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Teaching the Particulate Nature of Matter with Augmented Reality: A Study on Students' Attitudes and Motivation

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Abstract: Understanding abstract concepts in chemistry education is often a challenging process for students. Augmented reality (AR) technology stands out as an important tool that facilitates learning by visualizing abstract chemistry concepts. The aim of this study is to examine the effects of teaching the topic "The Particulate Nature of Matter" to 6th-grade students using the augmented reality application "VIDEOAR" via mobile devices on students' attitudes towards AR technology and their motivation to learn science. Using a quasi-experimental design, this study was conducted with 54 middle school students during the 2022-2023 academic year. The results of the study indicate that the group experiencing the AR application showed a significant increase in their attitudes towards AR technology and their motivation to learn science compared to the control group. In addition, no significant difference was found in attitudes and motivation based on gender. As a result, it was determined that AR technology enhances students' interest in the course and positively affects their motivation towards science learning in courses involving abstract subjects such as chemistry. The significant effect of integrating AR technology into education in terms of attitude and motivation, regardless of gender, is thought to stem from today's learners' interest in technology and represents an important finding for classroom practices. In this regard, it is suggested that AR applications be more widely integrated into science courses and that this technology be utilized in other subjects as well.
***Keywords**:* Augmented Reality (AR), Attitudes, Motivation, Chemistry Education, Abstract Concepts, Educational Technology.

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Introduction

While education undergoes a continuous transformation driven by technological advancements, significant changes are also occurring in learning methods. The increasing number and diversity of technologies used in educational settings have necessitated that educators adapt to these developments (Çolak Yazıcı & Erkoç, 2023). In particular, it is crucial for teachers to stay up to date with these advancements and integrate the most appropriate technological tools into their lessons to foster 21st-century skills. The primary advantages of technology-based instructional materials include enhancing students' ability to comprehend learning content, supporting individual learning capacities, and providing learners with unlimited opportunities for repetition by offering a learning environment independent of time and space (Adewoye & Akinde, 2023; Qomaruddin et al., 2024). The challenges faced by individuals born in the digital age regarding face-to-face communication necessitate the integration of individualized learning materials into educational environments, enabling students to work independently. In this context, the integration of technology into education addresses these needs by providing teachers with effective and functional resources (Çolak Yazıcı, 2024). Studies on Generation Z, who constitute today's students, indicate that students actively demand the integration of technology into traditional teaching methods (Chan & Lee, 2023; Granitz et al., 2021; Nazar et al., 2024). Students' perceptions of learning environments, their abilities, and the teaching strategies employed have a significant impact on their learning approaches and academic outcomes (Chan & Hu, 2023). Students who perceive the learning environment positively, demonstrate high levels of motivation and positive attitudes, and feel confident in their abilities are more likely to achieve desirable learning outcomes.

Today, Web 2.0 tools are frequently used in education, and recent advancements have led to a new transformation driven by artificial intelligence in educational settings (Feldman-Maggor et al., 2024). One of the prominent technologies utilized in education is Augmented Reality (AR) (Mahadzir & Phung, 2013). AR is defined as a technology that integrates computer-generated virtual images into the real world, enabling interaction with both physical and virtual objects (Azuma, 1997). This technology enhances students' engagement with educational materials in a more interactive and meaningful manner while also supporting their learning processes (Nazar et al., 2024).

Milgram and Kishino (1994) defined augmented reality as a continuum between reality and virtuality, stating that AR is a tool that integrates both real and virtual elements. Mazzuco et al. (2022) emphasized that AR systems should seamlessly merge virtual elements with the real environment, enable interactive and real-time processing, and be designed in three dimensions. Consequently, AR is a technology that bridges the real and virtual worlds, allowing users to engage in physical interactions within a real environment enhanced by virtual elements (Ripsam & Nerdel, 2024). The significance of AR in education lies in its ability to enhance the concretization of concepts and promote student-centered learning by providing a more motivating, effective, and interactive learning environment. AR, which supports practical applications in education, has the potential to enrich learning processes, particularly by fostering student-centered experiences, and, like other technological tools integrated into education, supports individualized learning (Jiang et al., 2025). The integration of AR into education plays a crucial role in facilitating students' conceptual understanding, particularly by enabling the visualization of abstract concepts, thereby increasing their motivation for the course and significantly improving their academic achievement.

Embodiment plays a crucial role in the teaching of concepts, especially in chemistry topics. Interacting with virtual objects and conducting experiments during lessons helps students better understand these abstract concepts and has a significant impact on students' attitudes and motivation towards the course. Cheng et al., (2024) emphasized that AR-enriched materials enhance students' attitudes and motivation towards science. Research by Kadıoğlu and Özyalçın Oskay (2025) also demonstrates that AR applications improve students' attitudes towards chemistry lessons and increase their engagement in the learning process.

The use of AR in subjects such as chemistry, which involves numerous abstract concepts, plays a significant role in helping students better understand these complex ideas (Nazar et al., 2024). Chemistry education is typically challenging for students due to the simultaneous need to comprehend the symbolic, microscopic, and macroscopic chemical worlds (Olim et al., 2024; Saidin et al., 2019). It is well-established that students often struggle to relate the chemical processes they observe in the laboratory to molecular-level phenomena. In this context, AR technology provides supportive learning materials that help students visualize invisible molecular structures and chemical bonds (Bullock et al., 2024). Aw et al. (2020) also emphasized that three-dimensional models enhance the understanding of chemical processes at the atomic level. These models facilitate the comprehension of complex chemical concepts, which are otherwise inaccessible through sensory experiences, and help to develop students' cognitive and spatial abilities.

Studies on the impact of AR technology in chemistry education have shown that AR facilitates the teaching process in topics such as molecular structures, chemical reactions, chemical bonds, and organic chemistry (Bullock et al., 2024; Karnishyna et al., 2024). In a study conducted by Bullock et al. (2024), teaching the electrophilic aromatic substitution mechanism in an AR environment enabled students to better grasp the topic and increased their positive attitudes toward the use of technology. Similarly, Hoai et al. (2024) demonstrated that teaching chemical bonding through AR simulations helped students better understand these concepts and engage more actively in the learning process. Numerous studies have highlighted that the use of AR technology in education enhances the quality of the teaching process and yields positive outcomes (Cheng et al., 2024; Mazzuco et al., 2022; Usta et al., 2016).

Yıldırım (2018) found that mobile AR applications had positive effects on students' science learning attitudes and academic performance. This study demonstrates that AR applications facilitate students' understanding of course topics by concretising abstract concepts. Similarly, Güngördü (2018) highlighted that AR has a positive impact on student achievement and attitudes in science subjects.

In conclusion, AR technology offers significant advantages for students, particularly in chemistry courses where abstract and complex concepts are taught. AR serves as a technological teaching tool that aids students in better understanding abstract chemical concepts by enabling their visualisation and concretisation. By providing an interactive and motivating learning environment, this technology enhances students' attitudes and motivation towards science. Research on the use of AR in education suggests that this technology increases both student achievement and engagement in lessons.

Importance of the Research

Although studies on the effects of AR technology on different materials in education for teaching chemistry subjects are included in the literature, there is a need for more comprehensive studies addressing these effects in different grade levels, learning areas and contexts. In the literature, it has been found that AR technology increases students' motivation (İbili & Şahin, 2015; Küçük et al., 2014) and positively affects their interest in the course (Akkiren, 2019; Sırakaya & Alsancak Sırakaya, 2018; Yıldırım, 2018). Especially its contribution to the concretization of abstract concepts in science courses (Abdüsselam & Karal, 2012) further increases the importance of AR technology in education. This technology makes abstract concepts more permanent by structuring them in visual ways.

It is noteworthy that AR technology has been widely researched in the field of science, especially in physics, but such studies are less common in other disciplines. In this context, the current study aims to teach the subject of ‘The Particulate Nature of Matter’, which is difficult to understand with traditional teaching methods, to 6th grade students using augmented reality technology. The study aims to examine the effect of AR technology on students' attitudes towards this technology and their motivation to learn science. Motivation is the force that moves an individual towards a certain goal. In other words, motivation is the sum of all efforts to continuously mobilise individuals or groups towards a certain ideal or goal. Attitude and motivation are concepts that play a critical role in the success and effectiveness of learning processes. In the research conducted by Chen (2024), it was concluded that students' motivation, class participation, perception and achievement were related (Liu, 2024). Therefore, the selection of attitudes and motivation in this study aims to provide an in-depth understanding of the affective and cognitive effects of AR technology on learning. Although there are numerous studies in the literature on the effects of attitude and motivation on learning, these concepts need to be further examined in the context of AR technology (Yang et al., 2024). In addition, the gender variable was selected to investigate the differences in the literature regarding the effects of gender on attitudes and motivation towards technology. The contribution of the gender variable to this study is to provide an opportunity to compare the effects of AR technology on different demographic groups. It is believed that this will contribute to the development of a more comprehensive and inclusive understanding of the use of AR technology in education by addressing a gap in the literature.

Purpose of the Study

The purpose of this study is to examine the effects of teaching the "Particle Nature of Matter" topic to 6th-grade students using the AR application ‘VIDEOAR’ via mobile devices on students' attitudes towards AR technology and their motivation to learn science. In this study, the impact of technology integration on students' engagement in the lesson and its implications for their motivation levels were examined in detail.

In this context, the study seeks to answer the following research questions:

1. Is there a significant difference between the pre-test and post-test scores of the experimental and control groups in terms of their motivation towards learning science?
2. Is there a significant difference between the pre-test and post-test scores of the experimental and control groups in terms of their attitudes towards augmented reality technology?
3. Do students' motivations towards learning science significantly differ according to the gender variable?
4. Do students' attitudes towards augmented reality technology significantly differ according to the gender variable?

Method

Research Design

The research method and design play a critical role in achieving the purpose of the study. The quasi-experimental design is a method that provides the most appropriate and reliable answers to research questions in cases where random assignment is not possible (Johnson & Christensen, 2014). In this context, the effects of AR activities on students' attitudes and motivation were examined by administering pre-tests and post-tests to the experimental and control groups. While augmented reality activities were implemented in the experimental group, traditional teaching methods were employed in the control group. This approach aims to clearly observe the effects of AR technology on the dependent variables. To enhance the validity and reliability of the research, a pre-test post-test design was used, and external influences were minimized.

Population and Sample of the Study

The population and sample of the study consist of 6th-grade students attending a secondary school in the central district of Düzce during the 2022-2023 academic year. In the sampling process, the criteria of a homogeneous gender distribution, similar class sizes, and having the same teacher were taken into consideration. Accordingly, the experimental group was selected from the 6/A class, which consisted of 27 students in total, including 12 girls and 15 boys, while the control group was selected from the 6/C class, comprising 13 boys and 14 girls. Random assignment was not employed in the selection of the classes; rather, it was ensured that the class characteristics were aligned with the purpose of the research.

Data Collection Tools and Analysis

Two different data collection tools were used in the study.

Augmented Reality Technology Attitude Scale:

The "Augmented Reality Attitude Scale," developed by Küçük et al. (2014), was used to measure students' attitudes towards augmented reality (AR) technology. This 15-item, 5-point Likert-type scale is composed of three factors: "Satisfaction with Use," "Anxiety about Use," and "Willingness to Use." The scale was administered to students in both the experimental and control groups as a pre-test and post-test.

The construct validity of the scale was comprehensively evaluated by the developers. Through factor analysis, the scale was found to exhibit a three-factor structure, supporting its construct validity. Additionally, the items of the scale demonstrated the ability to accurately represent the intended concepts, confirming the scale's content validity.

In terms of reliability, the Cronbach's Alpha reliability coefficient of the scale was calculated as 0.84 by the developers. According to the literature, a Cronbach's Alpha value above 0.80 indicates that the scale is reliable (Ursachi et al., 2015). These findings demonstrate the validity and reliability of the scale. Additionally, as the scale is widely utilized in educational research, no further validation study was deemed necessary in this context.

Motivation Scale for Learning Science:

The "Motivation Scale for Learning Science," developed by Dede and Yaman (2008), was used to measure students' motivation towards learning science. This 5-point Likert-type scale, consisting of 23 items, includes four sub-dimensions: "Motivation for Research," "Motivation for Performance," "Motivation for Communication," and "Motivation for Collaboration." The developers reported a Cronbach's Alpha internal consistency coefficient of 0.80 for the overall scale, indicating a high level of reliability.

SPSS 25.0 (Statistical Package for the Social Sciences) was used for data analysis, and all analyses were conducted at a 5% significance level. To test the normality of the data, the Shapiro-Wilk Test was applied. According to the results, the data were normally distributed ($p>0.05$) (Pallant, 2017). Upon confirming the normality assumption, both independent samples t-test and paired samples t-test were utilized to analyze the data. The independent samples t-test was used to examine the differences between the experimental and control groups, while the paired samples t-test was conducted to evaluate the pre- and post-test changes within each group. These two tests enabled a comprehensive examination of the effects of AR implementation on motivation to learn science and attitudes towards AR technology, considering both within-group and between-group differences.

Normality Test Results

According to the Shapiro-Wilk normality test results, the pre-test and post-test scores from the motivation and attitude scales towards learning science for students in the experimental and control groups were normally distributed ($p > 0.05$). For the motivation scale, the pre-test p-value of the experimental group was 0.882 and the post-test p-value was 0.100, while the control group's pre-test p-value was 0.283 and the post-test p-value was 0.119. Similarly, for the attitude scale, the experimental group's pre-test p-value was 0.560 and the post-test p-value was 0.438, whereas the control group's pre-test p-value was 0.147 and the post-test p-value was 0.417.

Since all of these p-values exceed 0.05, it can be concluded that the data meet the normality assumption. Therefore, parametric analysis methods were employed to examine the differences between the groups, and the independent samples t-test was applied.

Application

Application Process of the Experimental Group

The implementation process for the experimental group started with pre-tests to measure students' attitudes towards AR technology and their motivation to learn science. These tests were applied at the beginning of the course to evaluate the effect of AR activities. In addition to the 6 class hours allocated for the teaching of the ‘The Particulate Nature of Matter’ topic in the curriculum, 2 more class hours were added for the students to learn and use the AR application effectively. This process, which was carried out in 8 class hours for a total of 2 weeks, aimed to improve both the students' understanding of the subject and their experiences with AR technology. Unlike the control group, which was taught the same subject by the same teacher, the experimental group students also participated in augmented reality applications during the lesson. In this process, the students in the experimental group were asked to install the mobile augmented reality application named ‘VIDEOAR’ on their mobile phones before the lesson. The purpose of using the application is to make the particulate, porous, and dynamic structure of matter more concrete and to facilitate students' understanding of these abstract concepts.

In the lessons, using sample substances in solid, liquid, and gaseous states in the classroom, these substances were examined with the ‘VIDEOAR’ application. Thanks to AR technology, students were able to observe the atomic structure of these substances and how this structure moved. Especially in these abstract and challenging subjects, the ‘VIDEOAR’ application is thought to help students better understand the concepts (Langitasari et al., 2024). In this way, it was aimed to increase students' interest in the subject and to ensure their more active participation in the learning process.

At the end of the implementation process, the augmented reality attitude scale and the motivation scale for learning science were administered to the students as post-tests. It was aimed to examine the difference between the initial and post-tests and the extent to which the AR application influenced students' motivation towards science learning and their attitude towards AR technology.

Application Process of the Control Group

In the experimental and control groups, the scales were pre-printed and distributed to the students. In the control group, the implementation process started with pre-tests measuring students' attitudes towards AR technology and their motivation to learn science. However, the students in this group were educated with traditional teaching methods, and no AR application was used in the lessons.

In the control group, the topic 'The Particulate Nature of Matter' was taught using the textbook recommended by the Ministry of National Education. Throughout the lesson, the teacher generally used the direct instruction method and aimed to help students understand the concepts better by giving examples from daily life in some parts of the subject. Students were encouraged to take notes on the important parts of the subject, and traditional methods were preferred throughout the teaching process.

In the control group, at the end of 8 class hours of training lasting for 2 weeks, the attitude scale towards AR technology and the motivation scale for learning science were re-applied to the students as post-tests. These tests were used to determine the effect of traditional teaching methods on students.

Finding

The findings obtained within the scope of the research are presented below.

Table 1
Dependent sample t-test results for the pre-test and post-test findings of students' motivation and attitude scales for science learning

Scale	**Group**	**Test**	**N**	**X̄**	**SS**	**SD**	***t***	***p***
Motivation Scale	**Experimental Group**	Pre-test	27	42.29	5.61	26	18.40	0.00
		Post-test	27	75.96	7.75			
	Control Group	Pre-test	27	50.22	9.07	26	2.45	0.02
		Post-test	27	51.81	10.06			
Attitude Scale	**Experimental Group**	Pre-test	27	41.92	4.14	26	-5.09	0.00
		Post-test	27	47.81	3.75			
	Control Group	Pre-test	27	44.62	8.40	26	-1.20	0.24
		Post-test	27	45.25	8.39			

A statistically significant difference was found between the motivation to learn science pre-test ($\bar{X}$ = 42.29) and post-test ($\bar{X}$ = 75.96) scores of the Experimental Group students ($t=18.40$; $p<0.05$). This result shows that AR applications increased the motivation of the Experimental Group students. A statistically significant difference was also found between the motivation pre-test ($\bar{X}$ = 50.22) and post-test ($\bar{X}$ = 51.81) scores of the Control Group students ($t=2.45$; $p<0.05$). However, it was found that this difference was at a lower level compared to the Experimental Group.

A significant difference was found between the Attitude Scale pre-test ($\bar{X}$ = 41.92) and post-test ($\bar{X}$ = 47.81) scores of the Experimental Group students ($t=-5.09$; $p<0.05$). This shows that the AR application positively affected the attitudes of the students.

In the Control Group, no significant difference was found between the Attitude Scale pre-test ($\bar{X}$ = 44.62) and post-test ($\bar{X}$ = 45.25) scores (t=-1.20; p>0.05).

Table 2
Independent sample t-test results for the pre-test and post-test findings of students' motivation and attitude scales for science learning

Scale	**Test**	**Group**	**N**	**$\bar{X}$**	**SS**	**SD**	***t***	***p***
Motivation Scale	Pre-test	Experimental Group	27	42.29	5.61	52	9.87	0.00
		Control Group	27	50.22	9.07			
	Post-test	Experimental Group	27	75.96	7.75	52	-3.85	0.00
		Control Group	27	51.81	10.06			
Attitude Scale	Pre-test	Experimental Group	27	41.92	4.14	52	-1.50	0.14
		Control Group	27	44.62	8.44			
	Post-test	Experimental Group	27	47.81	3.75	52	1.44	0.16
		Control Group	27	45.25	8.39			

A significant difference was found between the Motivation Scale pre-test scores of the Experimental and Control Group students (t=9.87; p<0.05). The mean score of the Control Group ($\bar{X}$ = 50.22) was higher than the mean score of the Experimental Group ($\bar{X}$ = 42.29).

In the post-test scores, a statistically significant difference was found between the Experimental Group ($\bar{X}$ = 75.96) and the Control Group ($\bar{X}$ = 51.81) (t=-3.85; p<0.05). In the light of the results obtained, it is thought that AR-supported education is effective in increasing the motivation of students.

When the Attitude Scale pre-test scores were analyzed, no significant difference was found between the Experimental Group ($\bar{X}$ = 41.92) and the Control Group ($\bar{X}$ = 44.62) (t=-1.50; p>0.05). There was no significant difference between the Experimental Group ($\bar{X}$ = 47.81) and the Control Group ($\bar{X}$ = 45.25) in post-test scores (t=1.44; p>0.05). This shows that the difference between the attitudes of both groups is not statistically significant.

Table 3
Independent sample t-test results of motivation and attitudes towards AR technology according to gender

Scale	Test	Group	Gender	N	$\bar{X}$	S.S	S.D	*t*	*p*
Motivation Scale	Pre-test	Experimental Group	Female	13	39	5.01	13	-3.51	0.002
			Male	14	45.35	4.34	14		
	Post-test		Female	13	75.46	6.91	13	-0.319	0.749
			Male	14	76.42	8.7	14		
	Pre-test	Control Group	Female	12	51.15	10.8	12	-0.32	0.75
			Male	15	52.42	9.6	15		
	Post-test		Female	12	49.76	10.5	12	-0.25	0.81
			Male	15	50.64	7.9	15		
Attitude Scale	Pre-test	Experimental Group	Female	13	42.38	3.81	13	0.551	0.587
			Male	14	41.5	4.51	14		
	Post-test		Female	13	48.46	3.4	13	0.865	0.396
			Male	14	47.21	4.07	14		
	Pre-test	Control Group	Female	12	45.3	8.53	12	0.397	0.694
			Male	15	44	8.54	15		
	Post-test		Female	12	45.92	8.68	12	0.39	0.7
			Male	15	44.64	8.39	15		

There was no statistically significant difference between the Motivation Scale post-test scores of female ($\bar{X}$ = 75.46) and male ($\bar{X}$ = 76.42) students in the Experimental Group (t = -.319, p > 0.05).

There was no statistically significant difference between the pre-test and post-test motivation scores of male and female students in the Control Group (p > 0.05). It can be said that traditional teaching methods do not create a difference based on gender.

In the Experimental Group, there was no statistically significant difference between the pre-test and post-test attitude scores of male and female students ($p > 0.05$). This indicates that AR applications did not make a difference in the attitudes of the students based on gender.

Discussion

AR technology stands out as an effective tool that provides meaningful learning and enriches learning processes by enabling students to concretize abstract concepts in teaching chemistry concepts. In this study, the effects of teaching the Particulate Nature of Matter subject using AR technology on students' attitudes towards AR technology and their motivation towards science learning were examined. The findings supported that AR technology increased the participation of the students in the Experimental Group in the learning process and their level of understanding of the concepts in the teaching of an abstract and conceptually dense course such as chemistry. While more limited learning experiences were provided with traditional teaching methods in the Control Group, it would be appropriate to infer that the visual and interactive content provided by AR technology supported students' learning by making complex concepts more concrete, which affected the findings obtained. Integration of technologies in education facilitates making teaching materials interactive and meaningful to meet the individual learning needs of students (Çolak Yazıcı & Erkoç, 2023; Adewoye & Akinde, 2023).

AR facilitates students' comprehension of abstract chemistry concepts more effectively, thereby supporting their learning processes. This distinction was reflected in more significant positive changes in the attitudes and motivation of the students in the Experimental Group. Nazar et al. (2024) state that AR technology plays a crucial role in concretizing abstract concepts, fostering students' active engagement in the learning process. The literature also highlights that the individualised learning environments provided by AR technology enable students to regulate their learning pace more effectively (Chan & Lee, 2023; Granitz et al., 2021).

This finding supports the argument that AR technology has a positive impact on students' attitudes towards courses and enhances their engagement in learning processes, as highlighted in the findings of Bullock (2024). Specifically, AR technology is believed to transform an abstract subject such as the "The Particulate Nature of Matter" into a more comprehensible form through visual modeling and dynamic, interactive simulations. This process enabled the students in the Experimental Group to engage in deeper learning experiences by constructing meaning from the concepts. Mazzuco et al. (2022) underscore that AR facilitates students' understanding of abstract chemical processes by visualizing them through three-dimensional modeling. This process has contributed to the development of students' positive attitudes towards AR technology and has led to a significant increase in their motivation for science learning. In Hoai et al.'s (2024) study, it was found that teaching chemical bonding using AR technology enhanced students' conceptual understanding and motivation. In this context, AR is recognized as a tool that positively contributes to student achievement by providing both individualized and interactive learning opportunities.

Similarly, Bullock et al. (2024) highlight that AR plays a crucial role in the concretization of abstract concepts in disciplines such as chemistry and facilitates students' comprehension of these concepts. In particular, the visual representation of abstract topics such as the "particle structure of matter" enables students to grasp these concepts more effectively. In this study, it was observed that the students in the Experimental Group were able to comprehend this abstract subject more easily and engaged actively in the learning process due to the interactive content delivered through AR technology. Conversely, in the Control Group, it was determined that students lacked a similar visualization experience as a result of traditional teaching methods, which in turn led to more limited effects on motivation and attitude. Furthermore, the studies of Özdemir (2021) and Chan & Lee (2023) demonstrate that AR enhances cognitive development in teaching abstract topics and positively influences learning processes.

The analysis of motivation showed that the students in the Experimental Group demonstrated a higher level of motivation towards science learning in comparison to the students in the Control Group, who were taught with traditional methods. AR technology enhanced the interest of the students in the Experimental Group in the lesson and provided an interactive approach to teaching abstract chemistry concepts. As a result, the students' capacity to make sense of abstract concepts was strengthened, leading to a more significant increase in their motivation towards the lessons. Although there was a limited increase in the motivation level of the students in the Control Group, this increase was less pronounced compared to the Experimental Group. Demir and Başer (2020) assert that AR enriches students' learning processes in science and fosters their interest in the lessons. This finding aligns with the view that AR facilitates students' understanding of abstract concepts and enhances their motivation for learning. The findings of Güneş and Yıldırım (2020) and Mahadzir and Phung (2013) also corroborate the results of this study. Moreover, it is frequently highlighted in the literature that AR supports self-paced learning by providing individualized learning opportunities, thereby improving students' academic achievement (Qomaruddin et al., 2024).

The findings related to the gender variable indicate that AR technology does not lead to gender-based differences. No statistically significant difference was found between male and female students in both the experimental and control groups regarding their attitudes and motivation towards AR technology. This finding suggests that AR serves as an equally effective tool for both genders and that its accessibility ensures equal learning opportunities for Generation Z students, regardless of gender. This result aligns with Güngördü's (2018) study, which asserts that AR is equally effective across all student groups, irrespective of gender. The fact that Generation Z students demonstrate a gender-independent predisposition to technology reinforces AR technology's role as an equally effective learning tool for both genders (Chan & Lee, 2023; Granitz et al., 2021). This finding is considered particularly significant in terms of the use of AR in education.

In conclusion, AR technology has been found to offer significant advantages in courses that involve abstract and complex concepts, such as chemistry. When evaluated through a holistic approach alongside findings from other studies in the literature, it can be inferred that AR technology aids students in enhancing their conceptual understanding and boosting their motivation for learning by enabling the visualisation and concretisation of abstract concepts. The AR technology used in the Experimental Group facilitated students' comprehension of course content, supported them in overcoming conceptual difficulties, and encouraged active participation in the learning process. In contrast, in the Control Group, the absence of AR technology indicated that learning processes remained restricted to traditional methods, which had a more limited impact on student attitudes and motivation. As highlighted in the studies by DiSerio, Ibanez, and Kloos (2013) and Sarıoğlu (2021), AR technology serves as a powerful tool in science education and is an effective method for positively influencing students' attitudes and motivation towards lessons. Research on the integration of AR in education consistently demonstrates that this technology enhances student achievement and reinforces engagement in learning (Chan & Hu, 2023). Based on these findings, it is strongly recommended that AR technology be widely adopted, particularly for the teaching of chemistry concepts.

Recommendations

The results of this study show that AR technology can enhance students' comprehension of scientific concepts by improving their attitudes and motivation towards science. In this context, it is recommended that AR-based instructional materials be developed and that the integration of this technology into classroom applications be expanded.

The effective implementation of AR technology in education necessitates that teachers acquire sufficient knowledge regarding its use. Therefore, it is recommended that training programs on AR technology be designed and implemented for teachers.

This study is limited to the topic of the particulate structure of matter; thus, it is recommended to extend research to different subject areas and to investigate additional variables, such as analytical thinking skills and academic achievement.

To maximize the effective use of AR technology in education, schools' technological infrastructure must be improved. Providing the necessary devices and technical support in schools is essential to enhance students' access to AR applications.

Ethics Committee Approval:

Düzce University Scientific Research and Publication Ethics Committee, dated 11.07.2024, Decision No. 20247235.

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