching and learning physics with ten high school students. Augmented reality impacted long-term memory one month after the intervention. Thus, through the findings of the independent study, it is indicated that the use of augmented reality provides benefits in terms of long-term memory retention of a concept that has been learnt.

Thus, through the reference to various sources of independent studies on the development, effectiveness, and usefulness of modules in education, an investigation related to the use of modules was drawn up to be implemented in the elementary school curriculum in Malaysia. This study fills in the gap of previous studies by developing modules integrated with augmented reality technology for learning geometry, focusing on the topics: perimeter, area, volume and problem-solving of each topic. The module was designed to assist students in learning geometry topics and adopting AR applications using smart devices and acts as a guide to students and teachers so that progress in geometry can be identified clearly. GeomAR3 modules offer opportunities for students to visualise, and reinforce fundamental concepts of Geometry as well as collaborative learning opportunities.

II. Objectives and Hypotheses

A. Objectives

This study aims to determine the effects of using a module with AR compared to a module without AR integration in learning geometry among Standard Four (Year 4) pupils in primary school.

B. Hypotheses

The study hypotheses are as follows:

H1: There was a significant difference in the use of modules with AR reflected in the post-test mean score between students in the control group and those in the experimental group.

H2: There was a significant difference in the use of modules with AR reflected in the post-delayed test mean score between students in the control group and those in the experimental group.

III. Methodology

A. Research Design

The research design for this study is a pre-post quasi-experimental design to investigate the effects of using a module with the integration of Augmented Reality (AR) on students' cognitive performance in the form of a post-test and a delayed post-test. The choice of an experimental design arises following the researchers' aim to investigate the effect of using the module to integrate AR, known as GeomAR3. The quasi-experiment of causal comparing is ideal for investigating an intact group intervention's effectiveness and is used when a true experimental design is impossible [34]. The quasi-experimental design is based on the non-equivalence group [35] and does not involve random sampling [36]. Table I shows the quasi-experimental design.

The purpose of having different experimental and control groups is to control any confounding extraneous variables that may threaten the internal validity of the design. Two instructional strategies, the AR strategy with the GeomAR3 module and the conventional strategy with the Geom3 module, were conducted in both study phases. For the experimental groups, the GeomAR3 module was implemented.

Overall, the study ran for seven weeks, and the delayed post-test was conducted two weeks after the post-test was performed. The researchers appointed a teacher for each group in this design, and the teacher was chosen from the class's mathematics subject teacher. The students from the experimental and control groups were divided into three or four individuals per group to promote collaborative discussion. The selection of small group members should consist of students with various levels of performance, low, medium, and high, based on the scores from the pre-test given before the intervention. Students build knowledge with the help of better-achieving group members, as outlined in social constructivism theory [37].

TABLE I: Research Design

	Pre-test	Behaviour	Post-test	Delayed Post-test
Treatment	O_1	X_1	O_2	O_3
Control	O_1	X_2	O_2	O_3

O_1:Pre-test
X_1: Control group (Using module without AR integration)
X_2: Treatment group (Using module with AR integration)
O_2: Post-test
O_3: Delayed Post-test

B. Sampling Process

In this ongoing study, the researcher conducted a purposive sampling study on Year 4 students at a Muallim District, Perak, Malaysia school. Year 4 was selected based on the suitability of the subject under Geometry to be applied using augmented reality. The rationale for the selection of schools is that there are no more studies related to the use of augmented reality in Geometry carried out in the selected school. In addition, the consideration of school selection was made by looking at four criteria, namely: (1) the number of classes must exceed two classes to allow randomisation to be made; (2) primary schools with Mathematics instructional time of 30 minutes per period to comply with the number of time required in the GeomAR3 module; (3) there is an ICT base facility for the use of technology in teaching and learning; and (4) no streaming based on performance levels is done in determining students' ranking. As the selection is done purposively according to the characteristics the researcher sets, the possibility of generalisation is limited.

59 samples were involved in the study taken from two selected intact classes. 30 of them were in the control group, and the remaining 29 samples were in the experimental group. Group assignment was randomized.

C. Data Analysis

The results were further analyzed using a statistical tool known as IBM SPSS version 25. A one-way Multivariate Analysis of Covariance (MANCOVA) test was conducted on the two groups to determine any differences in the students' mathematical values on the Pythagoras theorem, transformation, solid geometry II, and statistics. Every individual in the sample was measured twice using a similar test before and after a period, and the two-measurement data were compared. This quasi-experimental study did not involve a random selection of the respondents in both the treatment and control groups. Hence, homogeneity testing was conducted to predetermine the intelligence profiles and levels of thinking ability among the samples. Therefore, a pre-test was conducted at the beginning of this study to determine the similarity between the two sample groups.

D. Module with Augmented Reality

The GeomAR3 module was developed based on spatial concepts, with the titles "perimeter," "area," "volume," and "problem-solving." The titles contained in this module are equivalent to the number of Standards-Based Curriculum for Primary School (KSSR) in Mathematics lessons for Year 4 students in national schools. The content includes introductory notes, reinforcement exercises, enrichment exercises, and quizzes at the end of each title and the end of the module. The answers are provided as a guide to the students to make it easier to check the answers independently. Meanwhile, the GeomAR3 module teacher's notes are also available to guide teachers in implementing teaching and learning with this module. The use of applications with augmented reality, known as Solidos RA is highlighted in every module activity. Students need to scan the QR code using the app (refer to Fig. 1), and the effect can be seen on the device (refer to Fig. 2). The impact of augmented reality can be seen in the shape characteristics, dimensions, and values displayed by identifying measurements such as perimeter, area, or volume content in solving daily problems, as in the diagram.

Fig. 1. AR scanning activity by student.

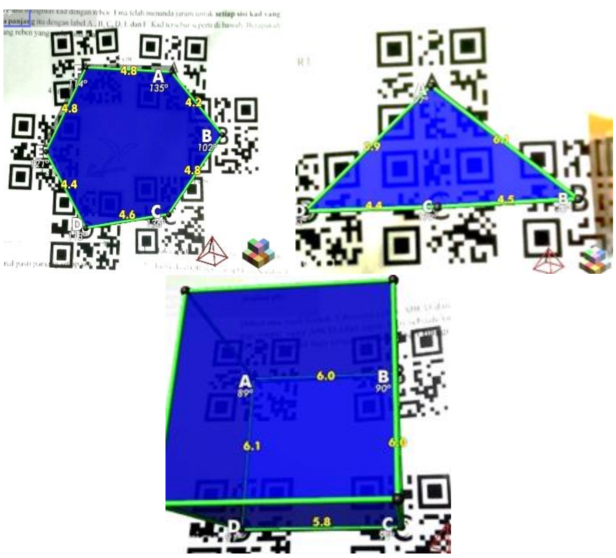


Fig. 2. AR effect on scanning in GeomAR3 module.

E. Module without Augmented Reality

The difference between the GeomAR3 module and the Geom3 module is the absence of augmented reality in the Geom3 module. The Geom3 module is a traditional module that contains the same Space content as the GeomAR3 module. This module also provides introductory notes, reinforcement exercises, enrichment exercises, and quizzes at the end of each title and the end of the module. The use of the Geom3 module was given to a control group that also received a traditional intervention.

IV. Results

A. Demographic Characteristics

In this study, 59 students participated, 30 in the control group and 29 in the experimental group; random selection was done to determine the groups (refer to Table II). The control group consisted of 17 male students and 13 female students. Meanwhile, the experimental group consisted of 20 male and nine female students.

TABLE II: Demography

	Control Group		Experiment Group	
Total respondents	30		29	
Gender	Male 17	Female 13	Male 20	Female 9

TABLE III: Summary Statistics of the Performance Test

	Group	Mean	Std. Deviation (SD)	N
Post-test	Control	12.3	7.795	30
	Treatment	23	11.219	29
Delayed Post-test	Control	12.37	9.301	30
	Treatment	19.48	11.444	29

The post-test and delayed post-test scores were analysed descriptively (refer to Table III) to obtain the mean and Standard Deviation (SD) for the experimental and control group students. Descriptive analysis showed that the mean score for the post-test of the control group was 12.3 (SD = 7.795), and that of the GeomAR3 experimental group was 23 (SD = 11.219). Meanwhile, the mean score of the delayed post-test for the control group was 12.37 (SD = 9.301), and that of the GeomAR3 experimental group was 19.48 (SD =11.444).

B. Multivariate Analysis

A one-way Multivariate Analysis of Covariance (MANCOVA) between groups was performed to compare the student performance in learning geometry for Standard Four students. The pre-test score was used as the covariate. The dependent variables in this study are two performance tests: the post-test and the delayed post-test. Meanwhile, the independent variable was the two groups (the group using the module with AR and the group without AR). The SPSS analysis met the normality assumption, with skewness and kurtosis values between −1.141 and 0.523. Pre-analysis screening procedures for examining multivariate assumptions (normality, outliers, multicollinearity, and homogeneity of covariance matrices) were carried out quantitatively using SPSS, and the analysis resulted in no severe noticeable violations. A further check on the homogeneity of variance-covariance matrices, calculated by Box's M test using SPSS (M = 10.204, F = 1.603, p = 0.142>0.05), indicates no violation.

A statistically significant difference existed in the mean of the students' mathematical performance between the two groups, with Wilks' lambda value = 0.622, sig = 0.000 ($p<0.05$), and a partial eta square of 0.378. The magnitude of the differences demonstrated a considerably significant effect (based on Cohen, 1988). When the result for the dependent variables was considered separately, there was statistical significance in the post-test: F (1,59) =33.848, p = 0.000; eta squared = 0.377; and in the delayed post-test, F (1,59) = 14.740, p = 0.000; eta squared = 0.208. An inspection of the mean score indicated that the treatment group reported higher mean scores in the post-test (mean = 23.00, SD = 11.219) than in the control groups (mean = 12.30, SD = 7.795). A similar result was also found in the delayed post-test, where the treatment group scored higher mean scores (mean = 19.48, SD = 11.44) than the control group (mean = 12.37, SD = 9.301) (refer Table III).

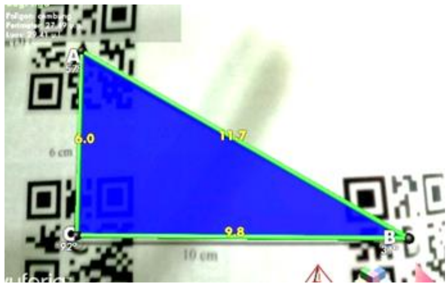
V. Discussion

A. Student Performance in the Post-Test

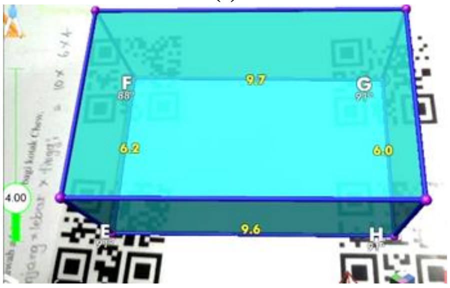
Post-test performance showed that students in the experimental group scored higher mean scores than students in the control group. This result indicates that the GeomAR3 module developed with the integration of AR positively impacts student performance after the related intervention. The mean score of the experimental group students was significantly better than the control group students' post-test mean score. Subsequent MANCOVA analysis showed that hypothesis 1 (H1) failed to be rejected. This significant result for students receiving the intervention with AR aligns with the study by Aspari and Hartono [24], which involved using modules with GeoGebra software and a modular approach [25] to teaching multivariate problem-solving. In addition, studies that use augmented reality also show significant results for experimental groups compared to groups that use traditional methods, such as those conducted by researches [26, 28, 38]

The effectiveness of using an AR application in this study is demonstrated by the fact that students could visualise the shape characteristics, length, size, and dimensions of the shape that can be controlled by the device rather than a printed diagram on paper, as is commonly used in teaching and learning. Fig. 3 shows the learning among students in the experimental group through exposure to augmented reality, where students could see the impact and difference between (a) two-dimensional (2D) and (b) three-dimensional (3D) shapes in the GeomAR3 module. In addition, the app also shows the measurements given virtually as a guide to get answers to the questions given in the GeomAR3 module.

This is in contrast to the approach in the Geom3 module, where students in the control group did not have the opportunity to see the dimensions of the shapes. Fig. 4 shows the shape drawings commonly used in teaching and learning involving (a) two-dimensional and (b) three-dimensional shapes. Students need to imagine the dimensional representation of the shapes involved without the help of embedded reality. Problem-solving depends on concept mastery and memory memorisation alone, without hands-on activity.

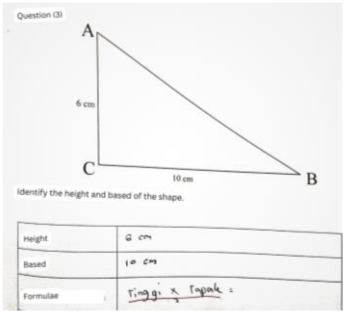


(a)

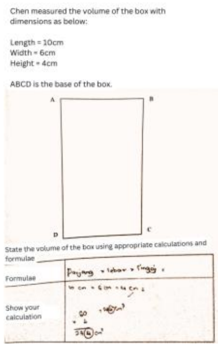


(b)

Fig. 3. AR effect on each dimensional shape: (a) two-dimensional shape; (b) three-dimensional shape.



(a)

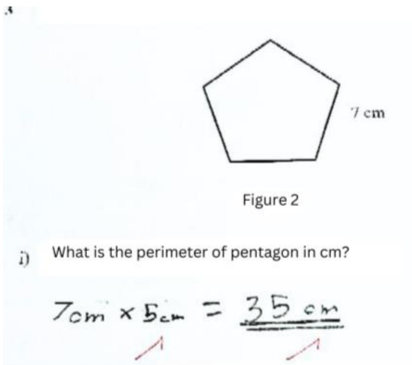


(b)

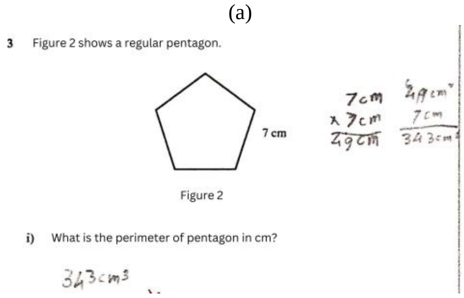
Fig. 4. AR effect on each dimensional shape: (a) two-dimensional shape; (b) three-dimensional shape.

The study's results by Maffei [39] also contradict this study in which the post-test did not impact either group, whether the experimental group was given an augmented reality intervention or a control group with an approach without augmented reality. The results were analyzed using Quade's Rank ANCOVA, showing an increase in performance in the post-test for both groups compared to the pre-test. This result contradicts the study [32, 40], which found no significant effect of augmented reality in the experimental group due to improved learning quality in both groups post-test. However, the findings in this study were not analysed by comparing pre and post-tests as in the previous study.

Based on the post-test results, the researchers concluded that the GeomAR3 module with augmented reality has features that enable students to master the concepts under Geometry of Space, namely "perimeter", "area", "volume content", and "problem-solving". The post-test given after the intervention for both groups showed that the students in the experimental group could reapply their understanding of "space" with the use of an augmented reality application more clearly. Referring to Fig. 5, the experimental group students' use of the perimeter concept calculation (a) was more useful than that of the control group students (b) in solving common problems. The question is about "perimeter", which requires students to add up the perimeter of a given shape. The experimental group students in (a) could add the measurements through the multiplication method and then give the correct answer, while the control group students in (b) made the mistake of using the volume formula for this question. Thus, the answer was given incorrectly, causing the performance of the control group students to be lower in the post-test.



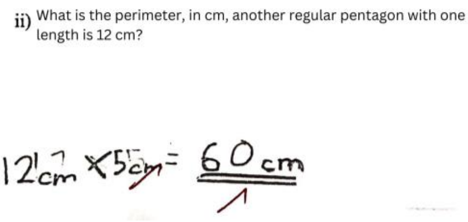
(a)



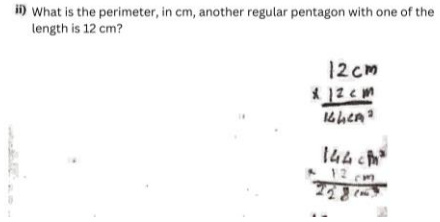
(b)

Fig. 5. Formula used in problem-solving question: (a) Formula applied by students in the experimental group; (b) Formula applied by students in the control group.

The questions in the post-test consist of related questions in the form of sub-questions and problem-solving. As Fig. 6 is a sub-question, it shows the Experimental Group (a), in which students could make correct calculations and answers along with units for the perimeter. Meanwhile, students in the Control Group (b) still made mistakes using the wrong formula in the perimeter problem-solving questions.



(a)



(b)

Fig. 6. Calculation shown: (a) Calculation shown by students in the experimental group; (b) Calculation shown by students in the control group.

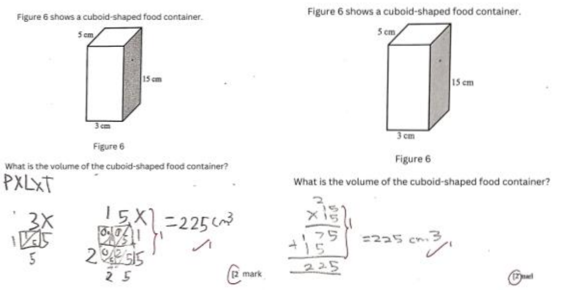
B. Student Performance in the Delayed Post-Test

Analysis of the delayed post-test showed similar results as the post-test. In the delayed post-test, students in the experimental group exhibited significantly higher mean scores than those in the control group. The results of the MANCOVA analysis show that the second hypothesis (H2) is also supported in this study. This result reaffirms the results of previous studies that learning using augmented reality has an impact in terms of better performance in the post-test and the delayed post-test [32, 33]. The findings of this study align with the period conducted by Gargrish *et al.* [32], which after two and four weeks, also showed the ability of students' memory to affect their performance subsequently. Similar findings for the use of modules were also demonstrated in a study by Ibrahim *et al.* [20] with an experimental group using HOTS modules showing significant differences in delayed post-test scores compared to a control group.

However, the findings of this study contradict the study by Elsayed *et al.* [27], which did not show any improvement between students who learnt using augmented reality in the experimental group versus the control group students in the delayed post-test two months after the intervention was implemented. According to Yiğit *et al.* [41], the deterioration of students' scores in the delayed post-test was influenced by the lapse of time during which the test was conducted, which caused the retention of memory of the intervention to decrease.

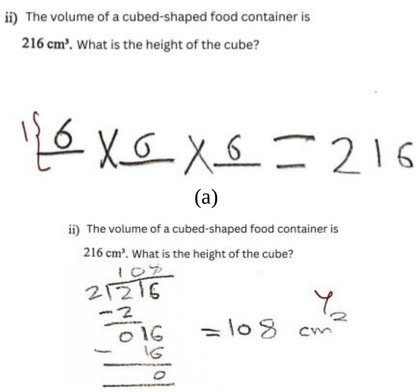
This study's delayed post-test results can answer the second hypothesis (H2) well. Even though both groups' mean score performance decreased in the delayed post-test, the experimental group still had a higher delayed post-test mean score than the control group. In the post-scheduled test, knowledge retention became the focus following a two-week study interval. Fig. 7 shows the experimental and control group students using the correct formula and calculation method to solve the volume content problem. In this question, both students could demonstrate good retention of the volume content concepts they have learnt.

However, for the series of sub-questions in Fig. 7, students faced difficulties solving non-routine questions such as those in Fig. 8. This question asks students to describe the shape according to the given feature and perform a successful method of trying to solve the problem. Students in the Experimental Group (a) who are used to manipulating size and shape in real-world applications were able to give correct answers, although less than perfect, due to the absence of unit writing at the end of the solution. In the experimental group, students could interpret and reapply the concept of volume content in solving non-routine problems. The error of these students was due to the absence of units written in the final answer, which made it unworthy of total marks. However, the solutions and calculating methods are suitable for solving non-routine volume content problems.



(a) (b)

Fig. 7. Correct calculation in routine question by: (a) Correct calculation in routine question by experimental students; (b) Correct calculation in routine question by control students.



(a)

(b)

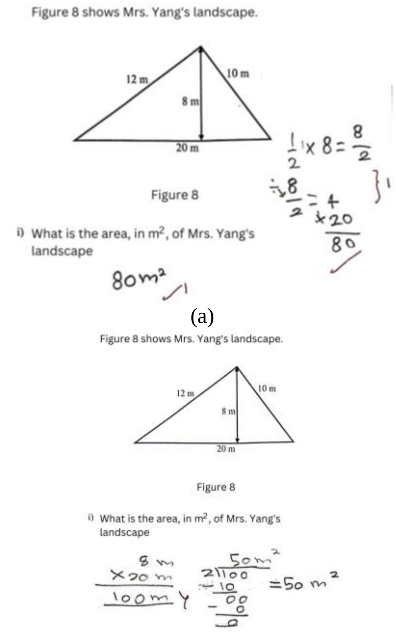
Fig. 8. Solution in non-routine question: (a) Solution in non-routine question by experimental student; (b) Solution in non-routine question by control student.

In contrast, students in the Control Group (b) could not imagine the shape according to the criteria given and could not produce the right way of calculating to solve the problem. The students in the control group only described the cube shape in two dimensions, even though this question is related to volume content. The given unit also demonstrates the answer to the area concept, which leads to two dimensions. This is because the control group students did not have the opportunity to experience the interactive experience in an augmented reality application that shows precise dimensions for three-dimensional (3D) shapes.

The delayed post-test showed good problem-solving skills for the experimental group students (see Fig. 9). The experimental group of Students (a) completed the operations involved in obtaining the area of a triangle and wrote a complete answer. While Students (b) could apply the correct triangle area formula for the control group, a discrepancy in the calculation caused the answer to be unmarked due to the error. This shows that the experimental group students can retain problem-solving skills well when allowed to learn with the application of augmented reality in the GeomAR3 module.

A related question to the problem in Fig. 9 also shows that students can give correct answers if the previous calculations are accurate. Fig. 10 shows that students in the Experimental Group (a) could provide correct answers because they already had a solid foundation, even though the analyses performed did not follow the actual division procedure. In contrast, students in the Control Group (b) still faced conceptual confusion in solving the problem correctly.

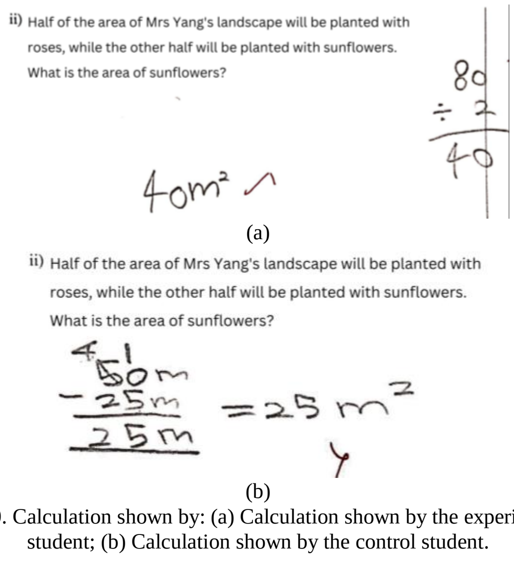
In conclusion, students who use augmented reality applications in modules have advantages in terms of long-term memory retention. The memory of a given intervention that is hands-on and interactive allows students to reapply to the geometry lesson they learnt in questions because they have mastered problem-solving skills well.



(a)

(b)

Fig. 9. Method of the calculation shown by: (a) Method of the calculation shown by experimental student; (b) Method of the calculation shown by control student.



(a)

(b)

Fig. 10. Calculation shown by: (a) Calculation shown by the experimental student; (b) Calculation shown by the control student.

VI. Conclusion

This study is about the effectiveness of using modules with augmented reality in aiding Year 4 students in primary school in learning Geometry. This quasi-experimental study with pre and post-test design aims to identify the extent of the effectiveness of modules developed with augmented reality technology (GeomAR3) compared to traditional modules without augmented reality (Geom3). The module's effectiveness is known through student performance in the post-test and the delayed post-test. The effectiveness study analysis was conducted through MANCOVA analysis, considering the pre-test as a covariate. The study results showed a significant difference in the overall mean score of the post-test and the delayed post-test, with the experimental group showing a significant difference in improvement compared to the control group. Conclusively, the use of modules with augmented reality technology was found to improve student performance in Geometry compared to traditional methods. Augmented reality technology can help students master Geometry concepts based on visualisation ability, strengthening students' long-term memory besides gaining conceptual understanding through the experience shown by AR.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ainur Yusra Nabila Mohd Nadzri conducted the research and writing of the manuscript; Ahmad Fauzi Mohd Ayub contributed as a supervisor and examined the manuscript; and Nurul Nadwa Zulkifli provided ideas and suggestions along with supervision. All authors have approved the final version of this manuscript.

References

[1] M. Akçayır and G. Akçayır, "Advantages and challenges associated with augmented reality for education: A systematic review of the literature," *Educational Research Review*, vol. 20, pp. 1–11, 2017, doi: 10.1016/j.edurev.2016.11.002

[2] T. Masood and J. Egger, "Augmented reality in support of industry 4.0—Implementation challenges and success factors," *Robotics and Computer-Integrated Manufacturing*, vol. 58, pp. 181–195, 2019, doi: 10.1016/j.rcim.2019.02.003

[3] S. I. Pochtoviuk, T. A. Vakaliuk, and A. V. Pikilnyak, "Possibilities of application of augmented reality in different branches of education," in *Proc. CEUR Workshop*, 2020, vol. 2547, pp. 92–106, doi: 10.31812/educdim.v54i2.3867

[4] G. M. Santi, A. Ceruti, A. Liverani, and F. Osti, "Innovation programs," *Technologies*, vol. 9, pp. 1–33, 2021.

[5] G. Papanastasiou, A. Drigas, C. Skianis, M. Lytras, and E. Papanastasiou, "Virtual and augmented reality effects on K-12, higher, and tertiary education students' twenty-first-century skills," *Virtual Reality*, vol. 23, no. 4, pp. 425–436, 2019, doi: 10.1007/s10055-018-0363-2

[6] KPM, *Pelan Pembangunan Pendidikan Malaysia 2013–2025*, 2013.

[7] N. M. Rusdin and S. R. Ali, "Amalan dan cabaran pelaksanaan pembelajaran abad ke-21," in *Proc. the Institute for Islamic Product and Malay Civilization (INSPIRE)*, pp. 87–103, 2019.

[8] S. Badge and T. Dhote, "Introduction of augmented reality and virtual reality in the growing education sector: A review," *International Journal of Modern Agriculture*, vol. 10, no. 2, pp. 181–188, 2021.

[9] Y. C. Chen, "Effect of mobile augmented reality on learning performance, motivation, and math anxiety in a math course," *Journal of Educational Computing Research*, vol. 57, no. 7, pp. 1695–1722, 2019, doi: 10.1177/0735633119854036

[10] N. Jamiat and N. F. N. Othman. "Examining kindergarten students' motivation on augmented reality apps: A survey using emoticons," *ASM Science Journal*, vol. 13, special issue 3, pp. 39–43, 2020.

[11] V. N. Taran, "Use of elements of augmented reality in the educational process in higher educational institutions," in *Proc. CEUR Workshop*, 2019, vol. 2494, pp. 20–23.

[12] M. Flores-Bascuñana, P. D. Diago, R. Villena-Taranilla, and D. F. Yáñez, "On augmented reality for learning 3D-geometric contents: A preliminary exploratory study with 6-grade primary students," *Education Sciences*, vol. 10, no. 1, 2020, doi: 10.3390/educsci10010004

[13] J. Aliman, "The effectiveness of using Aresa Kit, augmented reality technology in learning embedded design applications," in *Proc. SPSH Lifelong Learning Seminar*, December 2020, pp. 466–475.

[14] E. Demitriadou, K. E. Stavroulia, and A. Lanitis, "Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education," *Education and Information Technologies*, vol. 25, no. 1, pp. 381–401, 2020, doi: 10.1007/s10639-019-09973-5

[15] V. Rossano, R. Lanzilotti, A. Cazzolla, and T. Roselli, "Augmented reality to support geometry learning," *IEEE Access*, vol. 8, pp. 107772–107780, 2020, doi: https://doi.org/10.1109/ACCESS.2020.3000990.

[16] E. İbili, M. Çat, D. Resnyansky, S. Şahin, and M. Billinghurst, "An assessment of geometry teaching supported with augmented reality teaching materials to enhance students' 3D geometry thinking skills," *International Journal of Mathematical Education in Science and Technology*, vol. 51, no. 2, pp. 224–246, 2019, doi: 10.1080/0020739X.2019.1583382

[17] M. F. A. Hanid, M. N. H. M. Said, N. Yahaya, and Z. Abdullah, "Effects of augmented reality application integration with computational thinking in geometry topics," *Education and Information Technologies*, vol. 37, 2022, doi: 10.1007/s10639-022-10994-w

[18] O. M. Aldalalah, Z. Ababneh, A. Bawaneh, and W. Alzubi, "Effect of augmented reality and simulation on the achievement of mathematics and visual thinking among students," *International Journal of Emerging Technologies in Learning (IJET)*, vol. 14, no. 18, p. 164, 2019, doi: 10.3991/ijet.v14i18.10748

[19] M. A. Maulana, Y. Sujana, and A. Budianto, "Development of module and augmented reality-based android application computer assembly for vocational high school students," *Journal of Informatics and Vocational Education*, vol. 2, no. 2, pp. 82–87, 2019, doi: 10.20961/joive.v2i2.35751

[20] N. N. Ibrahim, A. F. M. Ayub, and A. S. Md. Yunus, "Impact of Higher Order Thinking Skills (HOTS) module based on the Cognitive Apprenticeship Model (CAM) on student performance," *International Journal of Learning, Teaching and Educational Research*, vol. 19, no, 7, pp. 246–262, 2020, doi: 10.26803/ijlter.19.7.14

[21] P. S. Dewi and H. Kuswanto, "The effectiveness of the use of augmented reality assisted physics e-module based on pedicab to improve mathematical communication and critical thinking abilities," *Journal of Technology and Science Education*, vol. 13, no. 1, pp. 53–64, 2022.

[22] Y. S. Su, H. W. Cheng, and C. F. Lai, "Study of virtual reality immersive technology enhanced mathematics geometry learning," *Front Psychol.*, vol. 17, no. 13, 760418, 2022, doi: 10.3389/fpsyg.2022.760418

[23] A. Arifuddin, W. Wahyudin, S. Prabawanto, M. Yasin, and D. Elizanti, "The effectiveness of augmented reality-assisted scientific approach to improve mathematical creative thinking ability of elementary school students," *Al Ibtida: Jurnal Pendidikan Guru Mi*, vol. 9, no. 2, pp. 444–455, 2022.

[24] D. C. Aspari and M. Hartono, "The effectiveness of module and Geogebra based learning media to improve mathematics learning outcomes of Grade IV students," in *Proc. 2021 7th International Conference on Education and Technology (ICET)*, Malang, Indonesia, 2021, pp. 315–319, doi: 10.1109/ICET53279.2021.9575088

[25] E. J. A. Lim, "Effectiveness of modular instruction in word problem solving of BEED students," *IOSR Journal of Mathematics (IOSR-JM)*, vol. 12, no. 5, pp. 59–65, 2021.

[26] C.-Y. Tsai and Y.-C. Lai, "Design and validation of an augmented reality teaching system for primary logic programming education," *Sensors*, vol. 22, no. 1, p. 389, 2022, doi: 10.3390/s22010389

[27] S. A. Elsayed and H. I. Al-Najrani, "Effectiveness of the augmented reality on improving the visual thinking in mathematics and academic motivation for middle school students," *Eurasia Journal of*

Mathematics, Science and Technology Education, vol. 17, no. 8, pp. 1–16, 2021, https://doi.org/10.29333/ejmste/11069
[28] B. Prabakaran and A. R. Saravanakumar, "Effectiveness of interactive E-content module in enhancing students' achievement in mathematics," *International Journal of Control and Automation*, vol. 13, special issue 2, pp. 84–94, 2020.
[29] M. Arvanitaki and N. Zaranis, "The use of ICT in teaching geometry in primary school," *Education and Information Technologies*, vol. 25, no. 6, pp. 5003–5016, 2020, doi: 10.1007/s10639-020-10210-7
[30] F. Çelik and C. Y. Ersanlı, "The use of augmented reality in a gamified CLIL lesson and students' achievements and attitudes: A quasi-experimental study," *Smart Learning Environments*, vol. 9, no. 1, 2022, doi: 10.1186/s40561-022-00211-z
[31] H. Cevahir, M. Özdemir, and M. H. Baturay, "The effect of animation-based worked examples supported with augmented reality on the academic performance, attitude, and motivation of students towards learning programming," *Participatory Educational Research*, vol. 9, no. 3, pp. 226–247, 2022, doi: 10.17275/per.22.63.9.3
[32] S. Gargrish, D. P. Kaur, A. Mantri, G. Singh, and B. Sharma, Measuring effectiveness of augmented reality-based geometry learning assistant on memory retention abilities of the students in 3D geometry," *Computer Applications in Engineering Education*, vol. 29, no. 6, pp. 1811–1824, 2021, doi: 10.1002/cae.22424
[33] A. Dünser, L. Walker, H. Horner, and D. Bentall, "Creating interactive physics education books with augmented reality," in *Proc. the 24th Australian Computer-Human Interaction Conference, Oz-CHI*, November 2012, pp. 107–114, doi: 10.1145/2414536.2414554
[34] J. W. Cresswell and J. D. Cresswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed., SAGE Publication, 2018
[35] D. T. Campbell and J. C. Stanley, *Experimental and Quasi-Experimental Designs for Research*, Ravenio Books, 2015
[36] J. R. Fraenkel, N. E. Wallen, and H. H. Hyun, *How to Design and Evaluate Research in Education*, 10th ed., 2019.
[37] R. Fernández-Enríquez and L. Delgado-Martín, "Augmented reality as a didactic resource for teaching mathematics," *Applied Sciences (Switzerland)*, vol. 10, no. 7, 2020, doi: 10.3390/app10072560
[38] H. A. Hussein, M. H. Ali, M. Hashimi, N. T. Majeed, Q. A. Hameed, and R. D. Ismael, "The effect of web augmented reality on primary pupils' achievement in English," *Applied System Innovation*, vol. 6, no. 18, 2023, doi: 10.3390/asi6010018
[39] J. T. Maffei, "The effect of augmented reality on learning in the mathematics classroom," Liberty University, 2020.
[40] S. Gargrish, A. Mantri, and D. P. Kaur, "Augmented reality-based learning environment to enhance the teaching-learning experience in geometry education," *Procedia Computer Science*, vol. 172, no. 2019, pp. 1039–1046, 2020, doi: 10.1016/j.procs.2020.05.152
[41] E. A. Yiğit, F. B. Kıyıcı, and G. Çetinkaya, "Evaluating the testing effect in the classroom: An effective way to retrieve learnt information," *Eurasian Journal of Educational Research*, vol. 14, no. 54, pp. 99–116, 2014, doi: 10.14689/ejer.2014.54.6