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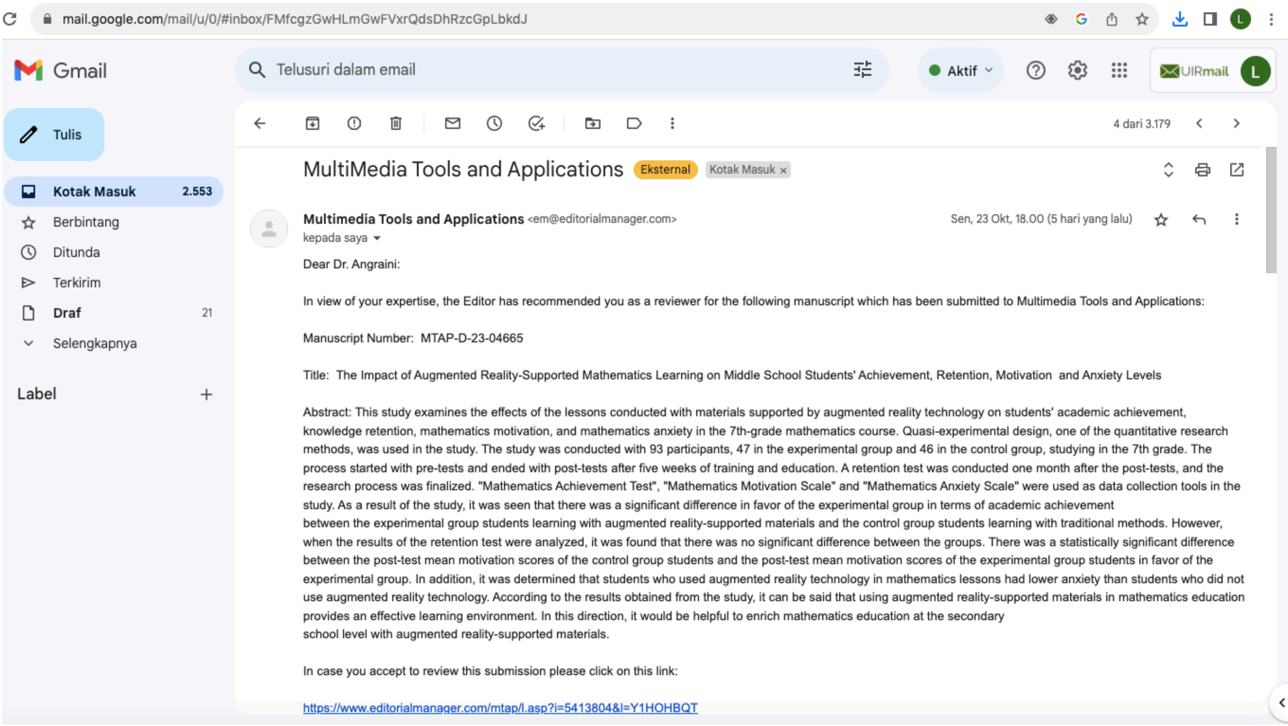

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MultiMedia Tools and Applications — Eksternal — Kotak Masuk

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Dear Dr. Angraini:

In view of your expertise, the Editor has recommended you as a reviewer for the following manuscript which has been submitted to Multimedia Tools and Applications:

Manuscript Number: MTAP-D-23-04665

Title: The Impact of Augmented Reality-Supported Mathematics Learning on Middle School Students' Achievement, Retention, Motivation and Anxiety Levels

Abstract: This study examines the effects of the lessons conducted with materials supported by augmented reality technology on students' academic achievement, knowledge retention, mathematics motivation, and mathematics anxiety in the 7th-grade mathematics course. Quasi-experimental design, one of the quantitative research methods, was used in the study. The study was conducted with 93 participants, 47 in the experimental group and 46 in the control group, studying in the 7th grade. The process started with pre-tests and ended with post-tests after five weeks of training and education. A retention test was conducted one month after the post-tests, and the research process was finalized. "Mathematics Achievement Test", "Mathematics Motivation Scale" and "Mathematics Anxiety Scale" were used as data collection tools in the study. As a result of the study, it was seen that there was a significant difference in favor of the experimental group in terms of academic achievement between the experimental group students learning with augmented reality-supported materials and the control group students learning with traditional methods. However, when the results of the retention test were analyzed, it was found that there was no significant difference between the groups. There was a statistically significant difference between the post-test mean motivation scores of the control group students and the post-test mean motivation scores of the experimental group students in favor of the experimental group. In addition, it was determined that students who used augmented reality technology in mathematics lessons had lower anxiety than students who did not use augmented reality technology. According to the results obtained from the study, it can be said that using augmented reality-supported materials in mathematics education provides an effective learning environment. In this direction, it would be helpful to enrich mathematics education at the secondary school level with augmented reality-supported materials.

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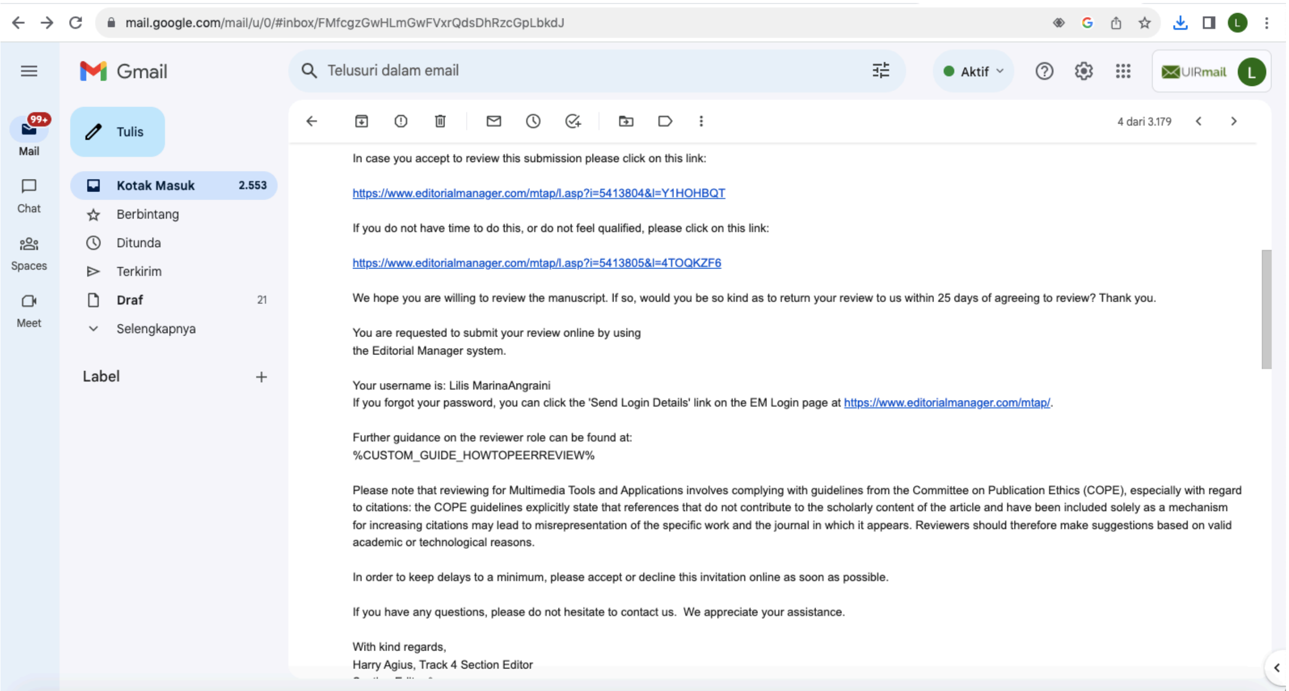

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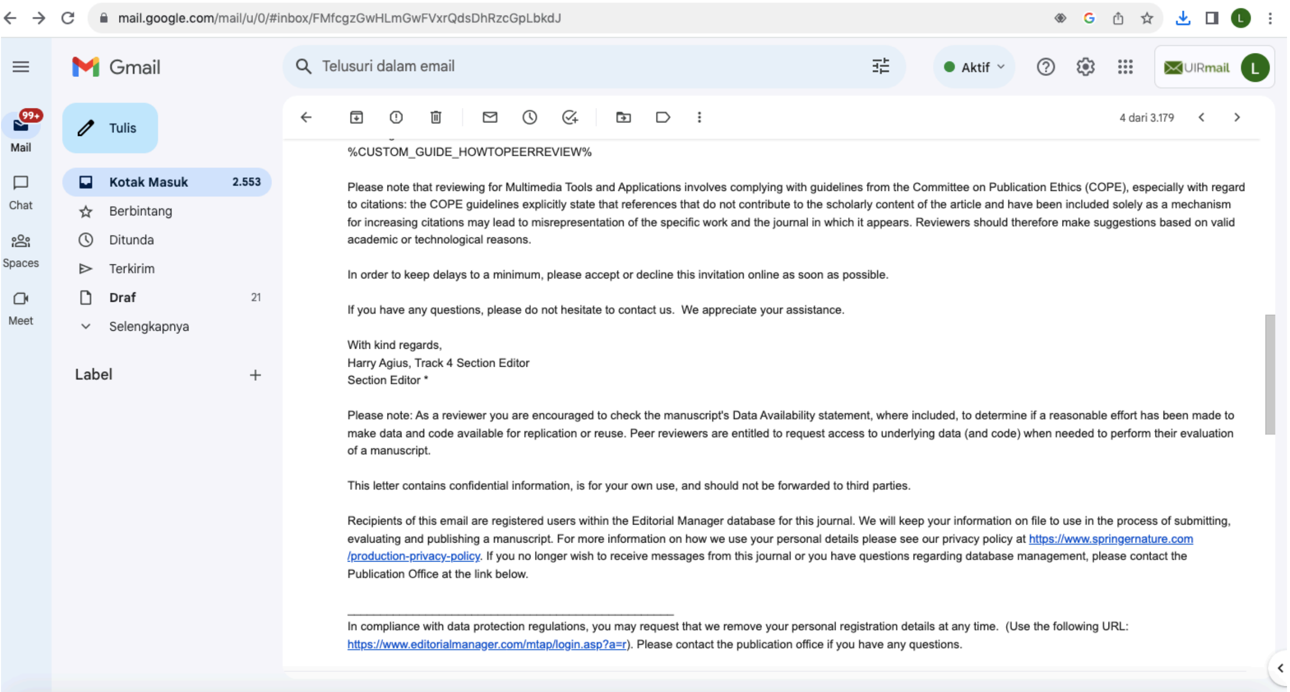
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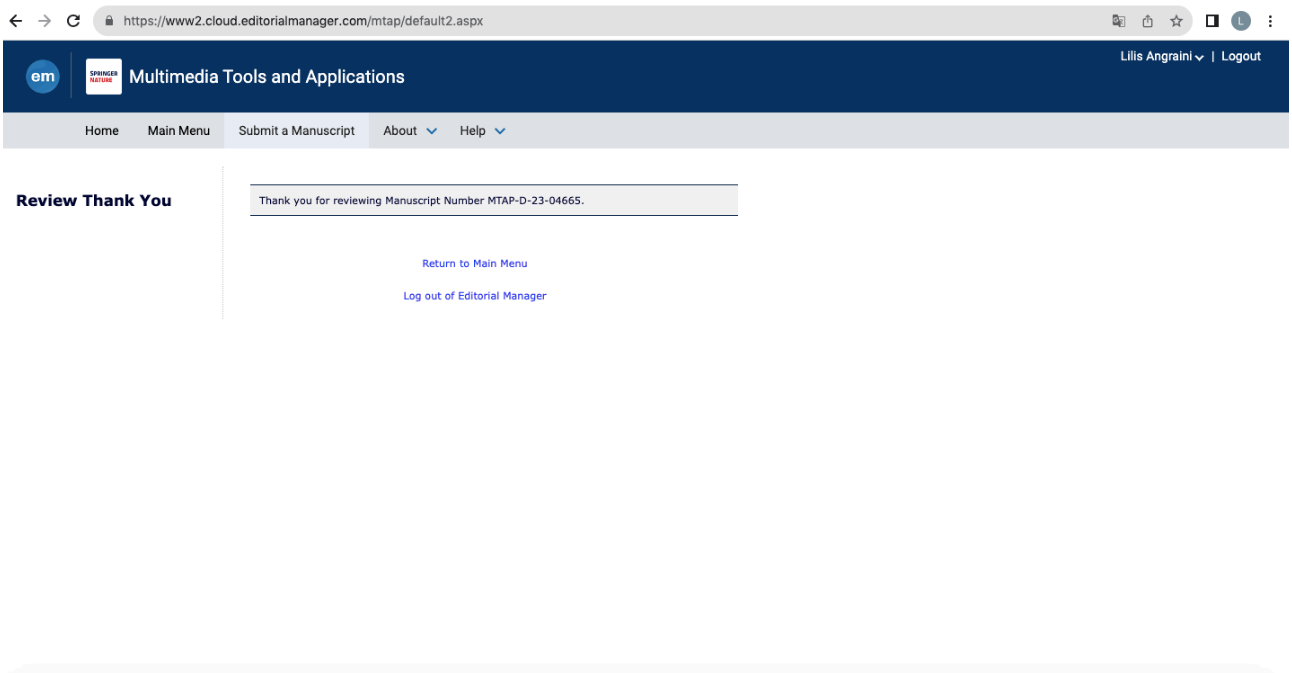

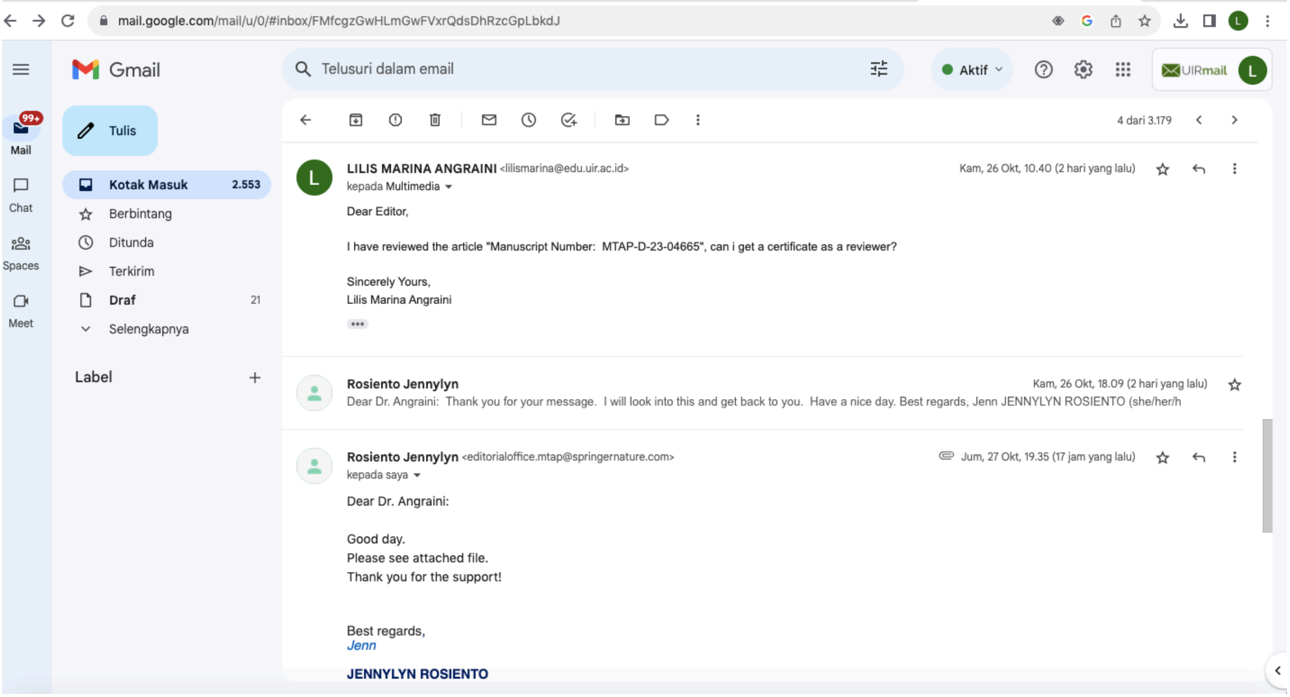

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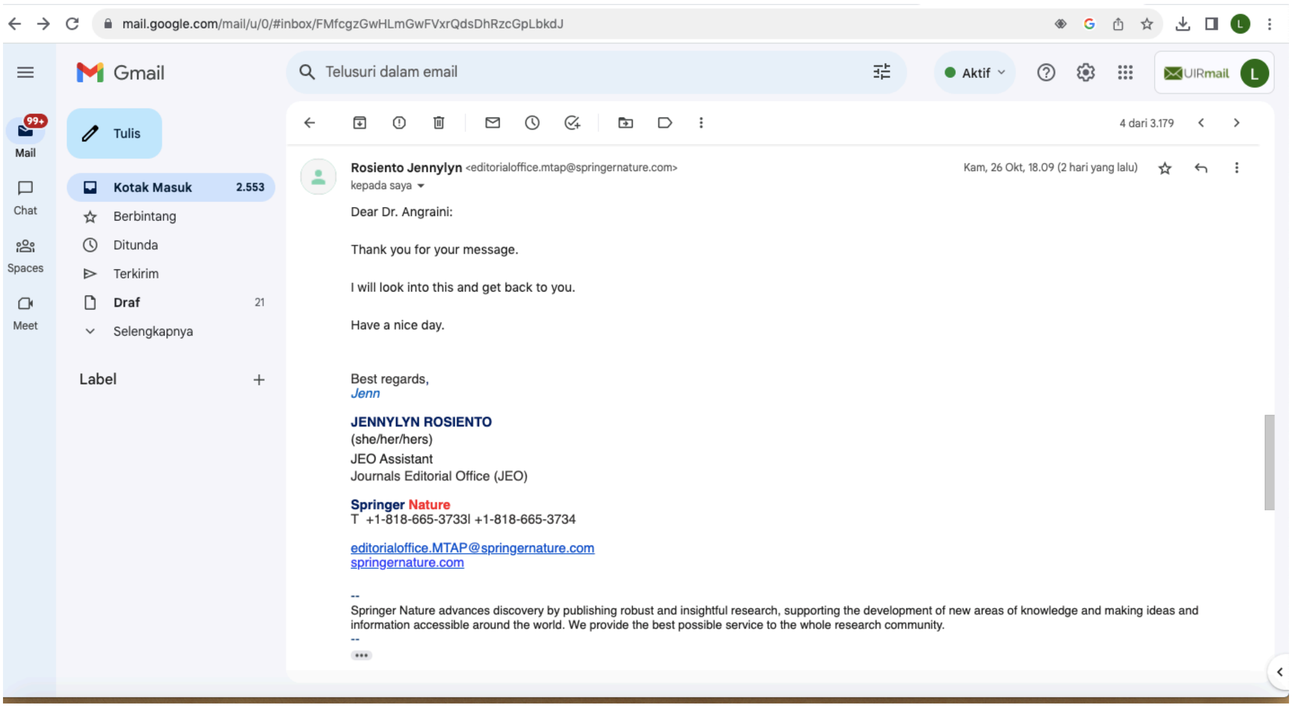

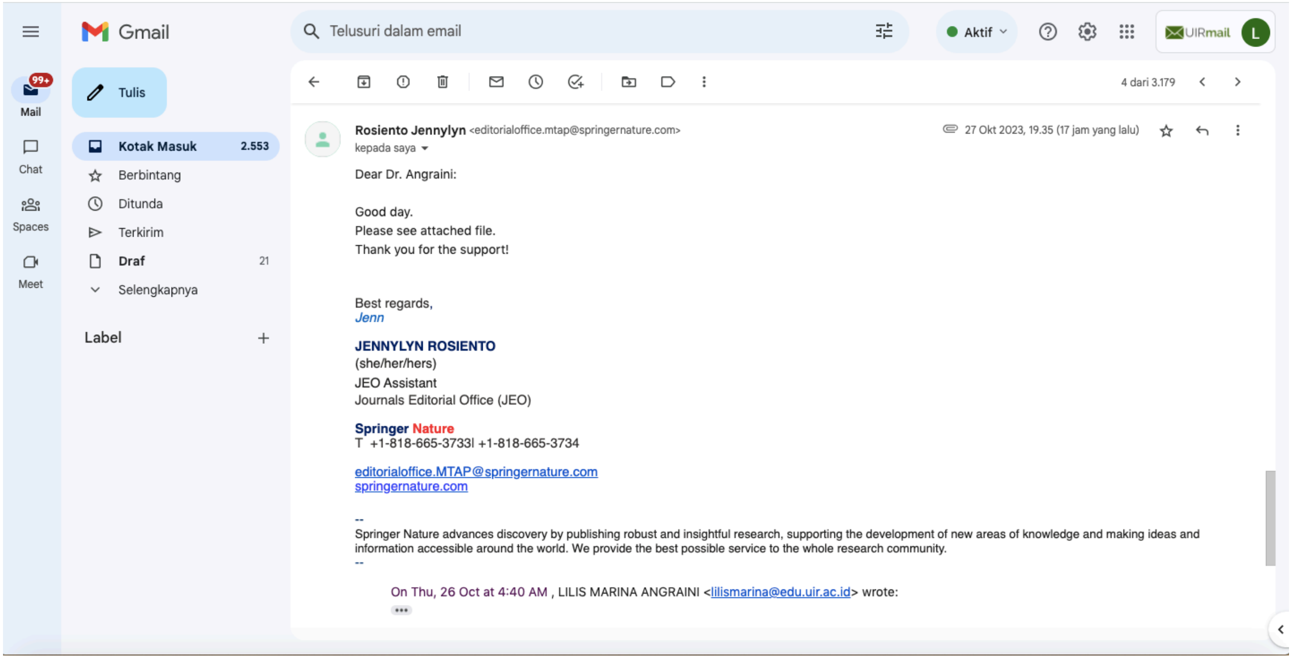

Rosiento Jennylyn <editorialoffice.mtap@springernature.com> 27 Okt 2023, 19.35 (17 jam yang lalu)
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Dear Dr. Angraini:

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Thank you for the support!

Best regards,
Jenn

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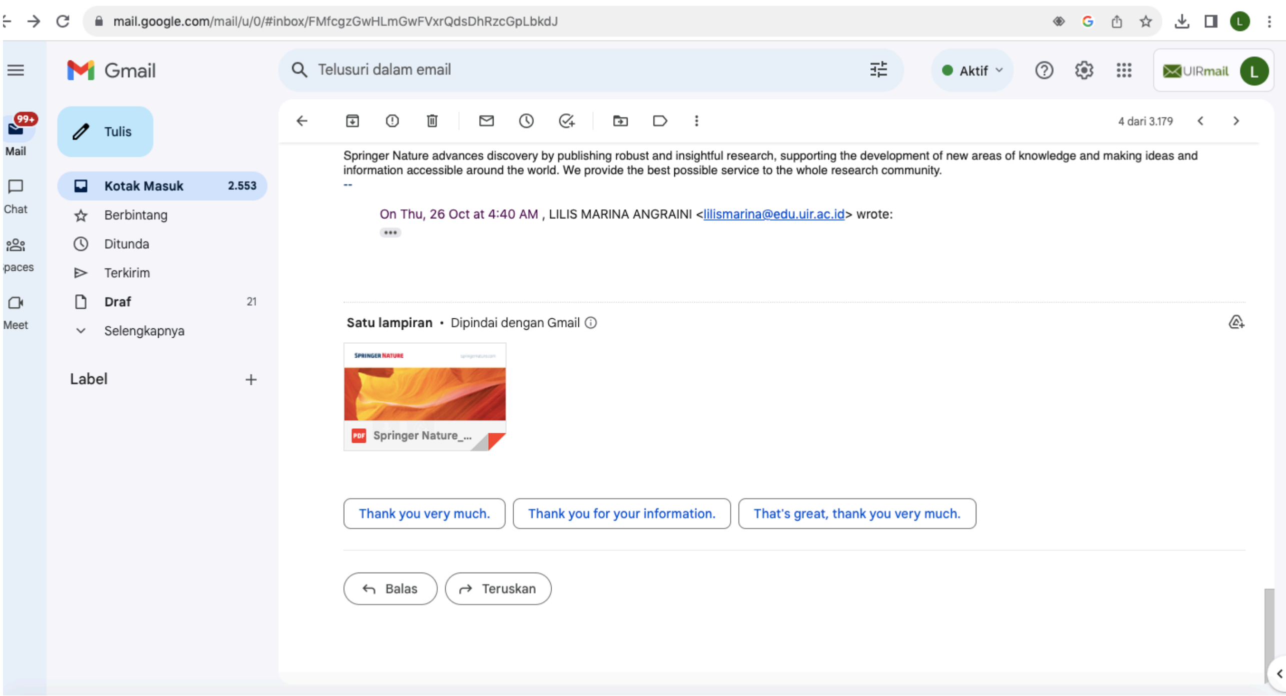

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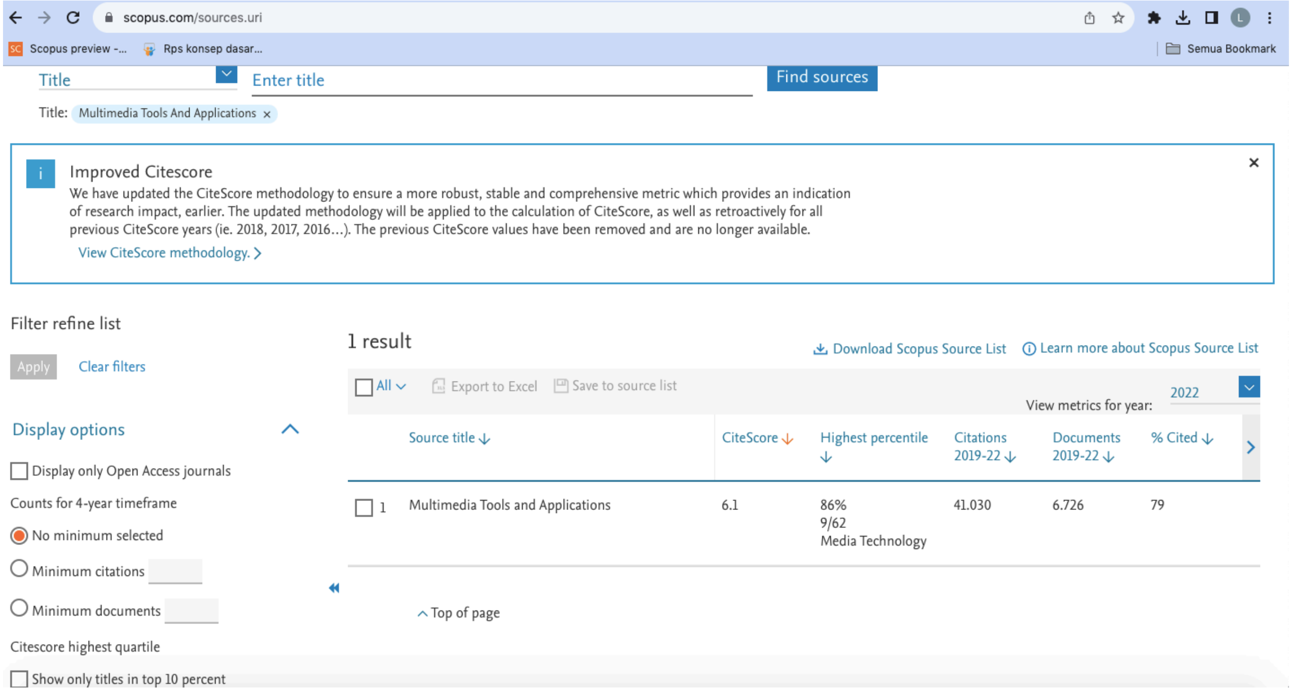

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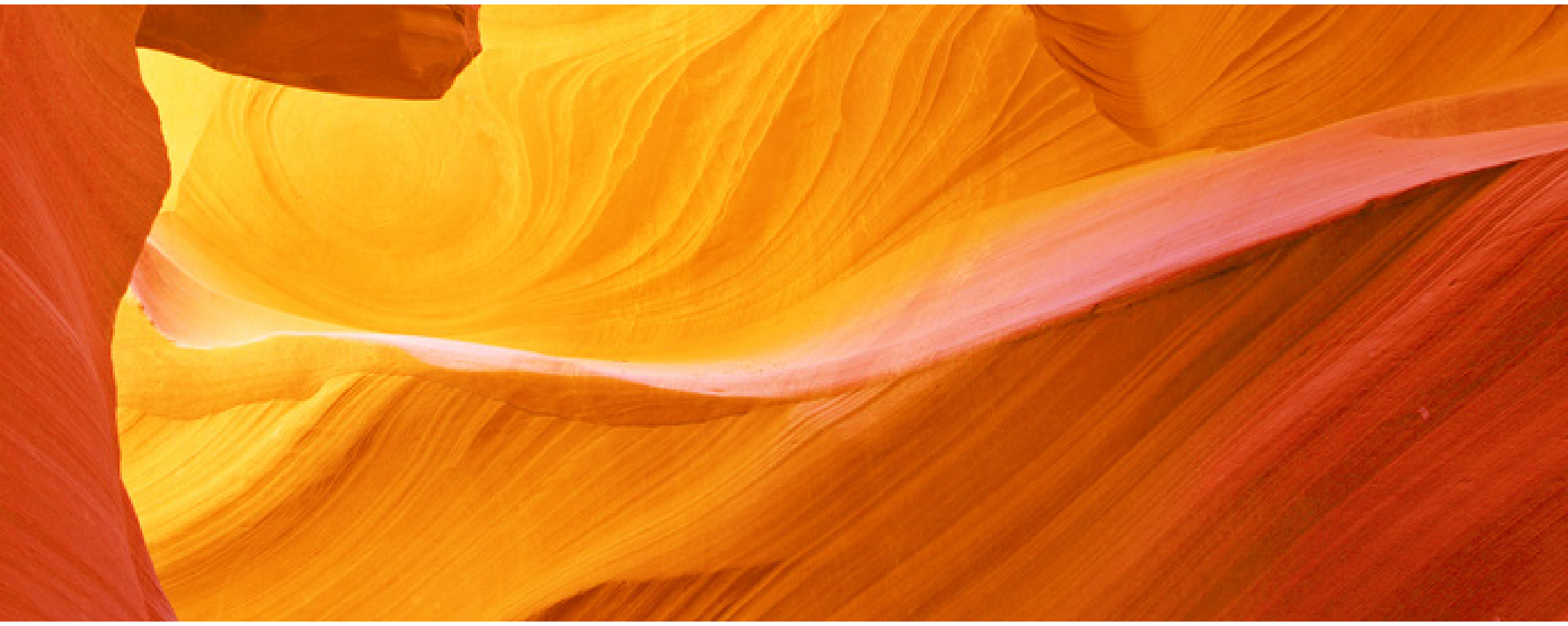

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Multimedia Tools and Applications

The Impact of Augmented Reality-Supported Mathematics Learning on Middle School Students' Achievement, Retention, Motivation and Anxiety Levels

--Manuscript Draft--

Manuscript Number:	MTAP-D-23-04665
Full Title:	The Impact of Augmented Reality-Supported Mathematics Learning on Middle School Students' Achievement, Retention, Motivation and Anxiety Levels
Article Type:	Track 4: Digital Games, Virtual Reality, and Augmented Reality
Keywords:	augmented reality; math; motivation; anxiety; retention

Abstract:	This study examines the effects of the lessons conducted with materials supported by augmented reality technology on students' academic achievement, knowledge retention, mathematics motivation, and mathematics anxiety in the 7th-grade mathematics course. Quasi-experimental design, one of the quantitative research methods, was used in the study. The study was conducted with 93 participants, 47 in the experimental group and 46 in the control group, studying in the 7th grade. The process started with pre-tests and ended with post-tests after five weeks of training and education. A retention test was conducted one month after the post-tests, and the research process was finalized. "Mathematics Achievement Test", "Mathematics Motivation Scale" and "Mathematics Anxiety Scale" were used as data collection tools in the study. As a result of the study, it was seen that there was a significant difference in favor of the experimental group in terms of academic achievement between the experimental group students learning with augmented reality-supported materials and the control group students learning with traditional methods. However, when the results of the retention test were analyzed, it was found that there was no significant difference between the groups. There was a statistically significant difference between the post-test mean motivation scores of the control group students and the post-test mean motivation scores of the experimental group students in favor of the experimental group. In addition, it was determined that students who used augmented reality technology in mathematics lessons had lower anxiety than students who did not use augmented reality technology. According to the results obtained from the study, it can be said that using augmented reality-supported materials in mathematics education provides an effective learning environment. In this direction, it would be helpful to enrich mathematics education at the secondary school level with augmented reality-supported materials.

- **TITLE PAGE**

The Impact of Augmented Reality-Supported Mathematics Learning on Middle School Students' Achievement, Retention, Motivation and Anxiety Levels

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Note: This article is derived from the master's thesis conducted by the first author of the study under the supervision of the second author.

Zeynep Turan is an associate professor at the Department of Computer Education & Instructional Technology at Ataturk University. Her research interests are in the flipped classroom, computer-based instruction, social media, augmented reality, and research methods.

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The Impact of Augmented Reality-Supported Mathematics Learning on Middle School Students' Achievement, Retention, Motivation and Anxiety Levels

Abstract

This study examines the effects of the lessons conducted with materials supported by augmented reality technology on students' academic achievement, knowledge retention, mathematics motivation, and mathematics anxiety in the 7th-grade mathematics course. Quasi-experimental design, one of the quantitative research methods, was used in the study. The study was conducted with 93 participants, 47 in the experimental group and 46 in the control group, studying in the 7th grade. The process started with pre-tests and ended with post-tests after five weeks of training and education. A retention test was conducted one month after the post-tests, and the research process was finalized. "Mathematics Achievement Test", "Mathematics Motivation Scale" and "Mathematics Anxiety Scale" were used as data collection tools in the study. As a result of the study, it was seen that there was a significant difference in favor of the experimental group in terms of academic achievement between the experimental group students learning with augmented reality-supported materials and the control group students learning with traditional methods. However, when the results of the retention test were analyzed, it was found that there was no significant difference between the groups. There was a statistically significant difference between the post-test mean motivation scores of the control group students and the post-test mean motivation scores of the experimental group students in favor of the experimental group. In addition, it was determined that students who used augmented reality technology in mathematics lessons had lower anxiety than students who did not use augmented reality technology. According to the results obtained from the study, it can be said that using augmented reality-supported materials in mathematics education provides an effective learning environment. In this direction, it would be helpful to enrich mathematics education at the secondary school level with augmented reality-supported materials.

Keywords: augmented reality; math; motivation; anxiety; retention

1. Introduction

Mathematics is one of the courses in which students develop the most negative attitudes and anxiety, it can be said that innovative methods and technologies in this field are of great importance. There is no need to be a mathematician to understand the importance and necessity of mathematics education. Moreover, mathematics achievement is essential to students' academic lives (Pitsia et al., 2017). In this direction, Yaşar and Papatğa (2015) stated that individuals who can understand mathematics and adapt mathematics to the situations they encounter are more successful in directing their future and are more likely to encounter different career options.

Therefore, it is evident that improving the teaching processes related to mathematics is of great importance. Indeed, human beings are intertwined with mathematics throughout their lives and benefit from its possibilities. However, while mathematics is so prevalent in all areas of life, people simultaneously develop anxiety and negative attitudes towards mathematics. Jackson (2008) stated that negative perceptions about mathematics and thoughts that mathematics is complicated affect students' learning processes. In this direction, it can be said that developing positive attitudes toward mathematics will help to learn mathematics better (Timmerman et al., 2017). Moreover, the exceptional circumstances caused by the COVID-19 pandemic made it necessary to change teaching and learning methods all over the world, and especially the pandemic period altered the agenda of mathematics education and brought the use of technology in mathematics education to the forefront (Borba, 2021). For these reasons, it is predicted that innovative technologies such as Augmented Reality (AR) in mathematics education can support students' affective and cognitive skills.

Mathematics anxiety is the reason for failure in mathematics courses, and the fear and reluctance felt towards this course. In addition, behaviors such as avoiding mathematical problems also cause mathematics anxiety (Hembree, 1990). At this point, it can be said that mathematics is abstract and difficult to visualize (Cai et al., 2019), causing students to approach the mathematics course with a negative perspective and fail the course. It can be said that students will perform better and have less anxiety because AR technology is easy to use and the system is practical and fun (Chen, 2019). In addition to enhancing students' learning, AR technology can encourage increased motivation (Elsayed & Al-Najrani, 2021). It is stated that students whose motivation towards mathematics increases will decrease their mathematics anxiety levels (Chen & Tsai, 2012).

By visualizing mathematical concepts, AR technology has the potential to help students better understand abstract concepts and make mathematics more fun. This provides students various motivational elements (Salinas et al., 2013). According to Sudirman et al. (2020), using AR positively affects learning motivation and a better understanding of geometric concepts. In the literature, it has been stated that associating abstract concepts with physical objects can help to understand memory and symbolic representations (Tversky, 2001). In this direction, it can be said that with the help of augmented reality technology, the effectiveness of learning environments can be increased as abstract concepts are concretized and demonstrated in a field such as mathematics, where abstract concepts take place a lot (Bujak et al., 2013). İbili and Şahin (2013) stated that the concretization of geometry subjects that require abstract thinking skills with tools such as paper, pencil, and ruler might not be sufficient and that new technologies such as augmented reality technology will support learning processes. In addition, Kaufmann and Schmalstieg (2003) also stated that AR-supported geometry teaching is an easy and effective educational technology for students to gain spatial skills such as spatial visualization and spatial orientation. Similarly, Lin et al. (2013) provided geometry education with augmented reality-supported materials in their study with high school students. As a result, they stated that the education supported students' geometry learning processes.

Mathematics is traditionally taught with non-digital tools such as paper, pencil, blackboard, and whiteboard (Lai & Cheong, 2022). Especially in teaching applied sciences such as geometry, which deals with the spatial relations of mathematics, there is a need for the use of technological tools and materials. Therefore, considering students' motivation, performance, and satisfaction in mathematics, AR technology can be one of the most valuable tools to improve students' motivation, performance, and attitudes, as it can provide interesting visual experiences (Chen, 2019). The literature has stated that AR-supported content can enhance memory encoding in individuals because it provides information to users through tactile methods compared to non-augmented reality-supported content (Vincenzi et al., 2003). In this way, within the framework of embodied cognition theory, it can be said that kinesthetic schemas are activated and increase the potential for deep learning (Abrahamson & Trninic, 2011). Research suggests that physically interacting with the educational content leads to stronger learning outcomes (Goldin-Meadow et al., 2009). In this direction, it can be said that augmented reality technology has the potential to support students' learning processes by combining the physical world with the virtual environment in students' mathematics learning processes.

It is recommended to examine the relationships between the learning process, learning achievement, and learning motivation in AR-supported learning environments (Cheng et al., 2018) and to compare augmented reality-supported geometry teaching with quantitative and qualitative data (İbili et al., 2019). In this direction, considering that this study aims to examine the effect of the lessons carried out with materials supported by AR technology on students' academic achievement, retention, mathematics anxiety, and mathematics motivation in mathematics lessons, it can be said that it will make significant contributions to both the literature and practitioners. In this direction, the following research questions were sought in this study:

1. Is there a significant difference between the experimental and control groups regarding students' academic achievement?
2. Is there a significant difference between the experimental and control groups regarding students' knowledge retention?
3. Is there a significant difference between the experimental and control groups regarding students' motivation for mathematics?
4. Is there a significant difference between the experimental and control groups regarding students' anxiety about mathematics courses?

2. Method

In this study, a quasi-experimental design, one of the quantitative research approaches, was used. A quasi-experimental method is frequently preferred in education because it divides the environment into artificial groups, and the pre-post-test approach can be easily adapted.

2.1. Study Group

The implementation process of this research was carried out in a secondary school in Turkey. In this context, the convenience sampling method was used because the school provides convenience regarding communication, transportation, and technological infrastructure and can be easily accessed and studied by the researcher. In the study four classes of 7th grade students were studied. Which of these classes would be in the experimental group and which would be in the control group was determined by the random assignment method. Two classes in this context constitute the control group, and the other two constitute the experimental group. The distribution of the research sample according to groups and gender is given in Table 1.

Table 1. Distribution of the Study Sample by Group and Gender

Group	Implementation Process	Number of Students		Total
		Girl	Boy	
Control	Traditional teaching with prepared materials (video, animation, etc.)	21	25	46
Experimental	Teaching with materials prepared with augmented reality support	26	21	47
			Total	*93*

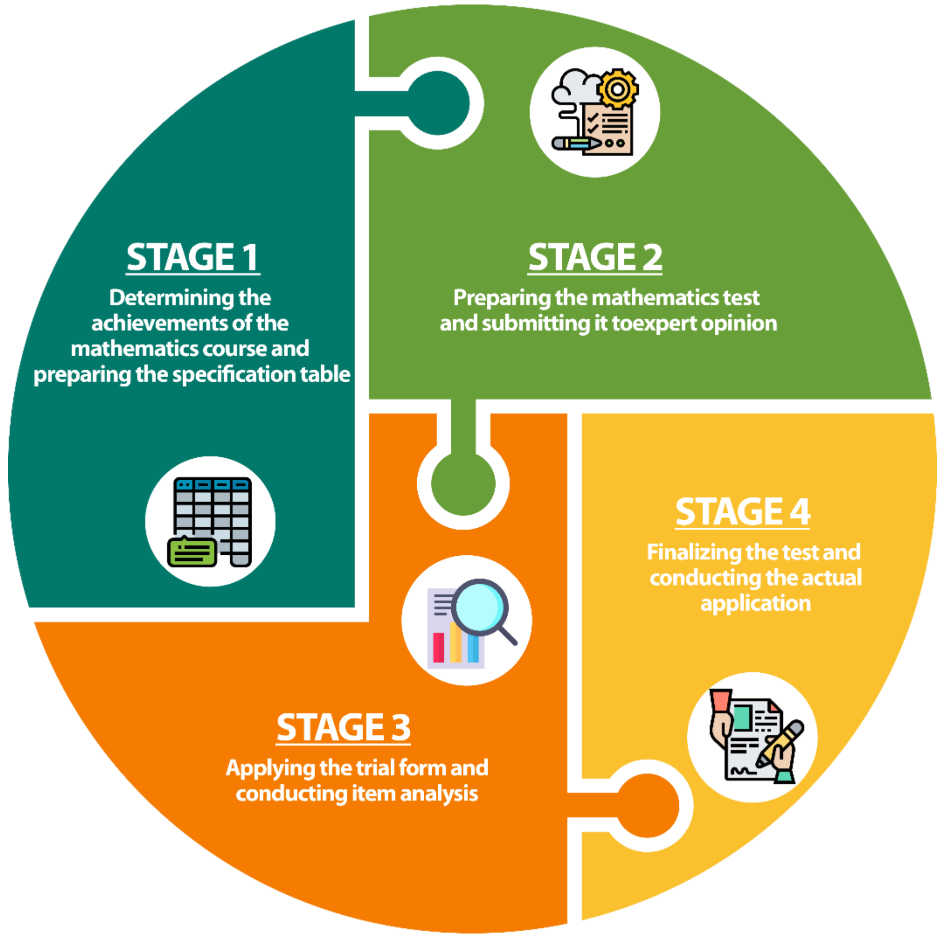
2.2. Data Collection Tools

Within the scope of the research, data were collected with the Mathematics Achievement Test, Mathematics Motivation Scale, and Mathematics Anxiety Scale.

- **Development of Mathematics Achievement Test**

In this study, a multiple-choice Mathematics Achievement Test consisting of 20 questions was prepared to determine students' academic achievement in mathematics. The development stages of the test are shown in Figure 1.

Figure 1. Development Stages of the Mathematics Achievement Test



As shown in Figure 1, in the first stage, the learning outcomes in the mathematics curriculum were examined in the presence of two mathematics teachers, and critical behaviors were identified. A specification table was prepared to determine the questions to be included in the mathematics achievement test according to the objectives, to ensure the validity and reliability of the test, and to determine the number of questions.

After the preparation of the specification table, the questions were prepared. In this context, a form consisting of 61 multiple-choice mathematics questions was designed. The opinions of 3 mathematics teachers and two academicians working in mathematics education were obtained through the trial form. In line with the feedback received, the number of questions was reduced to 20 to facilitate the achievements of the mathematics course and ease of application, and a mathematics achievement test was created.

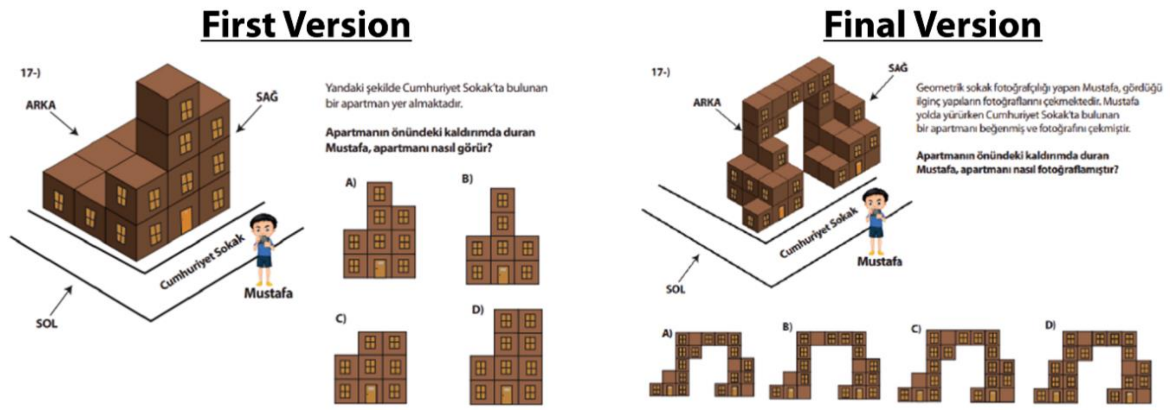
To carry out the validity and reliability study of the prepared mathematics achievement test, it was applied to a group of 104 students. Accordingly, the questions in the test were subjected to item analysis. The Microsoft Excel program used the data obtained after the pilot study to calculate item discrimination and difficulty indices of the test scores. The values obtained in this context are given in Table 2.

Table 2. Item Difficulty and Discrimination Indices of Achievement Test Items

Item No	Item Discrimination Index	Item Difficulty Index	Item Variance
1	.52	.56	0.25
2	.42	.72	.20
3	.50	.70	.21
4	.59	.53	.25
5	.68	.55	.25
6	.61	.56	.25
7	.46	.46	.25
8	.30	.24	.18
9	.25	.30	.21
10	.42	.66	.23
11	.31	.88	.11
12	.54	.71	.21
13	.41	.51	.25
14	.46	.38	.24
15	.57	.56	.25
16	.46	.46	.25
17	.25	.97	.03
18	.42	.94	.05
19	.54	.78	.17
20	.54	.82	.15

As the obtained result approaches 0, it can be interpreted that the item is difficult, and as it comes to 1, it can be interpreted as an easy item (Hasançebi et al., 2020). It is seen that the item discrimination index of questions 9 and 17 in Table 2 is weak. When the difficulty index of item 9 is analyzed, it can be said that the item has a low level of ease. Therefore, item 9 was not removed from the test. The 17th item was revised in line with the expert opinion, and the final version of the test was given. The first and last version of the 17th item is shown in Figure 2.

Figure 2. First and Final Version of the Seventeenth Item in the Mathematics Achievement Test



After the item analysis study on the mathematics achievement test, 20 questions were ready for the application. The scale's internal consistency was examined using the Kuder-Richardson 20 (KR-20) formula for the multiple-choice mathematics achievement test items. As a result of the analysis, the reliability coefficient (KR-20) of the mathematics achievement test was found to be 0.75. Fraenkel et al. (2012) stated that the minimum KR-20 value should be 0.70. Accordingly, as a result, it can be said that the achievement test's reliability is reasonable.

- **Mathematics Motivation Scale**

Motivated Strategies for Learning Questionnaire (MSLQ) developed by Pintrich et al. (1991) for elementary school students was used as the Mathematics Motivation Scale. Aktan and Tezci (2013) adapted the scale to the Turkish language and mathematics course context. MSLQ consists of 27 items in a 5-point Likert type. It consists of Intrinsic and Extrinsic goal orientation, task value, learning beliefs, self-efficacy, and test anxiety sub-dimensions. Cronbach Alpha reliability coefficient of MSLQ was calculated as 0.92.

- **Mathematics Anxiety Scale**

Mathematics Anxiety Scale was developed by Şentürk (2010). The Mathematics Anxiety Scale is a 5-point Likert-type (1-I never worry to 5-I always worry) scale comprising 22 items. Şentürk (2010) stated that the scale consists of the following five factors: anxiety arising from attitude, self-esteem anxiety, anxiety arising from field knowledge, learning anxiety, and exam anxiety. The Cronbach Alpha reliability coefficient of the Mathematics Anxiety Scale was calculated as 0.95 in this study.

2.3. Instructional Design Process

The processes within the scope of the research were structured according to the ADDIE model. The ADDIE model is one of the most well-known examples of instructional design (Özerbaş & Kaya, 2017). It is carried out in five stages: analysis, design, development, implementation, and evaluation. It is a flexible guide that helps instructional designers to create an effective support tool (Nadiyah & Faaizah, 2015). Accordingly, the stages followed in this study are as follows:

- **Analysis**

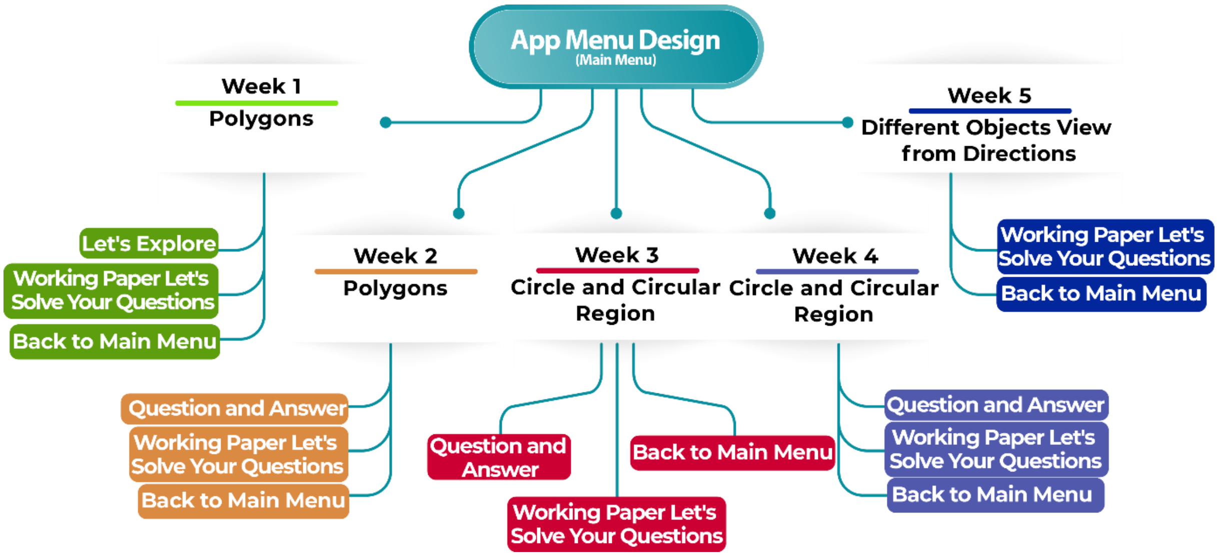
First, the course selection and the literature review were conducted to integrate technology into the educational environments related to the mathematics course. In this direction, as a result of the literature review, it was seen that the studies on the use of AR-supported materials in mathematics lessons are limited (Palancı & Turan, 2021; Zhang et al., 2022). For this reason, it was thought that using AR-supported materials in elementary mathematics lessons would be beneficial.

In addition, following the literature review, interviews were conducted with six mathematics teachers, and the topics that students had difficulty with were determined. Teachers stated that 7th-grade students had the most problem in the issues of circle and circular regions, angles and the view of objects from different directions, operations with natural numbers, and algebraic expressions. They stated this was because students could not think in 3D for the new generation's questions. Accordingly, as a result, it was decided to conduct the study on "Circle and Circular Regions", "Polygons" and "Views of Objects from Different Directions".

- **Design**

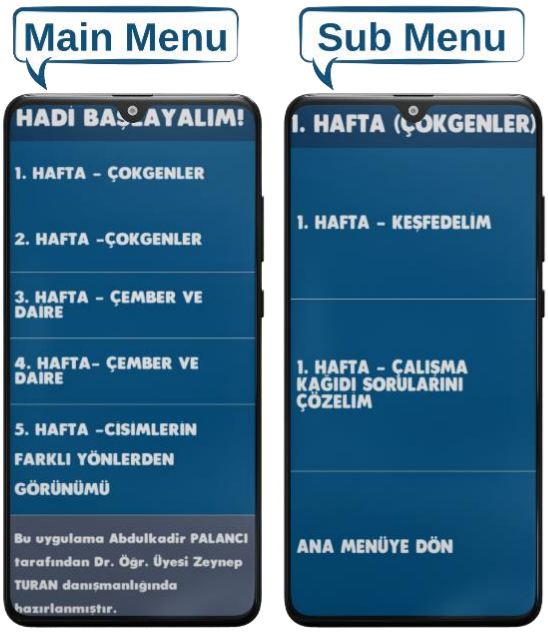
During the design process, weekly materials were developed and updated by considering the topics and outcomes to be covered in this study. Before starting the implementation process, the developed worksheets and AR-based mobile applications were regularly reviewed weekly by five students under the control of a mathematics teacher, and the researchers corrected the errors encountered. After all controls and corrections were made, the design process of the instructional materials was completed. In this context, the menu design hierarchy of the developed mobile application is shown in Figure 3.

Figure 3. General Architecture of AR-Supported Mobile Application



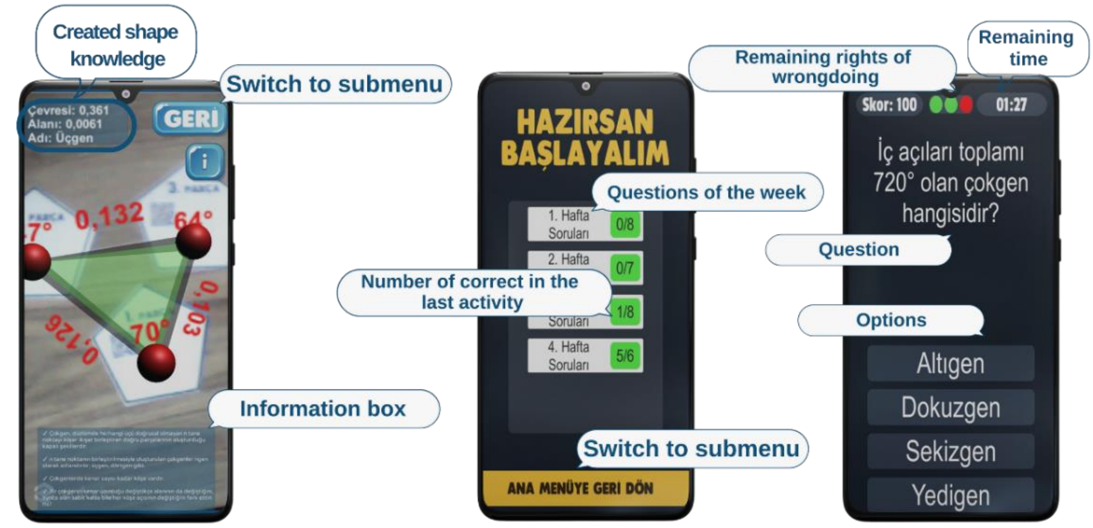
Unity 2019.4.1f1 version and Vuforia 9.8.12 software development kit were used to develop the mobile application. All the files required for the mobile application to work without an internet connection were placed there. For the experimental group of students to interact with the mobile application during the lesson, worksheets prepared by the researcher weekly by taking into account the relevant subjects and acquisitions and tablets with the mobile application installed were distributed to each student, one for each student. The main menu of the mobile application was titled to cover the weekly learning outcomes. From each heading in the main menu, the submenu of the week is accessed. The scenes that provide the interaction of activity and worksheets each week are accessed from the sub-menu. The main menu and submenu design of the application is given in Figure 4.

Figure 4. Main and Sub Menu Design of AR-Supported Mobile Application



In the augmented reality-supported worksheets used in the experimental group, the "Let's Explore" an activity or "Question-Answer" activities were developed weekly to draw students' attention to the lesson. The "Let's Explore" activity aimed for the students to comprehend that polygons are closed shapes and their names are determined accordingly, that the area is calculated as the side lengths increase, and that the interior angles will not change even if the side lengths change. In the "Question and Answer" activity, multiple-choice questions were prepared to remind the students about the previous week's topic. In each "Question and Answer" activity, three wrong answers and 120 seconds were allowed. All questions must be answered within the allotted time. The screenshots of the weekly "Let's Explore" and "Question and Answer" activities are given in Figure 5.

Figure 5. Screenshots of Let's Explore and Question and Answer Activity

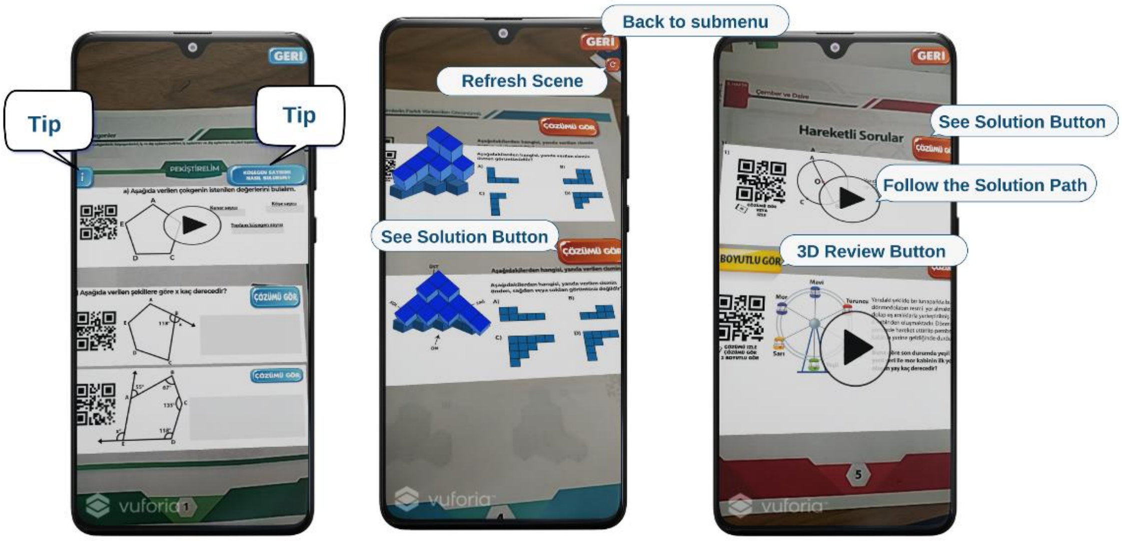


In addition, in the AR-supported worksheets, students were reminded of the relevant week's information with the "Let's Remember the Week's Topic Together" section before solving the questions in the lesson (Figure 6).

Figure 6. Images from the Let's Remember the Topic of the Week Section

3D objects were added to some of the questions in the augmented reality-supported worksheet so that students could see the critical points, and hints were added to some questions so that they could remember and reinforce the subject (Figure 7). In the pilot study, it was observed that 3D objects prevented the mobile application from working stably. To overcome this problem, a button was added to refresh the scene. While listening to the solutions to the video-supported questions during the application process, it was announced that all students should bring their headphones to prevent sound pollution. In addition, to provide instant feedback to the students, a "See solution" button was added to access the solution path and answer all questions.

Figure 7. Images of the AR-Supported Worksheet



Videos and animations in the AR-supported worksheet were prepared with Adobe After Effetct, Adobe Premier Pro, and Camtasia 2019 programs. The worksheet was designed with the Adobe Illustrator program. The 3D objects in the AR-supported application were prepared with the Blender program. Information about the multimedia in the developed AR-supported application is presented in Table 3.

Table 3. Digital Contents in the AR-Supported Application and Their Characteristics

Week-Subject	Number of 3D Objects	Number of Videos	Video Type	Total Duration (minutes)	Interaction Type
Week 1-Polygons	2	27	-Question Solution (25) -Animation (2)	43:34	Click on the Button, Magnification-Reduction, Different angle measures and polygon formation activity
Week 2-Polygons	4	27	-Question Solution (27) -Animation (1)	40:35	Click on the Button, Magnification-Reduction, Multiple Choice Test Activity

Week 3-Circle and Circular Region	4	22	- Question Solution (21) -Animation (1)	36:05	Click on the Button, Magnification-Reduction, Multiple Choice Test Activity
Week 4-Circle and Circular Region	3	16	- Question Solution (14) -Animation (2)	28:01	Click on the Button, Magnification-Reduction, Multiple Choice Test Activity
Week 5-Views of Objects from Different Directions	22	1	-Animation (1)	1:21	Click on the Button, Magnification-Reduction

- **Implementation Process**

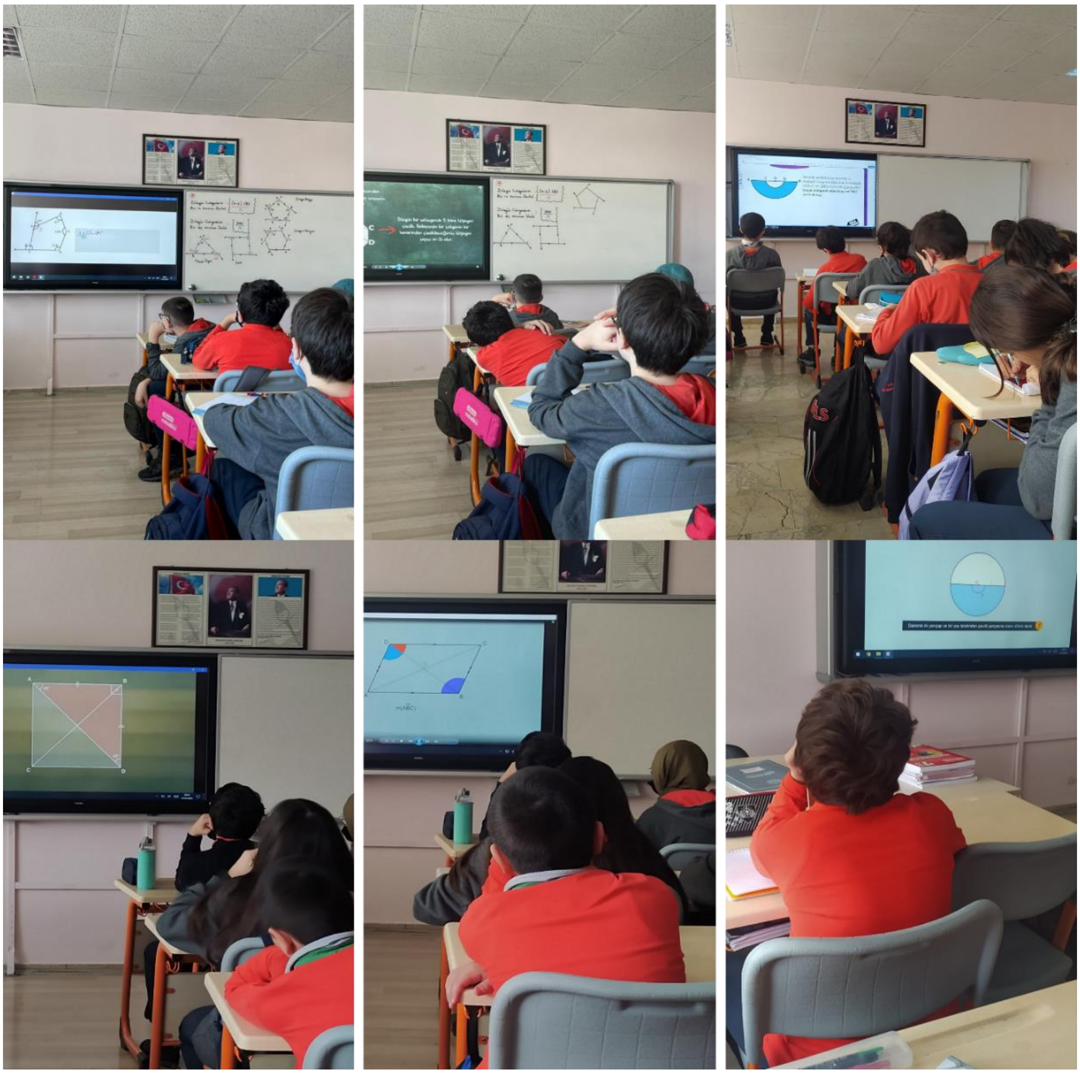
The researcher implemented the implementation in a middle school in the presence of the course teacher. In the experimental group, the lessons were conducted with the AR-supported workbook developed by the researcher. In the experimental group, after the teacher explained the subject weekly, the students were allowed to work on the subject of the relevant week in the AR-supported workbook during the lesson. While the students were working with AR-supported materials during the class, the teacher helped them when they had questions or problems.

The experimental procedures were started after the pre-test was applied for the experimental and control groups in the first week. After the application process of the experimental and control group, which was planned as 3 units-5 weeks, was completed, the post-test was applied. One month after the post-tests were applied, the process was completed by applying the retention test. Images of the implementation process in the experimental group are shown in Figure 8.

Figure 8. Images of the Experimental Group Implementation Process

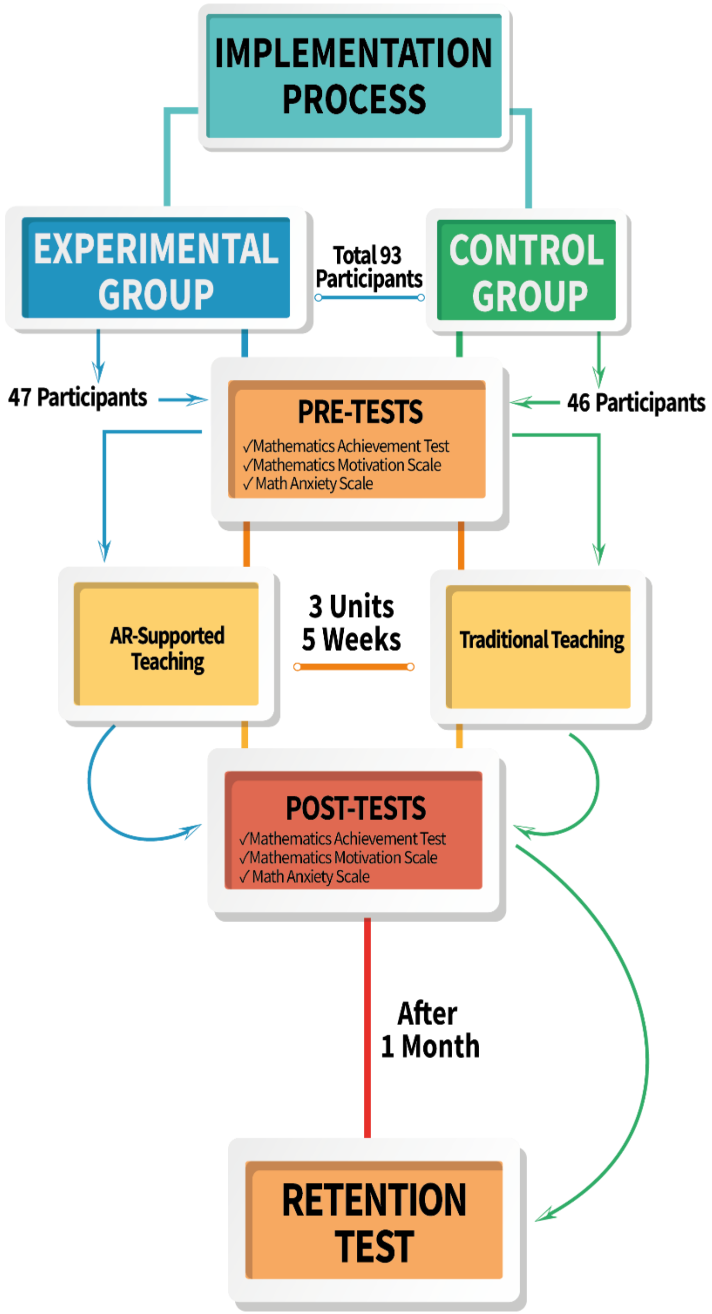
With 46 students in the control group, the lesson process continued with the methods currently used by the teacher, such as lecture and question-answer. The non-augmented reality-supported version of the study booklet was shared with the students in the control group. It aimed to obtain reliable results in a fairer environment to compare the groups. The implementation process of the control group students started with pre-tests. After five weeks of implementation, the process was completed with post-tests and a retention test one month later. Images of the implementation process of the control group are shown in Figure 9.

Figure 9. Images of the Control Group Implementation Process



The implementation process with 93 participants in the experimental and control groups is summarized in Figure 10. The implementation process of both the experimental and control groups lasted five weeks, with 4 class hours per week.

Figure 10. Summary of the Implementation Processes of the Experimental and Control Groups



- **Evaluation**

  One week after the end of the implementation process, post-tests were applied to both groups. One month after the post-tests, the process was completed by applying the retention test to both groups.

3. Results

This section determined the effects of augmented reality-supported mathematics learning in middle school on students' achievement, retention, motivation, and anxiety levels. The findings from analyzing the data collected in this section are included in this direction.

3.1. Findings Related to Pre-test Mathematics Achievement Scores Before the Implementation

The assumptions of normal distribution and homogeneity of variances were checked before conducting the independent samples t-test for the academic achievement pre-test scores of the experimental and control groups. Descriptive statistical results of the pre-test achievement scores are given in Table 4. When the achievement test pre-test scores were analyzed, it was seen that the kurtosis and skewness coefficients were between +1.96 and -1.96 for the experimental and control groups, and the data were normally distributed (Tabachnick & Fidell, 2013).

Table 4. Pre-Test Descriptive Statistics on the Achievement of the Groups

Group	n	$\bar{X}$	Sd	Min	Max	Skewness	Kurtosis
Control	46	50.98	15.37	15	80	.11	-.33
Experimental	47	52.55	16.08	25	80	-.05	-1.2

The results of the independent samples t-test analysis of whether there is a significant difference between the groups in terms of the pre-test scores of the experimental and control groups are given in Table 5.

Table 5. Pre-Test Independent Samples t-Test Analysis Results of the Groups' Achievements

Group	n	$\bar{X}$	Sd	t	p
Control	46	50.98	15.37	-.483	.63
Experimental	47	52.55	16.08		

When Table 5 is examined, it is seen that there is no significant difference between the mathematics pre-test achievement scores of the experimental group and the control group students ($t = -.483$, $p > .05$). Accordingly, it can be said that the experimental and control groups were equivalent in terms of mathematics achievement before the application.

3.2. Findings Related to Post-Test Mathematics Achievement Scores After the Implementation

The assumptions of normal distribution and homogeneity of variances were checked before conducting the t-test for the post-test academic achievement scores of the experimental and control groups. In the achievement test, each correct question was evaluated as 5 points, and each incorrect question was assessed as 0. The maximum score that can be obtained from the achievement test is 100. Descriptive statistics results for the post-test achievement scores are given in Table 6.

Table 6. Descriptive Statistics Results of the Achievement Post-Tests of the Groups

Group	n	$\bar{X}$	Sd	Min	Max	Skewness	Kurtosis
Control	46	59.46	17.89	15	95	-.27	-.07
Experimental	47	69.79	16.58	35	100	-.09	-.54

The results of the independent samples t-test analysis of the post-test achievement scores of the experimental and control groups are given in Table 7. When Table 7 is examined, it is seen that the mean mathematics post-test achievement scores of the experimental group students ($\bar{X}$=69.79, SD= 16.58) are statistically significantly higher than the mean mathematics post-test achievement scores of the control group students ($\bar{X}$=59.46, SD=17.89) ($t= -2.88$, $p < .05$).

Table 7. Post-test Independent Samples t-Test Analysis Results of the Groups' Achievements

Group	n	$\bar{X}$	Sd	t	p
Control	46	59.46	17.89	-2.88	.005
Experimental	47	69.79	16.58		

According to the independent samples t-test results, it can be said that there is a significant difference between the experimental group and the control group with a moderate effect size (Cohen's d= .60). As a matter of fact, it is stated that when Cohen's d value is less than .20, the effect size is small, when it is .50, the effect size is moderate. The effect size is strong when greater than .80 (Cohen, 1988).

3.3.Findings Related to Retention Test Scores

The assumptions of normal distribution and homogeneity of variances were checked before conducting the t-test for the retention test scores of the experimental and control groups. Descriptive statistics results for the retention test scores are given in Table 8. In this direction, when the skewness and kurtosis coefficients of the experimental group and the control group according to the retention test scores of mathematics achievement, it can be said that the normal distribution assumption is met.

Table 8. Descriptive Statistics Results of Retention Test

Group	n	$\bar{X}$	Sd	Min	Max	Skewness	Kurtosis
Control	46	68.26	19.27	10	95	-.58	.34
Experimental	47	75.43	16.54	25	100	-.81	.64

When Table 9 is examined, it is seen that there is no significant difference between the mean mathematics retention test scores of the experimental group students ($\bar{X}$=75.43, Sd=16.54) and the mean mathematics retention test scores of the control group students ($\bar{X}$=68.26, Sd=19.27) (t= -1.92, p>.05).

Table 9. Independent Groups t-Test Results of Retention Test

Group	n	$\bar{X}$	Sd	t	p
Control	46	68.26	19.27	-1.92	.057
Experimental	47	75.43	16.54		

3.4.Findings Related to Mathematics Motivation

The assumptions of normal distribution and homogeneity of variances were checked before conducting the t-test for the experimental and control groups' motivation pre-test and post-test scores. As a result, it was seen that the pre-test and post-test data of the motivation scale met the assumptions of the independent samples t-test. Independent samples t-test statistical results for the pre-test motivation scores are given in Table 10.

Table 10. Pre-test Independent Groups t-Test Results of the Groups Regarding the Mathematics Motivation Scale

Dimensions	Experimental (n= 47)		Control (n= 46)			
	$\bar{X}$	Sd	$\bar{X}$	Sd	t	p

Intrinsic Goal Orientation	3.73	.78	3.92	.73	1.20	.23
Extrinsic Goal Orientation	4.53	.58	4.60	.51	.67	.50
Task Value	3.82	.75	4.09	.66	1.85	.67
Learning Beliefs	4.17	.52	4.33	.63	1.33	.18
Self Efficacy	3.77	.79	3.87	.77	.61	.53
Test Anxiety	3.09	1.15	3.10	1.19	.03	.97
Overall Motivation	3.85	.49	3.99	.54	1.68	.208

When Table 10 is examined, it is seen that there is no statistically significant difference between the mean general motivation pre-test score of the control group students (X=3.99, SD=.54) and the mean overall motivation pre-test score of the experimental group students (X=3.85, SD=.49) t(91)=1.68, p>.05. When the findings regarding the sub-dimensions of the motivation scale of the groups are examined, it is seen that there is no significant difference between the experimental and control groups in terms of pre-test scores in the sub-dimensions of the scale. The post-test independent samples t-test results of the groups' math motivation are given in Table 11.

Table 11. Post-Test Independent Samples t-Test Statistical Results of the Groups Regarding the Mathematics Motivation Scale

Dimensions	Experimental (n=47)		Control (n=46)			
	$\bar{X}$	Sd	$\bar{X}$	Sd	t	p
Intrinsic Goal Orientation	4.04	.66	3.83	.84	-1.32	.18
Extrinsic Goal Orientation	4.62	.57	4.46	.77	-1.33	.26
Task Value	3.95	.79	3.74	1.01	-1.33	.26
Learning Beliefs	4.17	.71	4.06	.87	-.71	.47
Self Efficacy	3.71	1.03	3.55	1.01	-.74	.45
Test Anxiety	3.44	1.22	2.36	1.18	-4.29	.00
Overall Motivation	3.97	.58	3.67	.73	-2.19	.03

When Table 11 is examined, it is seen that there is a statistically significant difference between the post-test mean motivation score of the control group students (X=3.67, SD=.73) and the post-test mean motivation score of the experimental group students (X=3.97, SD=.58) t(91)=-2.19, p<.05. According to the post-test independent samples t-test result of the motivation scale, a significant difference was found between the experimental group and the control group with a small effect value (Cohen's d=.45). Accordingly, it was determined that students who used AR technology in mathematics lessons had higher motivation than students who did not use AR technology. In addition, when the sub-dimensions of the motivation scale were examined, it was seen that there was no significant difference between the groups in the sub-dimensions of "intrinsic goal orientation", "extrinsic goal orientation", "task value", "learning beliefs" and "self efficacy". At the same time, there was a significant difference in favor of the experimental group in the sub-dimension of "test anxiety".

3.5.Findings Related to Mathematics Anxiety

Before conducting the t-test for the experimental and control groups' pre-test and post-test math anxiety scores, the assumptions of normal distribution and homogeneity of variances were checked, and the independent samples t-test was conducted. Independent samples t-test results for pre-test math anxiety scores are given in Table 12, and independent samples t-test results for post-test math anxiety scores are shown in Table 13.

Table 12. Pre-test Independent Samples t-Test Statistical Results of the Groups Regarding the Mathematics Anxiety Scale

Dimensions	Experimental (n= 47)		Control (n= 46)			
	X̄	Sd	X̄	Sd	t	p
Anxiety arising from attitude	1.89	.87	1.72	.87	-.96	.33
Self-esteem anxiety	2.43	1.06	2.43	1.19	.39	.96
Anxiety arising from field knowledge	1.99	.95	1.86	.75	-.70	.48
Learning anxiety	3.71	.92	3.50	1.08	-.99	.32
Exam anxiety	3.20	1.12	2.70	1.20	-2.07	.041
Overall anxiety	2.65	.79	2.45	.88	-1.16	.247

When Table 12 is examined, it is understood that the pre-test mean score of the control group students on the mathematics anxiety scale ($\bar{X}$=2.45, SD=.88) did not differ statistically significantly from the pre-test mean score of the experimental group students on the mathematics anxiety scale ($\bar{X}$=2.65, SD=.79) $t(91)=-1.16$, $p>.05$. When the sub-dimensions of the scale are examined, it is seen that there is a significant difference between the groups only in the exam anxiety sub-dimension.

Table 13. Post-Test Independent Samples t-Test Statistical Results of the Groups Regarding the Mathematics Anxiety Scale

Dimensions	Experimental (n=47)		Control (n=46)			
	X̄	Sd	X̄	Sd	t	p
Anxiety arising from attitude	1.95	1	2.08	1.09	.57	.57
Self-esteem anxiety	2.33	1.09	2.87	1.51	2.32	.02
Anxiety arising from field knowledge	2.12	1.16	2.47	1.28	1.35	.17
Learning anxiety	3.10	1.23	3.78	1.11	2.79	.00
Exam anxiety	2.80	1.22	3.32	1.14	2.14	.35
Overall anxiety	2.47	.99	2.92	.96	2.22	.029

When Table 13 is examined, it is seen that there is a statistically significant difference between the post-test mean score of the control group students' mathematics anxiety ($\bar{X}$=2.92, SD=.96) and the post-test mean score of the experimental group students' mathematics anxiety ($\bar{X}$=2.47, SD=.99) $t(91)=2.22$, $p<.05$. In addition, it is seen that there is no significant difference between the groups in the sub-dimensions of anxiety arising from attitude towards mathematics course, anxiety arising from field knowledge, and test anxiety. At the same time, there is a significant difference between the groups in favor of the control group in the sub-dimensions of "self-esteem anxiety" and "learning anxiety".

4. Discussion and Conclusion

This study examined the effects of AR-supported materials in mathematics lessons on students' academic achievement, knowledge retention, mathematics anxiety, and motivation. Accordingly, the findings obtained in this section are interpreted and presented under headings concerning the literature.

4.1. The Impact of AR-Supported Instruction on Students' Academic Achievement in Mathematics Education

As a result of the analysis of the post-test data of the academic achievement variable, a significant difference was found in favor of the experimental group. As a result, it was found that students learning with AR-supported materials were more successful than students learning with traditional methods. This result supports the findings of studies in the literature examining learning environments where AR technology is used in mathematics education (Chen, 2019; Cheng et al., 2018; Conley et al., 2020). This finding may be because students studying with AR-supported materials interact more with their friends. AR technology can easily concretize abstract subjects, and students can examine the materials at their own pace. In addition, it can be thought that students who take courses with AR applications focus more on learning, progress, and research (Cai et al., 2019). Studies indicate that image-based AR is more suitable for learning spatial ability, conceptual learning, and application skills (Cheng & Tsai, 2013). In addition, it can be said that AR technology increases visual thinking skills in mathematics, makes learning environments interactive, and supports increasing students' participation in the learning process (Sun & Chen, 2019). For this reason, using AR technology in mathematics courses, which have many abstract concepts, can enable students to concretize abstract concepts (Coimbra et al., 2015).

When the literature is examined, it is seen that various studies are similar to this study. For example, Sun and Chen (2020) experimented with sixth-grade students using AR-supported textbooks with experimental and control group students and the traditional teaching process with control group students. As a result of the study conducted with 60 students, they concluded that there was a significant difference in the achievement of the experimental group students and that AR was more effective. In the study conducted by Sun and Chen (2019), fifth-grade students participated; the experimental group used an AR-supported textbook for five weeks, while the control group students were taught only with the traditional method. Accordingly, as a result of the study, it was concluded that the achievement of the experimental group students who studied with the math textbook supported by AR technology was higher than that of the control group students. Yu et al. (2016) included AR technology in geometry education with 52 fifth-grade students; the experimental group worked with AR-supported materials, while the control group was taught with traditional methods. As a result of the research, it was concluded that AR-supported mathematics education was more effective than the conventional method. Arvanitaki and Zaranis (2020) investigated the effect of AR technology with specially designed activities based on van Hiele model in teaching geometry to fourth-grade primary school students. As a result of the research, it was concluded that learning through AR is an interactive process for primary school students and has a positive effect on geometry learning compared to traditional teaching methods. As a result of the retention test, it was seen that there was no significant difference between the academic achievement of the experimental and control group students.

4.2. The Effect of AR-Supported Instruction on Students' Motivation in Mathematics Education

Motivation to learn mathematics is defined as the investment in solving mathematical problems, positive evaluation of mathematical skills, and the degree of success in solving mathematical problems (Gottfried et al., 2007). As a result of this study, it was determined that students who used AR technology in mathematics lessons had higher motivation than students who did not use AR technology. In addition, when the sub-dimensions of students' motivation are examined, it can be said that AR technology negatively affects test anxiety.

Many students accept mathematics as a boring course that is difficult to understand and is expressed with words such as nightmare, fear, and stress. In this direction, raising students' attitudes towards mathematics and making students see the subject as worth learning will increase their motivation to learn mathematics. Considering the findings obtained in the research, AR technology increases students' motivation (Cai et al., 2019; Chen, 2019; Demitriadou et al., 2020; Ibáñez et al., 2020; O'Shea et al., 2011). In this direction, it can be ensured that students who are newly introduced to AR technology can focus better on the lesson, obtain three-dimensional images and accelerate their learning processes.

To improve mathematics performance and transfer it outside of school and outside of current experiences, students need to be motivated to believe that they are successful in understanding and using mathematics and to overcome more significant challenges in mathematics (Hardré, 2011). For this purpose, students need to be instilled with positive feelings about their competence in mathematics (Timmerman et al., 2017). Therefore, it can be said that using applications developed with AR technology in mathematics lessons can increase students' mathematics motivation by interacting with the mathematics course content. In particular, AR technology allows students to examine and memorize mathematical formulas in detail.

4.3. The Effect of AR-Supported Instruction on Students' Anxiety in Mathematics Education

As a result of this study, there was a significant difference between the posttest anxiety levels of the groups in favor of the experimental group. In parallel with the findings of this study, there are studies in the literature reporting that students learning mathematics using AR technology have low anxiety (Chen, 2019; Lubis et al., 2022; Suryani & Hidayat, 2022; Wangid et al., 2020).

Mathematics course, which plays an important role in determining students' academic success throughout their lives, is one of the courses in which students fail the most, have anxiety and difficulties, and exhibit negative attitudes (Yaşar & Papatğa, 2015). Therefore, mathematics anxiety may result from failure in solving mathematical problems (Milovanović, 2020). Therefore, since attitude towards mathematics is related to many factors such as self-efficacy, mathematics anxiety, and mathematics achievement, it would be beneficial to use innovative technologies such as AR to reveal students' attitudes towards mathematics in educational environments and to make unique contributions to students' learning processes. Thus, especially for students with high self-efficacy, using AR technology while learning mathematics can help them apply broad strategies (Cai et al., 2019).

Funding and/or Conflicts of Interests/Competing Interests

- Conflict of Interest: The authors declare that they have no conflict of interest.

Data Availability Statement: Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Review Result

1. The article lacks a clear methodology and does not provide detailed information on data collection and analysis. This limits the validity and reliability of the results. The article does not adequately document, acknowledge or reference existing findings, research, practices and literature in its field. Although it briefly mentions some previous research on the use of AR in mathematics education, it does not provide a comprehensive overview of the existing literature and does not provide a strong theoretical foundation for the research.
2. The concepts of augmented reality (AR), math achievement, motivation, anxiety and retention are consistent with the research questions and objectives of the study. However, the article could have looked at other concepts or categories that may be related to the research. For example, the role of teacher support and teaching strategies in the implementation of AR-supported mathematics education could have been considered. Key terms in the article such as AR, math achievement, motivation, and anxiety are not adequately defined or used consistently throughout the article. The article lacks clear and precise definitions of these terms, which can lead to ambiguity and confusion in understanding the research findings and their implications. The article makes no necessary or significant connections to existing theory.
3. The article lacks reflexivity and does not take into account possible biases or limitations in research design or methodology.
4. The article does not effectively demonstrate the direct or indirect applicability, relevance or effectiveness of the practice or object under analysis. Although it contains some positive findings about the impact of augmented reality (AR) on mathematics learning, it does not address the practical implications of these findings or provide recommendations for educators or decision makers. The article lacks a clear connection between research findings and their real-world implications. It does not provide specific guidelines or strategies for implementing AR in mathematics education, nor does it address potential challenges or limitations of its application.
5. The article does not explore new possibilities or propose new approaches to integrate AR into educational practices. The article does not provide an in-depth analysis or discussion of the potential benefits and challenges of using AR in mathematics education. It does not address the scalability or sustainability of AR implementation in different educational contexts. Further research and clarification of AR in mathematics education is needed for the article and the wider worldview to be realized. Future research should consider the practical implications, challenges and potential benefits of using AR in various educational settings.