Teaching Scientists' Lives via Mobile Augmented Reality and Technology Awarenes

Cemre Kaplan [1], Pelin Yıldırım [2], Gonca Keçeci [3]

[1]kebircemre1@gmail.com, ORCID: 0009-0002-2228-2582, Ministry of National Education, Diyarbakır, Türkiye

[2]yildirim.pelin92@gmail.com, ORCID: 0000-0003-4425-2472, Faculty of Educational Sciences, Fırat University, Elazığ, Türkiye

[3]gkececi@firat.edu.tr, ORCID: 0000-0002-2582-3850, Faculty of Educational Sciences, Fırat University, Elazığ, Türkiye

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ABSTRACT

Mobile Augmented Reality (MAR) technologies offer new pedagogical opportunities by enriching learning environments through interactive and experience-based structures. This study examined the effect of teaching the lives of scientists belonging to the Islamic scientific tradition through the MAR application named TISAR-3D on 6th-grade students' awareness levels regarding the use of technology in lessons. The research was conducted within the scope of a quasi-experimental design with pre-test and post-test control groups. The study group consisted of 40 students (experimental = 20, control = 20) studying at a public secondary school in Turkey. During the eight-week implementation process, the content was presented interactively to the experimental group through the MAR-based TISAR-3D application, whereas the same content was taught to the control group through text-based instructional materials. The data were collected through the Awareness Scale for the Use of Technology in Lessons and analyzed using independent samples and paired samples t-tests. The findings revealed that there were no significant differences between the groups at both pre-test and post-test levels, and no within-group change over time was observed in either group. In this respect, it is suggested that MAR applications should be redesigned not only for content presentation but also based on task-based learning and pedagogical integration, and their effects should be evaluated through longer-term and multidimensional assessment approaches.

Keywords: Mobile augmented reality, Islamic scientists, technology awareness, secondary school students

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INTRODUCTION[1]

In the rapidly evolving digital age, educational processes have shifted from traditional approaches based mainly on knowledge transmission toward technology-supported learning environments that emphasize interaction, experience, and active knowledge construction (Bond et al., 2020; Mayer, 2009). Digital technologies provide new opportunities for students to access, interpret, and construct knowledge through multiple representations and interactive experiences. Among these technologies, Augmented

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Reality (AR) and Mobile Augmented Reality (MAR) have gained increasing attention in education by integrating digital information with real-world environments and enabling students to interact with three-dimensional (3D) and dynamic learning content (Akcayir & Akcayir, 2017; Radianti et al., 2020).

MAR technologies combine the accessibility of mobile devices with the interactive characteristics of AR and support student-centered learning environments. Through 3D models, animations, audio-supported explanations, and interactive digital objects, MAR applications enable students to actively engage with learning materials rather than passively receive information (Mayer, 2009; Moreno & Mayer, 2007). These characteristics are consistent with constructivist learning approaches, which emphasize that learners construct knowledge through interaction, exploration, and interpretation of experiences (Dunleavy & Dede, 2014; Wu et al., 2013). Furthermore, Mayer's Cognitive Theory of Multimedia Learning suggests that the integration of verbal and visual representations supports meaningful learning by facilitating cognitive processing and knowledge organization (Mayer, 2009, 2024).

One important educational context in which MAR technologies may provide meaningful contributions is the teaching of the history of science and scientists' lives. Understanding the historical development of scientific knowledge enables students to recognize science as a dynamic process shaped by human efforts, cultural contexts, and historical conditions rather than as a fixed collection of facts (Allchin, 2011; Lederman & Lederman, 2019; McComas, 2020). However, traditional approaches to teaching scientists' lives generally rely on text-based narratives and factual information, which may limit students' ability to visualize historical contexts and understand scientific developments as complex human processes (Henke & Höttecke, 2015; Matthews, 2014).

MAR technologies offer new possibilities for addressing these limitations by transforming historical scientific content into interactive and visual learning experiences. Presenting scientists' lives, discoveries, and scientific environments through 3D models and digital narratives may enable students to engage with historical scientific knowledge more concretely and meaningfully (Garzón et al., 2019; Ibáñez & Delgado-Kloos, 2018; Radianti et al., 2020).

Teaching the scientific contributions of scholars from the Islamic scientific tradition provides a valuable context for examining the relationship between science, technology, and knowledge production. The history of science demonstrates that scientific developments emerge through interactions among scientific inquiry, technological practices, and cultural contexts (Allchin, 2011; Erduran & Dagher, 2014; McComas, 2020). Examining the scientific activities, instruments, and problem-solving approaches of historical scholars may help students understand that technology is not only a product of scientific advancement but also a means that supports observation, experimentation, and knowledge construction (Matthews, 2014). Therefore, when scientists' contributions are presented through MAR environments, students may experience technology as a pedagogical medium that facilitates exploration and understanding of scientific knowledge rather than merely as a digital tool.

Such technology-supported experiences may contribute to students' awareness of technology use in educational contexts. Technology awareness involves not only the ability to use technological tools but also recognizing their instructional purposes, pedagogical functions, and contributions to learning processes (Fraillon et al., 2019; Tondeur et al., 2020). Through meaningful interaction with MAR-based learning environments, students may develop an understanding of technology as a component of scientific inquiry, knowledge construction, and learning rather than only as a device for communication or entertainment.

Although previous studies have demonstrated the potential of AR/MAR applications in improving academic achievement, motivation, attitudes, and learning outcomes (Akcayir & Akcayir, 2017; Garzón et al., 2019; Talan et al., 2022), research examining the integration of MAR technologies with history of science content remains limited. Moreover, studies investigating whether MAR-based experiences contribute to students' awareness of technology as an educational tool are scarce. This limitation highlights the need to examine how MAR-supported history of science instruction may influence students' perceptions regarding the educational role of technology.

Accordingly, this study aims to examine the effect of teaching the lives of scientists from the Islamic

scientific tradition through the MAR application TISAR-3D on sixth-grade students' awareness of technology use in lessons. By integrating history of science education with MAR technology, this study seeks to contribute to the literature by revealing how technology-supported historical content instruction may influence students' perceptions of technology's educational role.

THEORETICAL FRAMEWORK

Mobile Augmented Reality Technologies in Education

AR is an emerging technology that combines real-world environments with digitally generated information, enabling users to interact with virtual objects through real-time and 3D experiences (Azuma, 1997; Czok et al., 2023). When AR technologies are accessed through mobile devices such as smartphones and tablets, they are defined as MAR technologies (Ardiansyah, 2024; Shkilev et al., 2024). Due to their accessibility, portability, and interactive characteristics, MAR applications have become increasingly significant in educational contexts by providing opportunities for students to engage with learning content beyond traditional classroom boundaries.

The educational value of MAR technologies is primarily associated with their ability to present information through multiple representations, including 3D models, animations, simulations, and interactive digital objects. These features enable students to visualize abstract concepts, explore complex phenomena, and actively participate in learning processes (Akcayir & Akcayir, 2017; Garzón & Acevedo, 2019). Unlike traditional instructional approaches in which learners often receive information passively, MAR environments encourage exploration and interaction, supporting the construction of knowledge through meaningful experiences.

The theoretical foundations of MAR-based learning environments are closely related to constructivist learning approaches, which emphasize that learners actively construct knowledge through interaction with their environment and the interpretation of experiences (Dunleavy & Dede, 2014; Wu et al., 2013). In MAR environments, students interact with digital representations embedded within real-world contexts, allowing them to examine, manipulate, and interpret learning materials. This process supports active engagement and enables learners to develop more meaningful conceptual understandings.

Furthermore, Mayer's Cognitive Theory of Multimedia Learning provides an important theoretical explanation for the effectiveness of MAR applications. According to this theory, learning is enhanced when information is presented through coordinated verbal and visual representations because learners can organize and integrate information more effectively within their cognitive systems (Mayer, 2009, 2024). In this respect, MAR applications may support learning by combining visual, auditory, and interactive elements that facilitate cognitive processing and promote deeper understanding.

Despite these pedagogical opportunities, the effectiveness of MAR technologies depends not only on their technological features but also on the quality of their instructional design and pedagogical integration. Previous research indicates that inappropriate design, insufficient guidance, and limited teacher competence may reduce the educational effectiveness of AR/MAR applications (Akcayir & Akcayir, 2017; Ibáñez & Delgado-Kloos, 2018). Therefore, successful implementation requires designing learning experiences in which technology serves clear instructional purposes rather than functioning merely as an attractive technological addition.

Technology Awareness in Technology-Supported Learning Environments

The rapid integration of digital technologies into educational environments has changed expectations regarding students' technological competencies. Contemporary education systems aim not only to develop students' technical skills but also to support their ability to understand the purposes, functions, and educational implications of technology use (Organisation for Economic Co-operation and Development [OECD], 2021; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2023). In this context, technology awareness represents an important dimension of digital competence because it involves recognizing how technologies can support learning, knowledge construction, and problem-solving

processes.

Technology awareness extends beyond the ability to operate technological devices. It includes students' understanding of why and how technologies are used in educational contexts and their ability to evaluate the contribution of technology to learning processes (Fraillon et al., 2019; Hatlevik et al., 2015). Therefore, students who possess technology awareness are expected to perceive digital tools not merely as entertainment or communication devices but as meaningful resources that support inquiry, creativity, and learning.

The development of technology awareness is closely associated with students' experiences in technology-supported learning environments. Previous research suggests that direct and meaningful interaction with educational technologies can shape students' perceptions, attitudes, and beliefs regarding the value of technology in learning (Scherer et al., 2019; Teo, 2019; Tondeur et al., 2020). In this regard, technology integration practices that provide students with opportunities to actively experience technology may contribute more effectively to technology awareness than approaches based solely on teaching technical skills.

From this perspective, MAR environments may serve as meaningful contexts for developing technology awareness because they position technology as an integral component of the learning process. When students use MAR applications to explore scientific concepts, examine historical information, and construct knowledge, they experience technology as a pedagogical medium rather than merely as a digital tool. Therefore, MAR-supported learning experiences may contribute to students' understanding of the educational value and instructional functions of technology.

Based on these theoretical assumptions, the present study considers MAR-based instruction as a learning experience that may influence students' awareness regarding technology use in lessons. By integrating the history of science with an interactive MAR environment, the study investigates whether meaningful engagement with technology-supported historical content can contribute to students' perceptions of technology as a valuable component of learning processes.

RESEARCH METHOD

Research Model

In this study, a quasi-experimental design with pre-test and post-test control groups was adopted to evaluate the effect of the intervention aimed at increasing students' awareness of using technology in lessons. The reason for preferring this design is that it provides the opportunity to measure the effects of the intervention reliably by controlling the baseline level (Creswell, 2012; Fraenkel et al., 2019). Since full random assignment and complete control are not always applicable in educational settings, quasi-experimental designs are frequently used, particularly in classroom-based research (Campbell & Stanley, 1963). While the pre-test application helps control baseline differences between groups, the presence of a control group enables the effects of the intervention to be evaluated independently of other external variables (Shadish et al., 2002). This approach allows the measurement of the effect within the framework of experimental logic while preserving the realism of the classroom context (Creswell, 2012). Therefore, this quasi-experimental design was preferred in the study both to quantitatively evaluate the effect of the intervention and to collect valid and reliable data within the limitations of the educational environment.

Participants

This research was conducted with 6th-grade students studying at a public secondary school located in Diyarbakır, Turkey, during the 2023–2024 academic year. The study group consisted of a total of 40 students. In accordance with the research design, the participants were divided into experimental (N = 20) and control (N = 20) groups. Both groups included 11 female and 9 male students.

Purposeful sampling was adopted in the study. This method allows the selection of participants who are directly related to the research problem, who can experience the content of the study, and who can

provide in-depth data regarding the relevant phenomenon (Creswell & Plano Clark, 2011; Patton, 2002). In interventions conducted with a limited number of participants in educational settings, purposeful sampling is considered a reliable method for both evaluating the effects of the implementation in depth and increasing data quality (Etikan et al., 2016; Palinkas et al., 2015).

The research process was conducted in line with the approval of the relevant university Ethics Committee and the permissions obtained from the Ministry of National Education (MoNE). Voluntary participation of the participants was ensured, and informed consent was obtained from the parents of all students. The purpose of the research was explained in detail to both the students and their parents, and the participants were informed that they could withdraw from the study at any stage they wished. All collected data were anonymized, and participant confidentiality was ensured through a special coding system. These practices ensured the compliance of the research with ethical standards and the reliability of the data.

Research Process

This research was conducted over a period of eight weeks during the 2023–2024 academic year within the scope of the elective Science Applications course. The measurements conducted at the beginning and end of the study were carried out through pre-test and post-test applications and integrated into the process. In the formation of the experimental and control groups, students' year-end achievement scores were taken into consideration, and the groups were structured to have a heterogeneous composition. In order to determine students' awareness levels regarding the use of technology in lessons, the "Awareness Scale for the Use of Technology in Lessons" was administered as both a pre-test and a post-test.

During the implementation process, the lives, scientific studies, and inventions of scientists belonging to the Islamic scientific tradition were presented to the students in the experimental group through the MAR-based TISAR-3D application. Through AR technology, TISAR-3D provides an interactive learning experience by integrating the real-world environment with digital content. Within the scope of the application, students accessed content related to five scientists (Al-Jazari, Ibn al-Haytham, Abd al-Rahman al-Khazini, Abu Bakr al-Razi, and Ibn al-Nafis); the lives, scientific studies, and inventions of these scientists were presented in detail through 3D visuals, texts, and audio narrations. By scanning the visuals included in the worksheets with their mobile devices, students examined 3D models related to the relevant scientist, observed the functioning of the inventions, and had the opportunity to interact directly with the content. In the control group, the same content was presented only through reading texts. Students in the experimental group were asked to use tablets or smartphones throughout the process, and active participation in lessons was supported by installing the TISAR-3D application on the devices. In addition, worksheets appropriate to the application content were prepared to strengthen students' interaction with the application, and both in-class and out-of-class learning processes were supported.

The research process was structured each week in line with specific objectives. In the first week, groups of four students were formed, the TISAR-3D application was introduced to the experimental group, and worksheets designed to increase interaction were distributed. Both groups were informed about the research process, and the pre-test was administered. Beginning from the second week, the experimental group learned about the life and inventions of Al-Jazari through 3D visuals and interactive content, while the control group examined the same content through reading texts. In the third week, students were asked to explain and discuss the information learned through the application or text-based materials, and the experiments of Ibn al-Haytham were addressed.

In the fourth week, the scientific studies of Abd al-Rahman al-Khazini were presented to the experimental group through MAR, and in the fifth week, interactive learning was conducted regarding Abu Bakr al-Razi's contributions to the field of chemistry and the distillation apparatus. In the sixth week, Ibn al-Nafis's discovery related to pulmonary circulation was presented to the students. While the experimental group actively participated through the application, the control group continued to study the same content through text-based materials.

The seventh week was devoted to reinforcing the knowledge learned in both groups. In the experimental group, students re-examined and explained the inventions through the application, whereas reinforcement in the control group was provided through reading and question-answer activities. In the eighth week, the post-test was administered, and the research process was completed. Sample visuals related to the implementations are presented in Figure 1 and Figure 2.

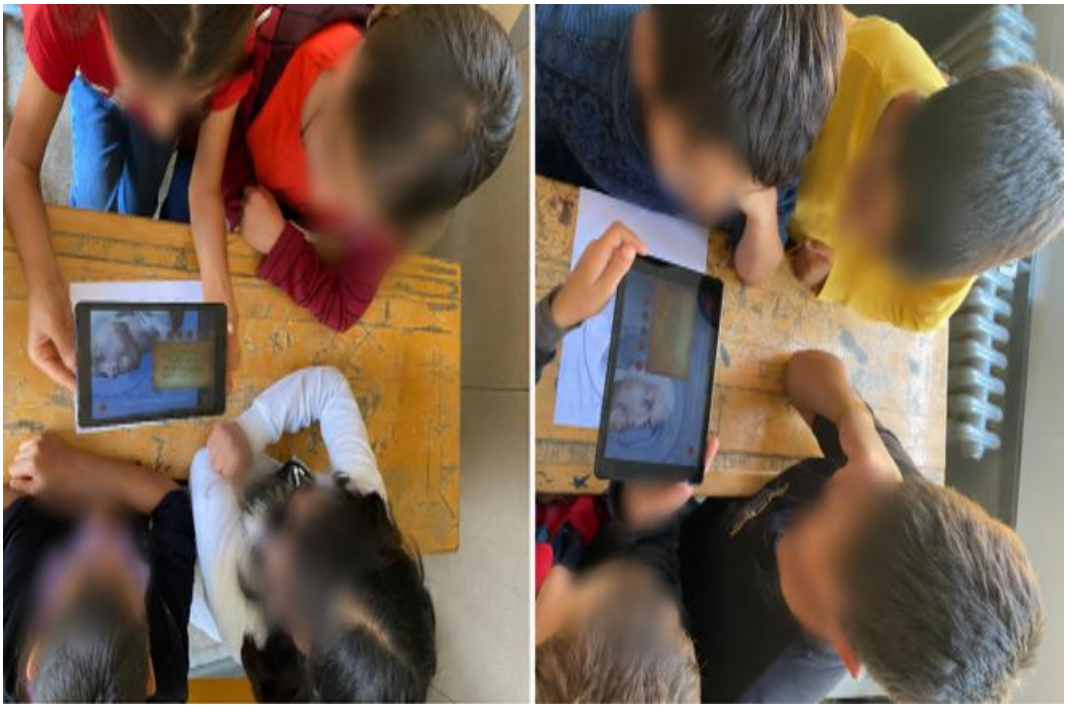

Figure 1. *Photographs of the Experimental Group during the Research Process*

Figure 2. *Photographs of the Control Group during the Research Process*

Data Collection Tool

In this study, the Awareness Scale for the Use of Technology in Lessons (ASUTL) was used as the data collection instrument. The scale was developed by Dagtekin (2016) to determine students' awareness levels regarding the use of technology in lessons. During the scale development process, a pool of 40 items

created through a review of the literature was utilized, and as a result of the analyses, the scale took its final form consisting of 22 items and two factors. The scale is a five-point Likert-type instrument, and the response options are “strongly agree”, “agree”, “undecided”, “disagree”, and “strongly disagree”.

In order to determine the construct validity of the scale, Exploratory Factor Analysis (EFA) was first conducted, and sample adequacy was confirmed through the Kaiser-Meyer-Olkin test (KMO = .87) and Bartlett’s Test of Sphericity (χ^2 = 4269.620, $p < .001$). As a result of the EFA, one item with a factor loading below .40 was removed from the scale, and a two-factor structure was obtained based on the remaining 22 items. These factors were named “benefits of technology” (16 items) and “harms of technology” (6 items), respectively.

The reliability of the scale was evaluated using Cronbach’s Alpha internal consistency coefficient; the reliability coefficients were found to be α = .85 for the entire scale, α = .86 for the first factor, and α = .81 for the second factor. These findings indicate that the scale has an adequate level of internal consistency reliability (Dagtekin, 2016).

Structural validity was tested through Confirmatory Factor Analysis (CFA). As a result of the CFA, the fit of the theoretical two-factor model to the data was evaluated through various goodness-of-fit indices; RMSEA = 0.073, NFI = 0.89, NNFI = 0.93, CFI = 0.93, IFI = 0.93, GFI = 0.86, and AGFI = 0.93. In the literature, these values indicate that the two-factor structure of the scale sufficiently explains the data and that its structural validity is supported (Byrne, 2001; Hu & Bentler, 1999).

Data Analysis

SPSS 22 software was used for the analysis of the quantitative data obtained in the study. Prior to the analyses, the data set was screened for missing or erroneous values, and all variables were coded appropriately for statistical analysis.

The data analysis process consisted of descriptive and inferential statistics. Descriptive statistics, including mean, standard deviation, minimum, and maximum values, were calculated to describe the general characteristics of the data set.

Before conducting inferential analyses, the assumptions required for parametric tests were examined. Normality was assessed through skewness and kurtosis coefficients, visual inspections (histograms and normal Q-Q plots), and the Shapiro–Wilk test due to the small sample size ($N < 50$) (Field, 2013; Razali & Wah, 2011; Royston, 1992; Tabachnick & Fidell, 2007). The findings indicated that the data were approximately normally distributed ($p > .05$) (Field, 2013; Ghasemi & Zahediasl, 2012; Pallant, 2020). Homogeneity of variances was examined using Levene’s test, and the results supported the assumption of equal variances ($p > .05$).

Independent samples t-tests were employed to compare the experimental and control groups in terms of pre-test and post-test scores, whereas paired samples t-tests were conducted to examine within-group changes over time. In addition to significance testing, effect sizes (Cohen’s d and Cohen’s dz) and 95% confidence intervals for mean differences were reported to provide a more comprehensive interpretation of the findings. Statistical significance was accepted at the .05 level for all analyses.

FINDINGS

In this section, the data obtained through the Awareness Scale for the Use of Technology in Lessons (ASUTL) are presented under two main headings: (i) Descriptive statistical findings and (ii) inferential statistical findings.

Descriptive Statistical Findings

In this subsection, the descriptive statistical findings related to the ASUTL pre-test (ASUTL_PRE) and post-test (ASUTL_POST) scores administered to the experimental and control groups are presented.

Within this scope, the arithmetic mean, standard deviation, minimum and maximum values, and distribution characteristics of the scores obtained by the 6th-grade students from the relevant scale were examined. In addition, before proceeding to inferential statistical analyses, normality analyses were conducted to determine whether the data set met the assumption of normality. The descriptive statistics and normality test findings related to the ASUTL_PRE and ASUTL_POST scores of the experimental and control groups are presented in Table 1.

Table 1. *Descriptive Statistics and Normality Test Findings Related to ASUTL_PRE and ASUTL_POST Scores*

Tests	Groups	N	Mean	SD	Skewness	Kurtosis	Range	Min	Max	Shapiro-Wilk
ASUTL_PRE	Experimental group	20	72.25	9.43	.915	.293	35	60	95	.089
	Control group	20	76.45	12.77	.475	-.353	46	55	101	.456
ASUTL_POST	Experimental group	20	73.60	7.03	-.399	-.213	27	59	86	.592
	Control group	20	73.60	12.02	-.399	-.150	46	48	94	.861

Table 1 shows that, when ASUTL_PRE scores are examined, the mean score of the control group (Mean = 76.45) is higher than that of the experimental group (Mean = 72.25); however, this difference is at a low level, and it is understood that the initial performance of both groups demonstrates a similar distribution. When ASUTL_POST scores are examined, it is observed that the mean score of the experimental group (Mean = 73.60) shows a limited increase compared to the pre-test level, whereas the post-test mean score of the control group (Mean = 73.60) remains largely similar to its pre-test level and does not indicate a noticeable change.

In terms of distribution characteristics, it was determined that the skewness and kurtosis coefficients of the pre-test and post-test scores of both groups fall within the acceptable limits reported in the literature. When the Shapiro–Wilk test findings regarding the assumption of normality are examined, it is seen that the significance values for all measurements are above .05 ($p > .05$), indicating that the data meet the assumption of normal distribution. Based on these findings, it was concluded that the data set satisfies the assumptions required for parametric analyses, and therefore the use of parametric tests (particularly the independent samples t-test) in subsequent statistical analyses was methodologically appropriate.

Inferential Statistical Findings

In this section, an independent samples t-test was conducted to determine whether there were statistically significant differences between the experimental and control groups in terms of ASUTL_PRE and ASUTL_POST scores. In the analysis process, pre-test scores were examined to compare the baseline levels of the groups, and then post-test scores were analyzed to investigate the post-intervention differences between the groups.

The findings of the independent samples t-test conducted to test the significance of the differences between the experimental and control groups in terms of ASUTL_PRE and ASUTL_POST scores are presented in Table 2.

Table 2. *Findings of the Independent Samples t-Test, Effect Sizes, and 95% Confidence Intervals for Mean Differences in ASUTL_PRE and ASUTL_POST Scores*

Variables	Groups	N	Mean	SD	df	t	p	95% CI for Mean Difference	Cohen's d
ASUTL_PRE	Experimental group	20	72.25	9.43	38	-1.18	.244	[-11.38, 2.98]	-0.37
	Control group	20	76.45	12.77					
ASUTL_POST	Experimental group	20	73.60	7.03	38	0.00	1.000	[-6.29, 6.29]	0.00
	Control group	20	73.60	12.02					

The findings presented in Table 2 indicate that there was no statistically significant difference between the groups in terms of ASUTL_PRE scores (t(38) = -1.18, p = .244 > .05). Similarly, no statistically significant difference was found between the groups regarding ASUTL_POST scores (t(38) = 0.00, p = 1.000 > .05). The effect size analysis indicated a small effect for the pre-test scores (Cohen's d = -0.37) and a negligible effect for the post-test scores (Cohen's d = 0.00). The negative sign of Cohen's d reflects the direction of the mean difference between groups. Furthermore, the 95% confidence intervals included zero, indicating that the observed differences between groups were not statistically significant.

In order to examine the change in ASUTL_PRE and ASUTL_POST scores of the students in the experimental and control groups, a paired samples t-test was conducted. This analysis was performed to determine whether the within-group changes in students' awareness levels regarding the use of technology in lessons showed statistical significance over time. The findings of the paired samples t-test are presented in Table 3.

Table 3. *Findings of the Paired Samples t-Test and Effect Sizes, and 95% Confidence Intervals for Mean Differences in ASUTL_PRE and ASUTL_POST Scores*

Groups	Variables	N	Mean	SD	df	t	p	Mean Difference	95% CI for Mean Difference	Cohen's dz
Experimental group	ASUTL_PRE	20	72.25	9.43	19	-.45	.657	1.35	[-4.93, 7.63]	0.10
	ASUTL_POST	20	73.60	7.03						
Control group	ASUTL_PRE	20	76.45	12.77	19	.88	.386	-2.85	[-9.63, 3.93]	-0.20
	ASUTL_POST	20	73.60	12.02						

The findings presented in Table 3 indicate that there was no statistically significant difference between ASUTL_PRE and ASUTL_POST scores in the experimental group (t(19) = -0.45, p = .657 > .05). The mean difference between post-test and pre-test scores was 1.35 points, with a negligible effect size (Cohen's dz = 0.10). Similarly, no statistically significant difference was found between pre-test and post-test scores in the control group (t(19) = 0.88, p = .386 > .05). The mean difference was -2.85 points, indicating a small negative effect (Cohen's dz = -0.20). The confidence intervals for both groups included zero, suggesting that the observed changes over time were not statistically meaningful.

DISCUSSION AND CONCLUSION

This study examined the effect of the MAR-based TISAR-3D application on sixth-grade students' awareness of technology use in lessons. The findings indicated that no statistically significant differences were found between the experimental and control groups in either the pre-test or post-test scores.

Likewise, no statistically significant within-group changes were observed following the eight-week intervention. Furthermore, the effect size analyses revealed negligible to small effects, and the confidence intervals included zero, indicating that the observed differences were both statistically and practically limited. These findings suggest that the implementation of TISAR-3D did not produce a measurable improvement in students' awareness regarding the educational use of technology.

Although statistically significant differences were not observed, the findings provide important practical implications for technology integration in educational settings. The negligible effect sizes suggest that merely incorporating MAR technology into classroom instruction may not be sufficient to enhance students' awareness of technology use. Rather than the presence of technology itself, the educational value of MAR appears to depend largely on how effectively it is integrated into pedagogically meaningful learning experiences. Accordingly, the findings emphasize that successful technology integration requires not only innovative digital tools but also instructional designs that actively engage learners in meaningful cognitive processes.

From a theoretical perspective, MAR environments are generally considered effective tools for promoting active learning, interaction, and meaningful knowledge construction within the frameworks of constructivist learning theory and the Cognitive Theory of Multimedia Learning (Mayer, 2009; Radianti et al., 2020; Sweller, 2011). However, the findings of the present study indicate that the educational effectiveness of MAR may depend not only on the technological features of the application itself but also on the quality of its pedagogical integration into the instructional process (Dunleavy & Dede, 2014; Tondeur et al., 2020). Although TISAR-3D provided 3D visualizations, animations, and interactive digital content, the application primarily functioned as a content presentation tool. Consequently, students may have had limited opportunities to engage in higher-order learning processes such as inquiry, collaborative problem-solving, reflection, and knowledge construction, which are considered essential for developing meaningful technology awareness.

Similarly, according to the Cognitive Theory of Multimedia Learning, meaningful learning occurs when learners actively select, organize, and integrate verbal and visual information (Mayer, 2005, 2024). Simply interacting with multimedia content does not necessarily result in deeper conceptual understanding unless learners are cognitively engaged in processing and applying the presented information. In the present study, students' interaction with the MAR application may have been largely observational rather than cognitively generative. Consequently, students may have perceived MAR primarily as an instructional visualization tool instead of developing a broader understanding of technology as a meaningful component of learning and knowledge construction.

Another possible explanation for the absence of statistically significant findings relates to the duration of the intervention. Technology awareness is considered a multidimensional and developmental construct that evolves gradually through repeated experiences, continuous interaction with educational technologies, teacher guidance, and opportunities for reflection (Fraillon et al., 2019; Hatlevik et al., 2015). Therefore, the eight-week implementation period may not have provided sufficient time for measurable changes in students' awareness levels to emerge. Although MAR may facilitate engagement and motivation in relatively short interventions, changes in higher-order perceptions regarding educational technology may require longer instructional experiences.

The characteristics of the outcome variable should also be considered when interpreting the findings. Unlike academic achievement or learning motivation, technology awareness reflects students' perceptions, beliefs, and understanding of the educational role of technology. Such constructs are generally more resistant to short-term instructional interventions because they develop cumulatively through multiple educational experiences. Therefore, the absence of statistically significant improvements should not necessarily be interpreted as evidence that the MAR intervention was ineffective, but rather that awareness-related outcomes may require more sustained pedagogical support.

Furthermore, the measurement instrument may have influenced the findings. The Awareness Scale for the Use of Technology in Lessons assessed students' general awareness regarding educational technology rather than awareness specifically associated with MAR-supported learning experiences.

Consequently, subtle changes in students' perceptions resulting from the TISAR-3D application may not have been fully captured by the measurement instrument, thereby reducing the likelihood of detecting statistically significant intervention effects.

The present findings differ from many previous studies reporting positive effects of AR and MAR technologies on academic achievement, motivation, engagement, and learning outcomes (Akcayir & Akcayir, 2017; Garzón et al., 2019; Talan et al., 2022). However, most previous studies have primarily focused on cognitive and affective outcomes, whereas relatively few have investigated technology awareness as a learning outcome. This distinction may explain why the present findings differ from much of the existing literature. The results suggest that technology awareness may represent a more complex educational outcome requiring different instructional strategies and longer implementation periods than those typically sufficient for improving academic performance or learner motivation.

The absence of significant changes in the control group further supports the interpretation that traditional instruction alone may also provide limited opportunities for students to develop awareness regarding the educational functions of technology. This finding is consistent with previous studies suggesting that content-oriented instructional approaches often fail to encourage students to perceive technology as an active learning and problem-solving resource (Cheng et al., 2025; Matthews, 2014). Consequently, both traditional instruction and technology-supported instruction may require more learner-centered pedagogical approaches to foster meaningful changes in technology awareness.

Despite the non-significant statistical findings, the practical implications of the study should not be overlooked. The results suggest that MAR applications may be more effective when integrated with inquiry-based learning, collaborative activities, authentic problem-solving tasks, classroom discussions, and reflective learning experiences rather than being used primarily as visualization tools. Future instructional designs should therefore emphasize active student participation, critical thinking, and knowledge construction in order to maximize the educational potential of MAR technologies.

Several limitations should be considered when interpreting the findings. First, the relatively small sample size (N = 40) may have reduced the statistical power of the analyses, limiting the ability to detect small intervention effects. Second, the intervention lasted only eight weeks, which may not have been sufficient for technology awareness to develop substantially. Third, the study was conducted in a single school, limiting the generalizability of the findings. Finally, the measurement instrument focused on students' general awareness of technology use in lessons and may not have been sufficiently sensitive to detect changes specifically associated with MAR-supported learning experiences. Therefore, future studies should employ larger and more diverse samples, extend the duration of interventions, and consider using measurement instruments specifically designed to evaluate technology awareness within MAR-supported learning environments.

In conclusion, the findings of this study indicate that the MAR-based TISAR-3D application did not significantly improve sixth-grade students' awareness of technology use in lessons. Nevertheless, these findings should not be interpreted as evidence of the ineffectiveness of MAR technologies in education. Rather, they suggest that the educational value of MAR depends on the quality of pedagogical integration, learner engagement, intervention duration, and the selection of appropriate outcome measures. Overall, the present study contributes to the growing body of literature by demonstrating that successful technology integration requires not only innovative technological environments but also pedagogically rich learning experiences that actively support students' cognitive and reflective engagement with educational technology.

Suggestions

Based on the findings of this study, the following recommendations are presented to enhance the effectiveness of AR-based instructional applications:

- MAR-based instructional applications should be designed to promote active learning by incorporating inquiry-based activities, collaborative learning, decision-making, and problem-solving tasks rather than relying primarily on observation and content presentation.

- Future research should investigate the effects of longer-term MAR interventions, as technology awareness is a developmental construct that may require sustained learning experiences to produce measurable changes.
- Researchers are encouraged to employ larger and more diverse samples from different grade levels, schools, and socioeconomic contexts to improve the statistical power, generalizability, and external validity of the findings.
- Future MAR applications should integrate historical scientific content with authentic real-life contexts, enabling students to recognize the educational role of technology beyond learning about scientists' lives.
- The instructional use of MAR should be systematically integrated into all phases of the teaching process, including lesson introduction, knowledge construction, practice, reflection, and assessment, rather than being limited to content presentation.
- Future studies should employ assessment instruments that are specifically designed to measure technology awareness in MAR-supported learning environments. In addition, self-report scales should be complemented with qualitative data, performance-based assessments, classroom observations, and reflective activities to obtain a more comprehensive evaluation of students' awareness development.
- Future experimental studies may also consider using statistical approaches such as ANCOVA or mixed-design ANOVA, where appropriate, to examine intervention effects while controlling for baseline differences and repeated measurements.

DECLARATIONS

Ethics Approval

Ethical approval for this research was obtained from the Ethics Committee for Social and Human Sciences Research at Fırat University during session number 2023/17 held on 21.09.2023.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Statement Regarding Research Involving Human Participants and/or Animals

This study was performed in line with the principles of the Declaration of Helsinki.

Consent to Participate

Informed consent was obtained from all individual participants included in the study.

Consent to Publish

The participants provided informed consent for the publication of their data.

Competing Interests

The authors have no relevant financial or nonfinancial interests to disclose.

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Author Contribution

Cemre KAPLAN contributed to conceptualization, data curation, formal analysis, investigation, methodology, project administration, and resources. Pelin YILDIRIM contributed to investigation,

methodology, visualization, writing – original draft, and writing – review & editing. Gonca KEÇECİ contributed to conceptualization, data curation, formal analysis, methodology, project administration, resources, supervision, and validation. All authors critically reviewed previous versions of the manuscript. All authors read and approved the final version of the manuscript and agreed to its submission for publication.

Availability of Data and Materials

The datasets generated and/or analyzed during the current reseach are available from the corresponding author on reasonable request.

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