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Effects of Interactive Augmented Reality Application on Primary School Students' Misconceptions and Attitudes in Mathematics Education

Sena Ölçer Çevik [1 *], Bilge Gök [2]

[1] Baskent University, Turkiye, 0000-0002-4878-3150
[2] Hacettepe University, Turkiye, 0000-0002-1548-164X
* Corresponding author: Sena Ölçer Çevik (senaolcer@gmail.com)

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Abstract

This study examines the effect of interactive augmented reality applications on correcting misconceptions in mathematics and enhancing attitudes towards the subject among 4th-grade students. The participant group consists of 4th-grade students attending a public school in the Etimesgut district of Ankara during the 2022-2023 academic year. The study involved 56 students, with 27 in the experimental group and 29 in the control group. The research employed a quasi-experimental design with a pre-test and post-test control group format. Quantitative data were collected using the "Attitude Towards Mathematics Scale" and the "Misconception Test on Measurement," developed by the researcher. Qualitative data from semi-structured interviews with 10 students in the experimental group supported the quantitative findings. All data were analyzed using the SPSS 23.0 software. A two-way ANOVA test was applied to analyze quantitative data in mixed designs, while content analysis was used for qualitative data. According to the quantitative results, interactive augmented reality applications were found to be effective in reducing misconceptions related to measurement and in improving students' attitudes towards mathematics in the experimental group. The qualitative findings supported these results, revealing that augmented reality applications are beneficial in correcting misconceptions and fostering positive attitudes towards the subject.

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Introduction

Studies on the use of augmented reality (AR) in education have increased over the years, encompassing various grade levels and subject areas (Akkuş et al., 2021; Çiloğlu et al., 2021; Jaber et al., 2024; Türel & Bayer, 2021). AR contributes positively by enhancing critical and conceptual thinking (Hwang & Hu, 2013; Jaber et al., 2024), boosting motivation, and increasing interest in lessons (Lee, 2012). Also, AR technology is particularly effective in supporting the learning of abstract and complex concepts, such as spatial reasoning in geometry. It enables students to visualize objects in three dimensions from various angles, thereby providing a more concrete and intuitive understanding of spatial relationships and enhancing their spatial skills (Gün & Atasoy, 2017). These studies generally report improvements in students' academic performance and motivation following AR-based interventions, particularly at the middle school level (Canbaz & Yalçın, 2024; Erşen & Alp, 2024). Despite these advantages, one of the most cited limitations of AR applications is their lack of interactivity, which may reduce student engagement (Akkuş & Özhan, 2017).

Misconceptions, especially at the primary level, can form early cognitive obstacles that hinder students' long-term understanding and transfer of mathematical knowledge. Yet, few AR studies directly address how these conceptual errors are diagnosed or corrected. Although it has been established that augmented reality applications enhance understanding of mathematical concepts at the primary school level (Apriza et al., 2024), a gap remains in the literature regarding their impact on eliminating conceptual misconceptions at this level. This represents a significant research gap, as effective mathematics instruction must not only teach concepts but also confront and remediate faulty prior knowledge that distorts future learning.

Due to the novelty of AR technology, studies on its use at various educational levels—particularly in primary education—remain limited, revealing a significant research gap (Criollo-C et al., 2024; Sünger et al., 2022). In particular, the number of studies focusing on the use of AR in elementary school mathematics is relatively small (Maas & Hughes, 2020; Tekedere & Göke, 2016; Usta et al., 2016). Although misconceptions in the measurement domain of primary mathematics are diverse and well-documented (Van de Walle et al., 2019), no research has examined the impact of AR applications on addressing these misconceptions.

Therefore, this study aims to fill these gaps by designing and implementing an interactive augmented reality (AR) application that specifically targets and addresses common mathematical misconceptions among primary school students, while also assessing its impact on their attitudes toward mathematics. By integrating cognitive and affective dimensions, this research offers a comprehensive understanding of AR's educational potential. The study aspires to contribute a more profound and focused perspective to the field of mathematics education. To address deficiencies in the existing literature regarding the influence of augmented reality on misconceptions, the research was conducted with fourth-grade students, given that measurement-related learning outcomes are approached in a spiral manner throughout primary education and are explicitly emphasized at the fourth-grade level within the Turkish curriculum. The objective is to investigate the impact of interactive AR applications on reducing misconceptions and improving attitudes toward mathematics. Accordingly, the following research questions are proposed: What is the impact of interactive use of augmented reality in mathematics education on fourth-grade students' misconceptions related to measurement and their attitudes toward mathematics lessons?

1. How does the use of interactive AR applications in primary school mathematics education contribute to the elimination of misconceptions by students in the measurement learning area?
2. How does the use of interactive AR applications in primary school mathematics education affect students' attitudes towards mathematics lessons?

Use of Augmented Reality Technology in Education

The new generation of digital natives is inherently connected with technology and increasingly anticipates its integration into educational settings (Axmadjonova & Axmadjonova, 2023). Failure to adapt to this expectation may result in technological tools diminishing their influence on student engagement. Among emerging educational tools, augmented reality (AR) and virtual reality (VR) have gained significant prominence. AR, defined as the integration of real and virtual elements (Azuma, 1997; Furht, 2011), was initially developed for entertainment purposes but has since been expanded into various domains, including healthcare, commerce, and education, to address several limitations (Abdusselam & Karal, 2020). Although early research on AR primarily concentrated on higher education, recent years have witnessed an increased interest in its application at the primary level (Dunleavy & Dede, 2014; Kelpšienė & Aydoğdu, 2021). It has been posited that instructional environments incorporating AR and SD applications will exert a positive influence on students' learning processes (Somyürek, 2014).

Research indicates that engaging multiple senses enhances retention (Rao, 2018), and augmented reality (AR) facilitates this by enabling students to manipulate three-dimensional objects within real space, thereby rendering abstract concepts more tangible (O'Brien & Toms, 2005; Shelton & Hedley, 2002; Wojciechowski & Cellary, 2013). This concreteness simplifies the comprehension of complex topics (Wu et al., 2014) and strengthens the associations between concepts, thereby supporting long-term memory retention (Ivanova & Ivanov, 2011). Furthermore, AR has demonstrated efficacy in supporting spatial visualization and deepening comprehension of geometric principles (Demitriadou & Lanitis, 2019; Nadzeri et al., 2024).

Misconceptions and Their Place in Mathematics

According to Vygotsky, concepts are categorized as either natural or scientific; while natural concepts develop gradually, akin to the cognitive development of students, scientific concepts evolve through verbal descriptions (Dede & Argün, 2004). Students enter the classroom with pre-existing beliefs and understandings (Murphy & Alexander, 2004), which may conflict with new scientific knowledge, potentially resulting in misconceptions (Allen, 2010). These misconceptions, often resistant to modification, can impede learning and adversely affect academic performance (Kıngır, 2019).

Mathematical concepts are fundamental for the development of critical thinking skills (Jannah et al., 2025). The mathematics curriculum systematically constructs these concepts through a spiral approach (Ministry of National

Education [MoNE], 2018), whereby early misunderstandings have the potential to impede subsequent learning and influence students' attitudes (Dede & Argün, 2004). Given their developmental stage, primary school students are particularly susceptible to misconceptions, especially within abstract domains such as measurement. For example, children generally acquire the understanding of the conservation of matter at ages 7–8, the conservation of area at ages 9–10, and the conservation of volume at ages 11–12 (Aktaş-Arnas, 2016), which demonstrates that their comprehension of measurement remains in development.

Measures should be implemented to dispel misconceptions within the educational process. One such approach involves integrating technology into teaching methods. The incorporation of technology facilitates students in reviewing and organizing their internal representations (Kabaca, 2016). Internal representations refer to the way students mentally construct and comprehend a subject. This prompts the inquiry as to whether analyzing these representations can assist in identifying potential conceptual misunderstandings.

Augmented reality (AR) has demonstrated its capacity to reduce misconceptions, particularly within the realm of science education (Kennedy et al., 2021; Yoon et al., 2017). Nonetheless, although evidence is accumulating indicating that AR enhances conceptual understanding in mathematics education (Apriza et al., 2024), research specifically examining how this technology can identify and rectify students' misconceptions remains limited. At the elementary school level, students are more susceptible to misconceptions due to difficulties in concretizing abstract mathematical concepts. However, current AR applications predominantly focus on outcomes such as capturing students' attention or improving overall academic performance (Pahmi et al., 2023), without directly addressing the correction of conceptual misunderstandings. Misconceptions can persist as significant obstacles within the learning process and may negatively impact subsequent knowledge development. Consequently, it is imperative for future research to concentrate on AR designs that specifically target misconceptions and to evaluate their effectiveness.

Attitude and Its Relationship with Mathematics

The education system aims to cultivate individuals endowed with knowledge, skills, and values (Ministry of National Education [MoNE], 2018). The shaping of behavior is imperative in achieving this objective, with attitudes playing a vital role in its development (Ajzen, 2005). Consequently, cultivating appropriate attitudes is indispensable. An attitude is defined as the evaluation of an object, representing a learned disposition (Eagly & Chaiken, 1998, as cited in Kretschmann & Wrobel, 2015). This evaluation is associated with behavior related to the object (Fazio & Towles-Schwen, 1999, as cited in Kretschmann & Wrobel, 2015). Attitudes play a crucial role in maintaining equilibrium among an individual's thoughts, emotions, and behaviors towards an object (Taylor et al., 2007). Accordingly, the cognitive, affective, and behavioral components of attitudes are interconnected, with alterations in one component influencing the others. A negative attitude may impede engagement and learning outcomes. Research indicates that attitudes toward mathematics significantly influence students' beliefs and academic achievement (Wiegfield & Eccles, 2000, as cited in Ramirez et al., 2012). However, there has been a growing concern over declining interest in math-related fields (National Research Council [NRC], 2012). To address this, Tarım and Dinç Artut (2016) emphasized that integrating interactive and technological tools can have a positive impact on students' attitudes.

Research indicates that augmented reality (AR) has the potential to enhance students' attitudes by rendering abstract mathematical concepts more accessible and engaging (Alizkan et al., 2021; Özdemir & Özçakır, 2019). For instance, Özdemir and Özçakır (2019) found that AR-based mathematics activities had a positive influence on students' attitudes toward mathematics during fraction instruction. Likewise, Demitriadou and Lanitis (2019) emphasized that AR fosters a more interactive and captivating approach to mathematics education for primary school learners. Nonetheless, some research also suggests that the impact of AR on student attitudes may not always be statistically significant and may vary depending on the manner of implementation and contextual factors (Baran et al., 2020; Canbaz & Yalçın, 2024). These findings underscore the importance of further investigation into how interactive AR applications influence primary school students' attitudes regarding mathematical measurement topics.

Method

This study intended to investigate the impact of lesson plans incorporating interactive Augmented Reality (AR) activities on fourth-grade primary school students' misconceptions in the area of measurement and their attitudes toward mathematics lessons. The primary methodology employed was experimental research, complemented by qualitative data to corroborate the experimental findings. Consequently, the research was divided into two phases. As illustrated in Figure 1, the initial phase involved conducting an experimental study to gather quantitative data, while the subsequent phase focused on collecting qualitative data to substantiate the quantitative results.

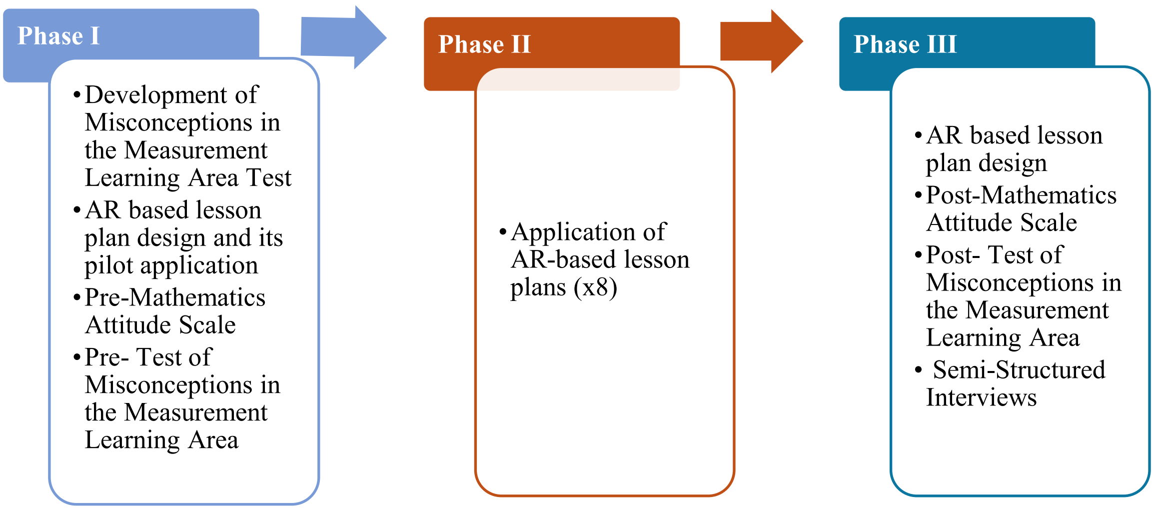

Figure 1. Symbolic Representation of the Research Process

In the experimental dimension of this study, a quasi-experimental pre-test and post-test design with a control group was employed. The quasi-experimental research design is utilized in situations where participants cannot be randomly assigned to groups, and such random assignment is generally not preferred in educational research, as it may adversely affect the learning process (Fraenkel et al., 2011). In quasi-experimental studies where participants in the experimental and control groups are not randomly assigned, the existing groups participate directly in the research process (Creswell, 2003). Given that it was not possible to randomly assign students to classes in the school where this research was conducted, the quasi-experimental research method was selected. In a pretest-posttest quasi-experimental design with a control group, the impact of the intervention implemented during the experimental phase on the dependent variable (s) is examined (Fraenkel et al., 2011).

The students in the experimental group participated in AR-supported mathematics activities for a total of 16 hours across 8 weeks, with sessions lasting 2 hours each week. All lesson plans developed for the experimental group adhered to the 5E instructional model, with AR technology integrated into STEM education over four weeks. These lesson plans were authored by the researcher using the CoSpace application. The curriculum outlined in the lesson plans addresses concepts such as length, area, perimeter measurement, and estimation within the domain of measurement education. Feedback on the lesson plans was received from experts in the field of mathematics. During the AR activities, students are presented with specific questions and scenarios upon interacting with designated objects. The scenarios evolve dynamically based on students' responses, facilitating interaction with the AR applications. This approach enables each group to progress independently, according to their interests and pace. A common misconception among students in the measurement domain is the belief that when using non-standard units, gaps may appear between units or units may be stacked on top of each other, leading students to think that unequal units can be used interchangeably. An illustrative scenario addressing this misconception is provided:

> *Students engage in the measuring market within the city where Bobo resides. To purchase an item in this market, click on the selected object. Upon clicking the object, a question is presented to the student. For instance, if a student wishes to add cheese to their shopping cart, they will receive the following prompt: 'There are statues approximately 1 meter tall located beside the milk and dairy products stand. Please estimate the height of the market door accordingly.' After this prompt, students are allocated 10 seconds to observe the task and formulate their estimate. Subsequently, the question "Which unit is the most appropriate to estimate the height of the market door?" is posed, with the expectation that students select the meter option, given that the reference length is provided in meters. Following this, students are asked to identify the unit of measurement they used for their estimate and to mark their result accordingly. To verify the students' estimates, two statues arranged vertically are displayed beside the door, enabling students to confirm that the door height is approximately 1.5 times the height of the statues.*

During the application process for the scenario, students were asked to make predictions. Subsequently, students verified their predictions and conducted comparative analyses. An illustrative example of this process is provided in Figure 2. As illustrated in the example scenario, interactive augmented reality (AR) content was not confined to passive visualizations; instead, it was specifically crafted as a decision-oriented learning environment whereby students actively engaged with the content. Each AR exercise was constructed around realistic and contextually detailed scenarios that incorporated assessment tasks, necessitating students to make predictions, test hypotheses, and receive immediate visual feedback. Their responses influenced the progression of the scenario, including whether additional clues were provided or if they advanced to subsequent stages. This branching logic fostered reflection on prior knowledge, error correction, and critical thinking processes.

Figure 2. Application Photo

During these sessions, the instructor functioned as a facilitator, observing the students and providing guidance on occasion while permitting them autonomy in their exploration. The researcher also conducted specific sessions to ensure uniform implementation of the study's procedures. Augmented Reality (AR) supported attitude development by gamifying the learning process and enhancing student engagement; participants reported feeling enthusiastic and entertained throughout the lessons. Furthermore, it directly addressed prevalent misconceptions documented in the literature, such as confusing areas with perimeter or applying inconsistent units in measurements. By visualizing these errors and promoting self-correction among students, the AR application contributed not only to attitude development but also to conceptual change.

A preliminary pilot study was conducted concerning the lesson plans before their implementation with a cohort of twenty-five students. Following this pilot study, it was determined that each group would be provided with a tablet, comprising three students each, for the augmented reality (AR) activities described in the lesson plans. During the pilot phase, several coding errors within the CoSpace application were identified and subsequently rectified. Before deploying the application within the experimental group, AR was introduced to the students, and instructions for its use were provided. In the experimental group, the eight-week instructional sessions were delivered by the author, who authored the code for the AR activities, while the classroom teacher functioned as an observer. The primary rationale for the researcher's active involvement was the classroom teacher's lack of familiarity with the application.

Study Group

Since the qualitative data supports the quantitative data of the study, there are two distinct study groups, one for the quantitative and one for the qualitative dimensions of the study.

Study Group for the Quantitative Dimension

Firstly, the research employed the criterion sampling method, a purposive sampling technique used for selecting the school. This methodology entails choosing a sample based on specific criteria (Fraenkel et al., 2011). The inclusion criteria for this study were schools equipped with advanced technological infrastructure and students who had access to tablets, facilitating remote learning. Subsequently, after identifying such schools in Ankara, a public school located in the Etimesgut district was selected. To ensure comparability between the experimental and control groups, various factors were considered, including students' mathematical grade averages, demographic characteristics, class size, and the technological, pedagogical, and content knowledge of teachers. Two classes were randomly selected to serve as the experimental and control groups, comprising 27 students in the experimental group (16 males and 11 females) and 29 students in the control group (17 males and 12 females). Group equivalence was assessed using an independent samples t-test, following a comprehensive review of the assumptions underlying the t-test. Normality was evaluated, revealing that skewness and kurtosis values were within ±1 and remained within ±1.96 standard errors. Additionally, the Kolmogorov-Smirnov and Shapiro-Wilk tests confirmed that the data demonstrated a normal distribution. The homogeneity of variances for the misconceptions test and attitude scale data was also examined, with $p=.21$ ($p>.05$) for the misconceptions test and $p=.83$ ($p>.05$) for the attitude scale, leading to the conclusion that variances were homogeneous in both cases.

Following the verification of assumptions, an independent samples t-test was performed to assess whether the groups were statistically comparable based on the outcomes of the Test of Misconceptions in the Measurement Learning Area and the Mathematics Attitude Scale. No significant difference was observed between the pre-test mean scores of the experimental and control groups in the Test of Misconceptions in the Measurement Learning Area ($t_{54}= .45$, $p> .05$) and the Mathematics Attitude Scale ($t_{54}= .23$, $p> .05$). Consequently, it was concluded that the experimental and control groups were equivalent in terms of misconceptions and attitudes towards mathematics.

Study Group for the Qualitative Dimension

Regarding the qualitative aspect of the research, ten students who actively engaged in augmented reality (AR) activities were selected from the experimental cohort. The prominent educator supervising the process was also included. The primary objective was to gain a comprehensive understanding of the students' perspectives on the impact of these activities on mathematics education, as well as the instructor's observations. The criteria for selecting students for interviews were active participation in AR activities and active engagement during lessons.

Data Collection Tools

In this study, three data collection instruments were employed. These included a semi-structured interview form, the Mathematics Attitude Scale, and a Test of Misconceptions in the Measurement Learning Area. Each instrument was utilized to gather comprehensive data on various aspects of students' learning and attitudes.

Semi-Structured Interview Form

Qualitative data supports the quantitative data gathered through interviews conducted with ten students and a teacher, using two separate interview forms that three experts evaluated. The experts, who were from the fields of Turkish and mathematics teaching, as well as primary education, evaluated the clarity, appropriateness of content, and overall quality of the questions. To increase clarity, two student interview questions were modified based on expert feedback. A pilot test confirmed the comprehensibility of the interview forms. While some of the interview questions for the students were "During the AR applications, did you realize that you had previously misunderstood information? What could AR applications have gained for you?", some of the teacher interview questions were "Do you think AR applications will be effective in eliminating students' misconceptions? Why?". The interviews were conducted in the classroom to provide a relaxed environment for the students. After the interviews, a researcher and another expert analyzed the data, and relevant themes were marked in a coding key for each question. Reliability was calculated using a formula developed by Miles and Huberman (1994), and a 100% agreement was found between the coders, surpassing the 80% threshold for reliability.

Mathematics Attitude Scale

In this study, the Mathematics Attitude Scale-Short Form, originally developed by Lim and Chapman (2013) and adapted for use in Turkey by Hacıömeroğlu (2017), was employed to assess students' attitudes toward mathematics. Turkish adaptation was conducted with 304 fourth-grade students, yielding a Cronbach Alpha reliability coefficient of .84 for the entire scale. Scale validity was established through a Kaiser-Meyer-Olkin [KMO] value of .906 and a significant chi-square value from the Barlett Sphericity Test. Exploratory factor analysis [EFA] revealed a three-factor structure with eigenvalues of 6.20, 3.33, and 1.33. The item-total correlation values ranged from 0.46 to 0.73. According to the results of the confirmatory factor analysis, the fit index values were found to be $\chi 2$=290.68, sd=11, GFI=.90 AGFI=.87 CFI=.94 NNFI=.93, NFI=.91 RMR=.014, SRMR=.0065 and RMSEA=. 007, and the ratio of the chi-square value to the degrees of freedom (χ^2=c^2) was found to be 2.5. These analyses confirmed the scale's validity and reliability in the Turkish context.

Test of Misconceptions in the Measurement Learning Area

Quantitative data were collected through administering the Test of Misconceptions in the Measurement Learning Area, which specifically targeted misconceptions associated with length, perimeter, and area measurements in the 4th-grade mathematics curriculum (Van de Walle et al., 2019/2024). The scale's validity was evaluated with guidance from twelve professionals, eight of whom are specialized in mathematics education and four in primary education. Content validity ratios (CVR) and content validity indices (CVI) were computed, and item 10 was eliminated as it fell short of the .56 threshold with a CVR of 0.5. To assess reliability, we used the Kappa Coefficient for the rubric utilized to score the test data, resulting in a Kappa value of .82, indicating a high level of agreement (Fleiss, 1971). After a pilot application, we analyzed the difficulty and discrimination of the items. As a result of the analyses, it was determined that the developed test contained six difficult items, 11 moderately complex items, and one easy item. After modifying items with a low discrimination index, item 19 was removed due to its inadequate discriminative power. We then analyzed the statistical data, which consisted of skewness and kurtosis values, and confirmed that the scores showed a normal distribution. The Cronbach Alpha coefficient, which determines the test's reliability, was found to be .71 across all 16 items (Büyüköztürk, 2019).

Results

Results of the Analysis of the Pre-test and Post-test Data from the Test of Misconceptions in the Measurement Learning Area

The data obtained from the pre-test and post-test, which aimed to identify misconceptions in the measurement learning domain among 4th-grade students in both the experimental and control groups, were analyzed using a two-factor ANOVA test for mixed designs. The results derived from this analysis are displayed in Tables 1 and 2. Initially, Table 1 presents the mean and standard deviation values of the pre-test and post-test scores for the experimental and control groups, as derived from the Test of Misconceptions in the Measurement Learning Area.

Table 1. Mean and Standard Deviation Values for the Test of Misconceptions in the Measurement Learning Area

		Experimental Group	**Control Group**
N		27	29
Arithmetic Mean	Pre-test	16.85	17.79
	Post-test	33.89	24.72
Standard Deviation	Pre-test	8.99	6.60
	Post-test	8.01	8.18

Note: The lowest score to be taken from the test is 0, and the highest score is 40

As shown in Table 1, the mean score of the students in the experimental group, as measured by the Test of Misconceptions in the Measurement Learning Area before engaging in mathematics activities involving AR, was 16.85. However, after the application, this value increased by 17.04 points to 33.89. In the control group, the pre-test mean score was 17.79. This value increased to 24.72 in the post-test, representing a 6.93-point rise. When the increase in the group mean is considered, it becomes apparent that the students in the experimental group, where the AR applications were implemented, experienced a greater increase in their scores on the Test of Misconceptions in the Measurement Learning Area compared to the students in the control group. In addition, when the arithmetic means of the groups in the post-test are compared, it can be concluded that, after the intervention, the students in the experimental group had fewer misconceptions than those in the control group.

The results of the two-factor ANOVA for a mixed design, conducted to ascertain whether a statistically significant difference exists between the pre-test and post-test mean scores of students in the experimental and control groups from the Test of Misconceptions in the Measurement Learning Area, are presented in Table 2. When Table 2 is examined, it is seen that there is a statistically significant difference between the pre-intervention and post-intervention stages in both the experimental group students exposed to an instructional process supported with AR applications and the control group students exposed to an instructional process conducted adhering to the curriculum in terms of the reduction of misconceptions in the measurement learning area [$F1.54 = 13.16$, $p < .05$]. When these findings are considered, it can be argued that the inclusion of AR activities in the teaching of the measurement learning area affects the elimination of students' misconceptions in this learning area. While the pre-test and post-test means for the students in the experimental group, who used AR activities, are 16.85 and

33.89, respectively, the pre-test and post-test means for the students in the control group are 17.79 and 24.72. Thus, better results were obtained in terms of eliminating misconceptions in the experimental group in which the AR application was conducted. For this reason, it can be concluded that the use of AR applications in teaching the objectives in the measurement learning area is more effective in eliminating students' misconceptions in this learning area.

Table 2. ANOVA Results of the Pre-test and Post-test Scores from the Test of Misconceptions in the Measurement Learning Area

Source of the Variance	Sum of Squares	*SD*	Mean Square	*F*	*P*	η^2
Between-Groups	3614.06	55				
Groups (Experimental/Control)	26.65	1	260.70	4.20	.04*	.07
Error	3353.41	54	62.10			
Within-Groups	7660.57	56				
Measurement (Pre-test/Post-test)	4016.15	1	4016.20	74.00	.00*	.58
Group*Measurement	714.01	1	714.00	13.16	.00*	.20
Error	2930.41	54	54.30			
Total	11274.63	111				

Note: *p< .05

The effect size of the mathematics activities containing AR on the elimination of misconceptions in the relevant learning area was calculated. The effect sizes of the studies are determined by the Eta-squared value, which ranges between 0 and 1. Studies with an effect size between .01 and .06 have a small effect size, studies with an effect size between .06 and .14 have a medium effect size, and studies with an effect size greater than .14 have a large effect size (Cohen, 1988). When the effect size values of the current study were examined, they were calculated as 0.72 for between-groups measurements, 0.58 for between-measurements, and 0.19 for the Group*Measurement joint effect. Since the effect size values of the study are greater than .14, it can be concluded that the study has a large effect size. Thus, it can be said that the AR applications tested within the scope of the current study have a sufficiently large effect on eliminating misconceptions in the measurement learning area.

Results of the Analysis of the Pre-test and Post-test Data from the Mathematics Attitude Scale

To determine the attitudes of 4th-grade students in the experimental and control groups towards mathematics lessons, the pre-test and post-test data obtained from the scale were analyzed using a two-factor ANOVA test for mixed designs. The findings obtained from the analysis are presented in Tables 3 and 4. First, the mean and standard deviation values of the pre-test and post-test scores obtained from the Mathematics Attitude Scale by the experimental and control group students are shown in Table 3. As shown in Table 3, the pre-test mean score for students in the experimental group is 71.41, whereas the pre-test mean score for the control group is 70.79. Following the completion of the eight-week intervention, the mean score of students in the experimental group rose by 7.03 points to 78.44, whereas the mean score of students in the control group increased by 0.93 points to 71.72.

Table 3. Mean and Standard Deviation Values for the Mathematics Attitude Scale Second Level Headings

		Experimental Group	Control Group
N		27	29
Arithmetic Mean	Pre-test	71.41	70.79
	Post-test	78.44	71.72
Standard Deviation	Pre-test	9.75	10.06
	Post-test	4.40	6.84

Note: The lowest score to be taken from the scale is 0 and the highest score is 85

The outcomes of the two-factor ANOVA for a mixed design, designed to ascertain whether a statistically significant difference exists between the pre-test and post-test mean scores of students in the experimental and control groups, as measured by the Mathematics Attitude Scale, are presented in Table 4.

Table 4. ANOVA Results for Pre-test and Post-test Scores on the Mathematics Attitude Scale

Source of the Variance	Sum of Squares	*SD*	Mean Square	*F*	*P*	η^2
Between-Groups	4172.42	55				
Groups (Experimental/Control)	376.10	1	376.10	5.35	.03*	.09
Error	3796.32	54	70.30			
Within-Groups	4057.92	56				
Measurement (Pre-test/ Post-test)	443.86	1	443.86	7.15	.01*	.12
Group*Measurement	260.65	1	260.65	4.20	.04*	.07
Error	3353.41	54	62.10			
Total	8230.34	111				

Note: *p< .05

An analysis of Table 4 reveals that there exists a statistically significant difference between the pre-intervention and post-intervention phases among both the experimental group students, who experienced an instructional process augmented with Augmented Reality (AR) applications, and the control group students, who underwent instruction by the established curriculum, about their attitudes towards mathematics [$F_{1.54}=4.20$, $p< .05$]. These findings suggest that integrating AR applications into the mathematics learning domain influences students' attitudes towards mathematics. Regarding the pre-test and post-test mean scores derived from the Mathematics Attitude Scale, it can be observed that students in the experimental group demonstrated greater gains compared to their counterparts in the control group. Consequently, it can be concluded that AR applications exerted a beneficial influence on the students within the experimental cohort.

Finally, the effect size of the AR activities on students' attitudes towards mathematics was calculated. When examining the effect size values from the current study, the following results were obtained: 0.09 for between-groups measurements, 0.12 for within-measurements, and 0.07 for the Group*Measurement joint effect. Since the effect size values fall between .06 and .14, it can be said that the current study demonstrates a medium effect size. In other words, using AR applications in mathematics lessons has a moderate impact on students' development of a positive attitude towards mathematics.

Analysis of the Findings Obtained through the Interview

The data obtained from interviews with ten students in the experimental group were analyzed and interpreted using the content analysis method. The data derived from the interviews were categorized into themes, categories, and codes. The opinions of the students in the experimental group regarding the mathematics lesson plans enhanced by AR applications are presented in Figure 3.

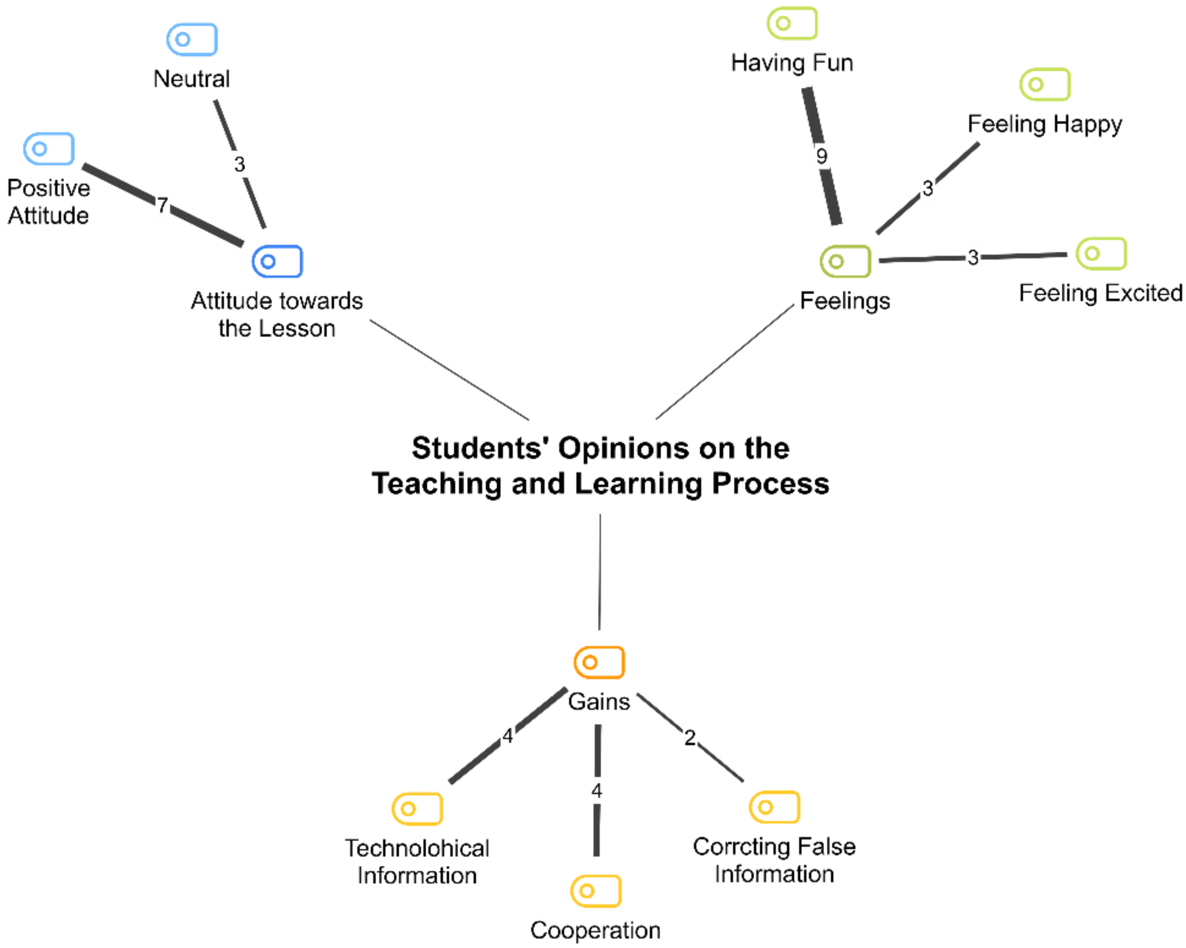

Figure 3. Experimental Group Students' Opinions about Teaching and Learning Process

Figure 3 presents the views of the students in the experimental group about the AR-supported lesson teaching process. The students' opinions are divided into three main categories: attitudes, emotions, and outcomes. Most of the students stated that they were not bored and found the lessons more fun in mathematics lessons supported with interactive AR applications. They also stated that the AR applications help students to both improve their technological knowledge and correct some of their misconceptions, and that collaboration was supported. The opinions in the visual reveal that students see this process as a more positive and engaging learning experience. Students' views on each category are presented in Table 5.

Table 5. Students' Opinions on the Application

Category	Code	Quote
Attitude towards the Lesson	Positive Attitude	*"Mathematics is a lesson that everyone is afraid of. I was not afraid before, but I thought some subjects were very boring. Every lesson is enjoyable with activities like these. I used to find mathematics a bit boring, but not anymore* (S10)*"*
	Neutral	*"I used to love mathematics, and I still love it. Nothing has changed* (S4)*"*
Feelings	Having Fun	*"I felt like I had fun, I was never bored in class, I didn't even realize how the lesson was going. Every week we played new games on the tablets. I liked Bobo very much. He was very big, almost as big as me. I played the games at home too. Our teacher was very enjoyable* (S6)*"*
	Feeling Happy	*"I felt really good; I felt happy because doing things with tablets was so nice. They used to tell us not to play with tablets, but you prepared games for us on the tablets. I learned something and had fun at the same time. That's why it was really great* (S9)*"*
	Feeling Excited	*"I was never bored in class; I didn't even realize how the lesson was passing. We were very excited for the days to come. We were playing new games on the tablets every week. I liked Bobo very much. He was very big, almost as big as me. I played the games at home too. Our teacher was very enjoyable* (S6)*"*
Gains	Technological Information	*"I always use the tablet at home, but the game we use at our school is quite different. When you press the bottom right, Bobo comes to us. Actually, it becomes difficult to control the tablet when it comes near. I had a hard time in the first weeks, but then I got used to it* (S1)*"*.
	Cooperation	*"Every time you came, we worked with the same group of friends. I used to not be very good at group work before. But in the activities, I worked with all my group mates* (S8)*"*
	Correcting False Information	*"I used to think that we could calculate the perimeter of any shape if we knew its area, but we cannot. I understood why when we were designing the city* (S5)*"*.

At the end of the interview with the students, an interview was conducted with the teacher who was present in the classroom and had observed the process for 8 weeks. The teacher was asked to evaluate the process, and questions were asked about the effects of the AR applications on students' misconceptions and attitudes. The opinions of the teacher about the process are as follows: *"I believe the 8-week process was very effective. Doing activities on the tablet was especially beneficial. I wish there were always such applications; they are needed for all subjects. I think the applications are beneficial."* In the second question, the teacher's views on the effect of applications on misconceptions were asked. The teacher gave the following answer to this question: *"When the first test was done, I thought that there were no misconceptions in children. Yes, there were misconceptions. I think that the applications had a positive effect on misconceptions."* Finally, the teacher's opinions on the effect of AR applications on student attitudes were gathered. The teacher expressed the following opinions: *"This generation spends more time with computers. The use of tablets in the classrooms increased their interest in the lesson. That is why I think it affected their attitudes towards the lesson positively."*

Discussion

Within the context of the current study, the effects of interactive AR activities on primary school 4th-grade students' misconceptions in the measurement learning area and their attitudes towards mathematics were examined. The discussion on misconceptions and attitude variables is presented under two separate headings.

Misconceptions

The findings of this study demonstrate that interactive augmented reality (AR) applications significantly mitigated misconceptions among fourth-grade students within the domain of measurement education. This outcome aligns with prior research in the field of science education, such as Shelton and Hedley (2002), who identified that AR could rectify misconceptions regarding Earth-Sun relationships, and Gün and Atasoy (2017), who documented enhancements in spatial abilities via AR-supported measurement activities. These results reinforce the premise that the visual and interactive characteristics of AR facilitate the clarification of abstract or misunderstood concepts.

Nevertheless, the current investigation distinguishes itself from previous studies by focusing on domain-specific mathematical misconceptions within primary education, with particular emphasis on the area of measurement, a subject known for persistent misunderstandings. Compared to Koklu and Topcu (2012), who reported no significant influence of technology-based applications on misconceptions in secondary mathematics, this study observed a statistically significant improvement. This discrepancy may be attributed to the increased interactivity and feedback mechanisms incorporated into the augmented reality (AR) activities utilized in this research. Students were not merely passive observers or manipulators of visuals; instead, they engaged in making predictions, receiving immediate feedback, and participating in branching scenarios, thereby rendering the learning process more reflective and individualized. Moreover, AR applications should be user-friendly to facilitate the comprehension of mathematical concepts (Pahmi et al., 2023). The simplicity of the AR application employed in this study may have contributed to the statistically significant reduction in misconceptions.

In conclusion, while previous studies often highlight overall conceptual understanding, this study provides specific evidence of misconception reduction in areas such as length, area, and perimeter. This adds detail to the existing literature and shows that AR can be used not only to visualize but also to reorganize students' prior knowledge. By designing AR tasks around common misconceptions and embedding them into real-life scenarios, the study presents a new instructional approach for using AR as a targeted conceptual tool.

Attitude

In terms of affective outcomes, the study revealed that students who participated in AR-based math lessons developed more positive attitudes toward mathematics. This finding supports earlier research, such as Özdemir and Özçakır (2019) and Cai et al. (2019), which have shown that AR applications can increase students' interest, enjoyment, and attitudes toward mathematics. However, unlike these studies, which primarily focus on specific topics like fractions, probability, or general science in literature, the current study makes a novel contribution by examining this effect specifically in the measurement domain. This topic is relatively underrepresented in AR attitude research. This distinction shows that the effectiveness of AR in promoting positive attitudes may extend to more abstract and conceptually challenging areas of mathematics, such as measurement.

Moreover, while earlier research has relied solely on quantitative methods (e.g., attitude scales) to assess affective outcomes, this study combines both quantitative and qualitative data for a more comprehensive perspective. Students in this study reported feeling more entertained and less bored during lessons, which aligns with findings from qualitative AR studies like Durak and Karaoğlan-Yılmaz (2019). However, unlike studies that only collected post-activity impressions, this research triangulated scale data with student interviews, enabling a deeper understanding of how emotional engagement and conceptual clarity developed together. As a result, it offers a more robust view of AR's influence on student attitudes compared to studies using only surveys (Canbaz & Yalçın, 2024; Özdemir & Özçakır, 2019).

In conclusion, while this study aligns with previous research recognizing augmented reality (AR) as a motivational tool, it contributes to the academic discussion by demonstrating that positive attitude changes are linked to cognitive improvements when AR is used through interactive, concept-focused designs. This dual effect sets the current study apart from many earlier ones that tend to focus only on either cognitive or emotional outcomes. By demonstrating that AR can simultaneously correct misconceptions and improve attitudes, especially in a less-studied area like measurement, the research offers both validation and new insights within the existing scholarly community. It strengthens the case for using augmented reality not just to capture attention but to meaningfully enhance educational experiences.

Conclusion

This study demonstrated that the incorporation of interactive augmented reality (AR) applications into fourth-grade mathematics instruction at the primary school level notably diminished students' misconceptions in the domain of measurement and positively affected their attitudes towards the subject of mathematics. The results indicated that AR applications serve not merely as engaging tools but also as supportive aids in identifying and rectifying deeply rooted conceptual errors. Notably, the observed enhancement in students' comprehension of measurement concepts implies that AR has the potential to foster meaningful cognitive development within early mathematics education.

More importantly, this study contributes novel and original insights to existing literature in several significant ways. Firstly, it explicitly addresses and examines specific conceptual misconceptions within the domain of mathematics, an area that remains relatively underexplored, particularly at the primary school level. While most prior augmented reality (AR) studies tend to concentrate broadly on academic achievement or motivation, this research fills an essential gap by demonstrating how AR can serve as a targeted intervention tool for rectifying misconceptions in fundamental topics such as length, area, and perimeter. This specialized approach differentiates the study from preceding research and provides a more precise framework for developing AR-based interventions with a focus on conceptual accuracy.

Secondly, the study offers a dual perspective by concurrently examining both cognitive outcomes (reduction of misconceptions) and affective outcomes (enhancement of attitudes). This approach provides a more comprehensive understanding of the impact of Augmented Reality (AR) on learning. Whereas numerous prior studies address motivation and learning outcomes independently, this research demonstrates that improvements in attitude and conceptual understanding can simultaneously occur when AR is employed within well-structured and interactive scenarios.

Thirdly, the study presents a reproducible instructional framework that integrates augmented reality (ar)-supported, scenario-based learning with collaborative small-group activities and teacher guidance. The interactive scenarios enable students to make predictions, obtain immediate feedback, and participate in inquiry-led learning. This methodology is founded on constructivist principles and may serve as a model for educators and researchers aiming to employ AR not merely as an innovative novelty but as a means for structured pedagogical transformation.

In summary, this study contributes to the literature by demonstrating that augmented reality (AR) applications, when purposefully designed with pedagogical objectives, can effectively correct persistent misconceptions while simultaneously fostering improved student attitudes. Furthermore, it expands the understanding of AR's influence within mathematics education by highlighting its potential to support conceptual development at the primary level. These findings advocate for the ongoing integration of AR into classroom environments and invite future research to investigate its long-term impacts and scalability across various mathematical domains.

Recommendations

Additional research in the literature corroborates the findings of this study, and several recommendations are proposed for future research endeavors in light of these findings.

- This research investigated the impact of augmented reality (AR) technology on misconceptions within the measurement educational domain and concluded that such activities positively contribute to rectifying misconceptions. The study encompassed topics related to length, perimeter, and area measurement within this domain. Future research could explore the influence on additional subtopics, such as volume, within the measurement learning area.
- Upon examination of the qualitative data in the study, it can be concluded that augmented reality (AR) applications enhance students' technological knowledge and collaborative learning capabilities. Future

research may investigate the impact of these applications on digital literacy skills and collaborative learning skills, which are essential components of 21st-century competencies.

- The classroom teacher stated in the interviews that the new generation of students spends a considerable amount of time on the computer; therefore, their attitudes towards mathematics are positively influenced by the use of tablets in the classroom. Consequently, a similar study may be replicated with students who do not spend significant time on the computer or who lack advanced technological knowledge, in order to examine how the applications impact students' attitudes towards mathematics.
- At the primary school level, infrastructure should be established for AR technology, and interactive AR applications should be used to eliminate students' misconceptions.

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