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Augmented Reality-Enriched Gamification for Teaching Astronomy: Effects on Middle School Students' Motivation and Science Achievement

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Augmented Reality-Enriched Gamification for Teaching Astronomy: Effects on Middle School Students' Motivation and Science Achievement

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Abstract

Advances in technology and space research have increased the need to improve students' motivation and understanding in astronomy education. Gamification, particularly when integrated with emerging technologies, has drawn growing interest as a way to improve learning. This study aimed to examine the effects of Augmented Reality (AR)-enriched gamification and gamification alone on seventh-grade students' academic achievement and motivation toward learning science within the "Solar System and Beyond" unit. A quasi-experimental pretest–posttest control group design was employed. The study involved 51 seventh-grade female students from a middle school in Ankara. AR-enriched gamification was implemented in Experimental Group 1 ($n = 20$), gamification in Experimental Group 2 ($n = 16$), and textbook-based instruction in the control group ($n = 15$). Data were collected using the Astronomy Achievement Test and the Science Learning Motivation Scale. The findings revealed that although all groups showed statistically significant improvements in academic achievement from pre-test to post-test, no statistically significant between-group differences were observed in post-test achievement scores. With respect to motivation, statistically significant between-group differences emerged in Motivation for Performance, Motivation for Participation, and the overall Science Learning Motivation Scale in favor of the AR-enriched gamification group over the control group, and in Motivation for Communication in favor of the AR-enriched gamification group over the gamification-only group. Within-group analyses further indicated that Experimental Group 1 showed significant improvements across all motivation subdimensions, whereas Experimental Group 2 showed improvements in selected subdimensions only, and no significant changes were observed in the control group. These results suggest that integrating AR into gamified instruction may provide additional benefits for some motivational outcomes. Overall, the findings suggest that AR-enriched gamification may be a promising instructional approach for supporting students' motivation in science education.

Introduction

Science education is important for enabling individuals to think critically, generate solutions to problems, and become scientifically literate. Effective science education is necessary not only for academic success but also for building awareness in daily life, promoting scientific thinking, and equipping individuals to develop solutions to problems (National Research Council, 2012). The interdisciplinary connections among physics, chemistry, and biology in science education and astronomy, together with recent technological developments, have increased interest in learning about space. This interest has heightened the importance of education in this field. Beyond student curiosity, awareness of astronomical phenomena has wider relevance for career development and scientific literacy (Çiv et al., 2022).

Although astronomy education can be a source of curiosity and fascination for students, it may also lead to serious misconceptions and learning difficulties due to limited opportunities for visualization and mental imagery (Ayvaci & Sezer, 2019; Baybars Görecek & Can, 2018). Two-dimensional diagrams in textbooks are often insufficient for teaching astronomy concepts. Therefore, innovative teaching methods that help students make these concepts concrete are needed. Augmented Reality (AR) applications, which support three-dimensional learning of concepts, have gained growing prominence in astronomy education over the past decade (Aktamış & Arıcı, 2013; Wang & Tseng, 2020). The 3D capabilities of AR technologies make phenomena such as day–night cycles, the formation of seasons, lunar and solar eclipses, and lunar phases more readily understandable. Three-dimensional

visualization technologies can support students' reasoning and interpretation of astronomical phenomena (Yair et al., 2003). Effective astronomy education should aim not only to teach students scientific concepts but also to increase their intrinsic motivation to learn science. Numerous studies have shown that high motivation in science lessons is associated with higher academic achievement (Alkan & Bayri, 2017; Howard et al., 2021a; Howard et al., 2021b; Yeşiltepe, 2019). The use of AR technologies in teaching astronomy topics in science lessons also contributes to increased student motivation (Demircioğlu et al., 2022).

Gamification and Augmented Reality in Science Learning

Games have the potential to increase student motivation and enable effective learning (Aykut, 2022; Kalli, 2023; Paras & Bizzocchi, 2005). Games are considered one of the most powerful forms of engagement in learning environments, as they are typically risk-free, accessible, and easy to implement. These game characteristics have attracted the attention of educational researchers, and game types have been the subject of numerous studies. With the advent of digitalisation, digital games have been adopted for educational purposes. When used correctly, digital games provide significant educational benefits (Watson et al., 2011). The concepts of game and gamification are sometimes confused (Bozkurt & Genç-Kumtepe, 2014; Şenocak & Bozkurt, 2020). While the primary purpose of a game is to entertain, that of gamification is to motivate. Indeed, Berber (2018, p. 44) emphasises the distinction between games and gamification in his book "Gamification," stating, "Game designers design entertainment, gamification designers design motivation using games".

According to the most widely accepted definition, gamification is "the use of game design elements in non-game contexts" (Deterding et al., 2011; Polat et al. 2022). This definition has been widely adopted in the educational literature (Samur & Şahin, 2017). Gamification alone is not an effective method; incorporating various game-design elements can increase motivation (Sailer et al., 2017). Various models have been proposed to improve the effectiveness of gamification. Gamification models in science education can offer a holistic learning experience, not only by imparting knowledge but also by raising motivation and supporting social interaction (Othman & Ching, 2024). One of the most comprehensive models in this field is the Octalysis Gamification Model, developed by Yu-kai Chou (2015). Octalysis advocates that game elements be strategically designed not only to provide entertainment but also to create behavioural effects. The Octalysis model has been used in educational settings to increase student participation, support motivation, and facilitate learning (Chou, 2015). Gamification is also used in conjunction with various technologies. For example, researchers have investigated gamification supported by artificial intelligence (Çöpgeven et al., 2023), problem-based science teaching supported by AR (Fidan, 2018), and gamification integrated with AR (Redep & Hajdin, 2021) in education.

Due to its flexible structure, AR technology can be applied in a wide range of fields. Research has shown that AR learning materials can improve success (Abdusselam & Karal, 2020; Arymbekov et al., 2024; Ateş, 2018; Coşkun, 2019; Fleck & Simon, 2013; Liao et al., 2025; Özarslan, 2013; Sırakaya & Kılıç Çakmak, 2018; Yıldırım, 2020), attitudes towards science lessons (Akçayır, 2016; Çankaya, 2019), laboratory skills, and the retention of learned information (Aktamış & Arıcı, 2013). Furthermore, a literature review of 61 studies published between 2012 and 2018 revealed that the most frequently reported advantages of AR technology in education were increased motivation and improved academic achievement (Garzón et al., 2019).

Previous studies indicate that the integration of AR applications and gamification methods increases students' motivation and achievement (Ding et al., 2024; Lampropoulos et al., 2022; Zhonggen, 2019). Furthermore, the use of mobile AR science games has had a positive impact on both achievement and motivation among middle school students (Bressler & Bodzin, 2013). When self-regulation strategies such as goal setting, progress monitoring, and reflection are integrated into AR-based gamification environments, middle-school science students' academic achievement, participation, and self-confidence significantly increase. The game-and-gamification method, enriched with AR technology, represents an innovative approach that supports multidimensional learning (Ateş & Polat, 2025). Despite these findings, research specifically examining the effects of AR-based gamification on astronomy achievement and motivation at the middle-school level remains limited, underscoring the need for further research.

Purpose of the Study

The present study aims to examine the comparative effects of AR-enriched gamification and conventional gamification-based instruction, relative to standard textbook-based instruction aligned with the Ministry of National Education (MoNE) science curriculum, on seventh-grade students' academic achievement and

motivation toward learning science within the "Solar System and Beyond" unit. Specifically, this study addresses the following research questions:

1. Is there a statistically significant difference in students' academic achievement among the AR-enriched gamification group (Experimental Group 1), the gamification-based instruction group (Experimental Group 2), and the textbook-based instruction group (Control Group)?
2. Is there a statistically significant difference among these groups in terms of students' motivation toward learning science?

Method

Research Design

A pretest-posttest control-group quasi-experimental design was employed in this study. Quasi-experimental studies are used when research groups are preexisting (Shadish et al., 2002). When well-designed, quasi-experimental studies can produce reliable results (Trochim et al., 2016). The study included two experimental groups and one control group. Experimental Group 1 (AR-Enriched Gamification) received instruction supported by AR-integrated gamification, whereas Experimental Group 2 (Gamification) received instruction that was gamified without AR support. In the control group, instruction followed the Ministry of National Education (MoNE) science textbook. The research process was designed as shown in Figure 1. In the first and last weeks of the study, the Astronomy Achievement Test and the Science Learning Motivation Scale were administered to all students as pretests and posttests, respectively.

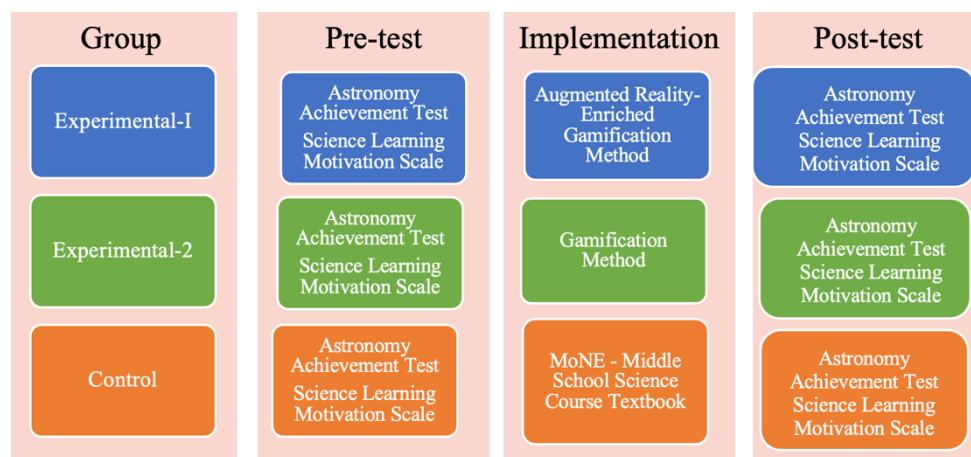


Figure 1. Research process

Sample of the Study

An appropriate non-randomised sampling technique was employed. This method is preferred when random sampling is not possible and is practical in terms of time, cost, and accessibility (Fraenkel et al., 2012). The study was conducted at a school in Ankara that admits students through a centrally administered entrance examination; therefore, students' academic achievement levels were comparable across classes. The research sample consisted of seventh-grade students enrolled in this school, which provided separate classes for girls and boys. The study sample consisted of 51 girls in three preexisting classes, which were assigned to experimental and control conditions (Table 1).

Table 1. Sample groups

Group	Number of Students (n)
Experiment-1	20
Experiment-2	16
Control Group	15
Total	51

As shown in Table 1, Experimental Group 1, Experimental Group 2, and the control group consisted of 20, 16, and 15 girls, respectively.

Data Collection Tools

In this quantitative study, data were collected using the Astronomy Achievement Test (AAT) and the Science Learning Motivation Scale.

Astronomy Achievement Test, developed by Öner Armağan and Demir (2019), was initially prepared with 31 questions; following item analyses, it was reduced to 27 items. The test consists of multiple-choice questions, each with four options, and is based on the learning outcomes of the 7th-grade Solar System and Beyond unit. The average item difficulty index was 0.60, and the item discrimination index was 0.38. The developers reported that the test is suitable for seventh-grade students. The AAT was administered as a pre-test during the first week of the study and as a post-test after the intervention.

Science Learning Motivation Scale, developed by Dede and Yaman (2008), consists of 23 five-point Likert-type items structured into five factors: motivation for research, performance, communication, collaborative work, and participation. The motivation for research dimension refers to students' willingness to explore scientific topics and their curiosity about natural phenomena. Motivation for performance relates to goals related to academic achievement, such as obtaining high grades and completing tasks successfully. Motivation for communication reflects students' tendency to share ideas, ask questions, and participate in discussions during science lessons. The collaborative work dimension refers to students' willingness to work in groups and learn through peer interaction, whereas motivation for participation refers to active involvement in classroom activities such as discussions, experiments, and hands-on tasks. The scale was piloted with 183 middle school students, revised, and subsequently administered to 421 students. Factor analysis indicated that the five factors explained 47% of the total variance, with an overall reliability coefficient of .80. In the present study, internal consistency was assessed using Cronbach's alpha coefficients, yielding values of .88 for the pre-test and .90 for the post-test.

Instructional Design of the Activities

The instructional activities were designed based on the Octalysis Gamification Framework developed by Chou (2015), which conceptualizes motivation through eight core drives: epic meaning and calling, development and accomplishment, empowerment of creativity and feedback, ownership and possession, social influence and relatedness, scarcity and impatience, unpredictability and curiosity, and loss and avoidance. Based on this framework, a set of gamified tasks was developed for the experimental groups. At the beginning of the implementation, students were divided into groups and asked to create their own team identities, including team names and symbolic elements (e.g., group hats), to promote ownership and group belonging. The instructional process was introduced through a narrative scenario in which students assumed the roles of astronauts preparing for a Mars mission. Task lists were then provided to guide students through the activities. To reinforce development and accomplishment, clearly defined tasks were shared with students, and a dynamic leaderboard was used to track progress and performance throughout the implementation. Epic meaning was reinforced through scenario-based storytelling embedded in the lesson plans. Empowerment of creativity and opportunities for feedback was fostered by allowing students to generate their own designs and solutions, and to receive immediate feedback during activities.

Ownership and possession were further supported through group-based structures, while social influence and relatedness were encouraged through collaborative tasks and a badge system. Various badges (e.g., Teamwork, Deep Thinker, Fast Achiever, Responsibility, and Helpfulness) were awarded according to predefined criteria. For example, the "fast achiever" badge was awarded to groups that completed tasks within a shorter time frame. Scarcity and impatience were incorporated through time-limited tasks and countdown mechanisms. Unpredictability and curiosity were introduced through surprise rewards that were not disclosed in advance. Finally, loss and avoidance were operationalized as a point-deduction system, applied when tasks were not completed as required. Following development of the activities, a validation workshop was conducted with nine in-service teachers (bachelor's degrees), three teachers (master's degrees), one teacher (a doctoral degree), and five preservice science teachers. Participants evaluated the scope of the study, the gamification design, and the appropriateness of the AR applications. Minor revisions to the activity plans were made based on their feedback, and the overall design was confirmed to be aligned with the intended learning objectives.

Implementation Process

The implementation took place over four weeks and comprised a series of structured tasks aligned with the learning outcomes of the 7th-grade “Solar System and Beyond” unit. Both experimental groups followed the same instructional sequence; however, in Experimental Group 1, the gamification activities were enriched with AR applications, whereas Experimental Group 2 completed similar tasks without AR support. In the first week, students explored space technologies and examined visual representations of spacecraft. Experimental Group 1 used AR-enriched materials (e.g., Space 4D cards) to explore three-dimensional models of space vehicles, whereas Experimental Group 2 relied on textbook-based visuals. In addition, students in both groups completed an inquiry-based task focusing on the question, “Why do humans explore space?” Experimental Group 1 participated in a virtual space station tour using a three-dimensional simulation application, whereas Experimental Group 2 participated in a discussion-based activity on the same topic. During the second week, activities focused on space pollution, spacecraft, and satellites. Students in Experimental Group 1 examined AR-based content developed using ROAR, while students in Experimental Group 2 used conventional instructional materials. Both groups developed solutions to prevent or mitigate space pollution. In the spacecraft design task, students in Experimental Group 1 examined NASA spacecraft using an AR application (SpacecraftAR) (Figure 2), which allowed them to explore three-dimensional models, such as the Curiosity rover, and to analyze their structural features.



Figure 2. SpacecraftAR Application

Students were then asked to design their own spacecraft. The task was gamified using a scoring system: the group with the most preferred design received 30 points; groups that completed appropriate designs on time received 20 points; and groups that failed to complete the task on time lost 5 points. In contrast, students in Experimental Group 2 examined spacecraft using textbook images and subsequently designed their own models based on these representations. All groups presented their designs; examples of products created by students in Experimental Group 1 are shown in Figure 3. These activities were supported by gamification elements such as scoring, peer evaluation, and group-based competition.

In the third week, the focus shifted to telescopes and astronomical observation. Students in both groups wrote a letter from the perspective of Hans Lippershey, the inventor of the telescope. For sky observation, Experimental Group 1 used a mobile AR application (Star Chart) to identify and examine celestial objects, whereas Experimental Group 2 conducted direct observations and discussed the difficulties of observing the night sky in urban environments. In the fourth week, students completed activities aimed at consolidating their learning. These included classification tasks distinguishing stars from planets and redesigning posters that represent the life cycle of stars. Students examined celestial objects through visual materials. In Experimental Group 1, students used the augmented-reality features of the January 2023 issue of *Science for Children* to examine three-dimensional representations of celestial bodies and record key observations. In Experimental Group 2, students examined the same materials without AR support. At the end of the activity, each group presented its results to the class. Finally, students completed a sequencing task involving cosmic structures (e.g., the universe, galaxies, constellations, and stars).

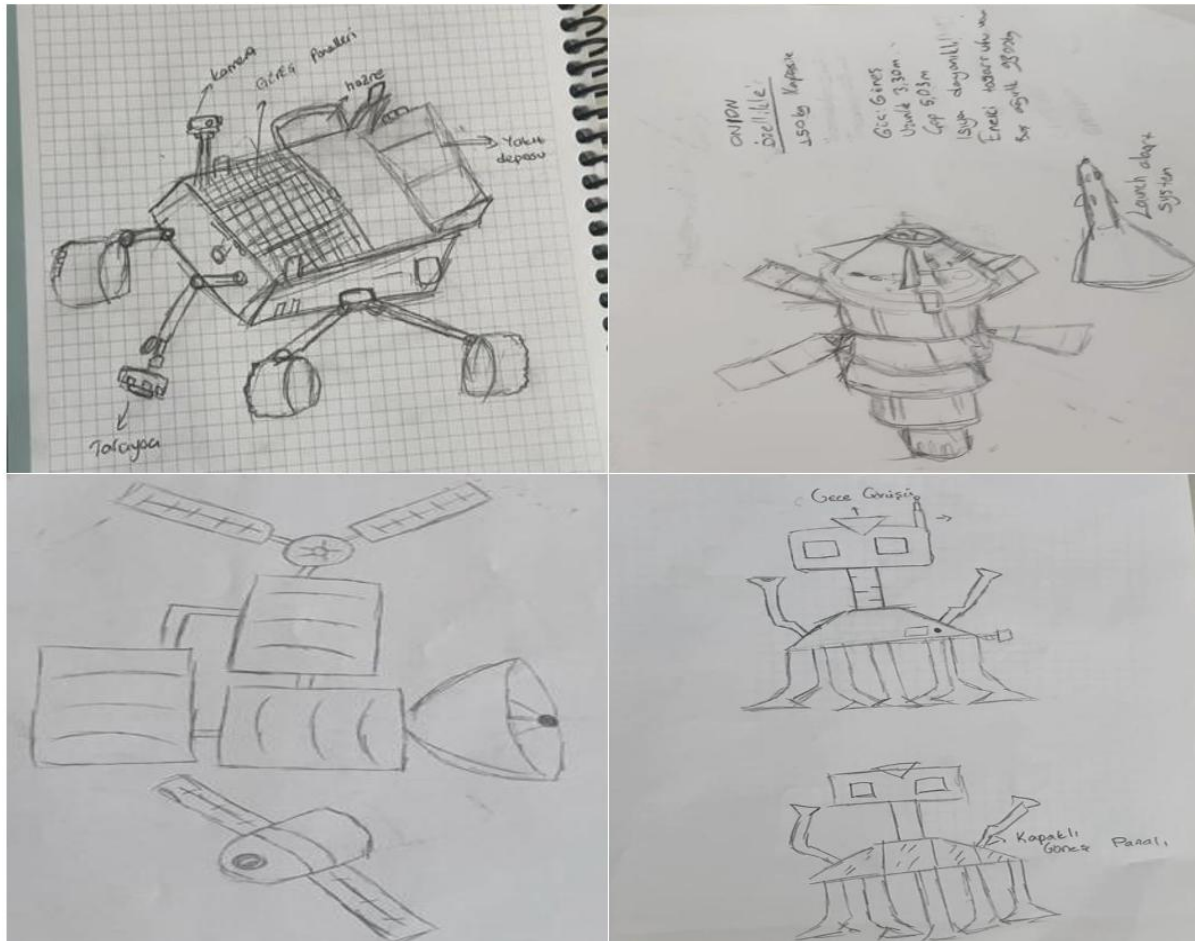


Figure 3. Spacecraft drawings by students in the Experiment-1 group

Data Analysis

Prior to the analyses, the assumptions underlying the statistical procedures were examined. Given that the sample size in each group was less than 50, normality was assessed using the Shapiro–Wilk test. The results indicated that the normality assumption was satisfied for the total scores of the Science Learning Motivation Scale and the achievement test ($p > .05$), whereas some sub-dimensions of the motivation scale deviated from normality ($p < .05$). Accordingly, parametric tests were applied to variables that satisfied the assumption of normality, whereas nonparametric alternatives were applied to variables that did not.

Homogeneity of variances was also evaluated, and when this assumption was violated, Welch's ANOVA was employed. Group comparisons were conducted using one-way ANOVA or the Kruskal–Wallis test, depending on the distributional characteristics of the variables. For within-group comparisons of pre-test and post-test scores, the normality of the pre-test–post-test difference scores was assessed using the Shapiro–Wilk test; paired-samples t-tests were used when the difference scores were normally distributed, whereas the Wilcoxon signed-rank test was used otherwise. When a statistically significant omnibus effect was identified, post-hoc pairwise comparisons were conducted using the Games–Howell test following Welch's ANOVA and Dunn's test with Bonferroni adjustment following the Kruskal–Wallis test. The level of statistical significance was set at $p < .05$.

Normality was assessed separately for each group within each sub-dimension, and the choice of test was made accordingly at the group level rather than uniformly across all groups. As a result, for certain subdimensions, different tests were applied across groups depending on whether the assumption of normality was satisfied. Furthermore, for between-group comparisons, normality was assessed independently for pre-test and post-test scores. Consequently, for certain sub-dimensions, the statistical test applied to between-group comparisons at pre-test may differ from that used post-test, reflecting the distributional characteristics of each measurement occasion rather than a methodological inconsistency. The specific statistical test applied to each group and variable is explicitly reported in the corresponding tables.

Effect sizes were calculated to determine the magnitude of the observed differences, using d_z (computed as $d_z = t/\sqrt{n}$, which indexes the effect relative to the standard deviation of difference scores) and $r = |Z|/\sqrt{N}$ for Wilcoxon signed-rank tests, where Z is the standardised test statistic and N is the number of pairs. For between-group comparisons, η^2 (eta-squared) was calculated for one-way and Welch's ANOVA as $\eta^2 = (F \times df_1) / (F \times df_1 + df_2)$, and ϵ^2 (epsilon-squared) was calculated for Kruskal–Wallis tests as $\epsilon^2 = (H - k + 1) / (n - k)$, where H is the Kruskal–Wallis statistic, k is the number of groups, and n is the total sample size.

Findings

Findings Related to Research Question 1: Academic Achievement

This section presents the findings on students' academic achievement in the experimental and control groups.

Table 2. Comparison of pre-test achievement scores across groups

	Group	n	Mean	SD
Achievement Test	Exp-1	20	38.85	9.86
	Exp-2	16	36.77	9.31
	Control	15	36.26	9.40

As presented in Table 2, the one-way ANOVA indicated no statistically significant differences among the groups in pre-test achievement scores, $F(2, 48) = 0.37$, $p = .69$.

Table 3. Comparison of pre-test and post-test achievement scores

Group	Variable	Test	n	Mean	SD	t	p
Exp-1	Achievement Test	Pre-test	20	38.85	9.86	-18.21	< .001
		Post-test	20	70.68	9.46		
Exp-2	Achievement Test	Pre-test	16	36.77	9.31	-10.42	< .001
		Post-test	16	69.15	7.38		
Control	Achievement Test	Pre-test	15	36.26	9.40	-8.12	< .001
		Post-test	15	62.41	13.18		

As presented in Table 3, the paired-samples t-tests showed statistically significant increases in achievement scores from pre-test to post-test across all groups (Exp-1, Exp-2, and Control; $p < .001$). In all groups, post-test mean scores exceeded pre-test mean scores, indicating that students' academic achievement improved over the course of the intervention. These increases were associated with large effect sizes (Exp-1: $d_z = 4.07$; Exp-2: $d_z = 2.60$; Control: $d_z = 2.10$). As d_z is computed relative to the standard deviation of difference scores, d_z values reflect the consistency and magnitude of improvement within each group.

Table 4. Comparison of post-test achievement scores across groups

	Group	n	Mean	SD
Achievement Test	Exp-1	20	70.68	9.46
	Exp-2	16	69.15	7.38
	Control	15	62.41	13.18

As shown in Table 4, the one-way ANOVA indicated no statistically significant differences among the groups for post-test achievement scores ($F(2, 48) = 3.06$, $p = .06$, $\eta^2 = .11$). Inspection of group means showed that both experimental groups (Exp-1: $M = 70.68$; Exp-2: $M = 69.15$) had higher scores than the control group ($M = 62.41$); however, these differences did not reach statistical significance. Although statistical significance was not achieved, the effect size ($\eta^2 = .11$) suggests a medium-to-large practical effect; this lack of statistical significance may reflect limited statistical power resulting from the relatively small sample size. This suggests that, although all instructional approaches improved achievement, differences between groups were insufficient to reach statistical significance.

Findings Related to Research Question 2: Motivation Toward Learning Science

This section presents findings on students' motivation for learning science in the experimental and control groups.

Table 5. Comparison of pre-test motivation scores across groups

	Group	n	Mean	SD
Motivation for Research	Exp-1	20	3.24	0.90
	Exp-2	16	3.19	0.65
	Control	15	3.19	1.38
Motivation for Performance	Exp-1	20	3.45	0.91
	Exp-2	16	3.65	0.90
	Control	15	2.93	1.28
Motivation for Communication	Exp-1	20	3.13	0.76
	Exp-2	16	3.14	1.11
	Control	15	3.52	1.03
Motivation for Collaborative Work	Exp-1	20	3.55	1.00
	Exp-2	16	3.97	0.83
	Control	15	3.93	0.94
Motivation for Participation	Exp-1	20	3.58	1.38
	Exp-2	16	3.79	1.29
	Control	15	3.31	1.07
Science Learning Motivation Scale	Exp-1	20	3.36	0.70
	Exp-2	16	3.49	0.65
	Control	15	3.35	0.90

Note1. Motivation for Research: Welch's $F(2, 28.73) = 0.02$, $p = .98$; Motivation for Performance: Welch's $F(2, 29.39) = 1.58$, $p = .22$; Motivation for Communication: Welch's $F(2, 28.30) = 0.81$, $p = .46$; Motivation for Collaborative Work: $\chi^2(2) = 2.20$, $p = .33$; Motivation for Participation: $\chi^2(2) = 1.60$, $p = .45$; Science Learning Motivation Scale: Welch's $F(2, 29.86) = 0.20$, $p = .82$

Note2. Welch's F test was applied to the Motivation for Research, Performance, and Communication subscales and to the overall Science Learning Motivation Scale when the assumption of homogeneity of variances was violated. χ^2 = Kruskal–Wallis test.

Table 6. Comparison of pre-test and post-test motivation scores within groups

Group	Variable	Test	n	Mean	SD	Test Stat.	p
Exp-1	Motivation for Research	Pre-test	20	3.24	0.90	$Z = -3.25$	.001
		Post-test	20	4.03	0.74		
	Motivation for Performance	Pre-test	20	3.45	0.91	$t(19) = -3.88$	.001
		Post-test	20	4.35	0.65		
	Motivation for Communication	Pre-test	20	3.13	0.76	$t(19) = -4.60$	< .001
		Post-test	20	4.26	0.60		
	Motivation for Collaborative Work	Pre-test	20	3.55	1.00	$t(19) = -2.72$	.014
		Post-test	20	4.24	0.68		
	Motivation for Participation	Pre-test	20	3.58	1.38	$t(19) = -2.64$	.016
		Post-test	20	4.50	0.54		
	Science Learning Motivation Scale	Pre-test	20	3.36	0.70	$t(19) = -5.29$	< .001
		Post-test	20	4.25	0.44		
Exp-2	Motivation for Research	Pre-test	16	3.19	0.65	$t(15) = -3.23$	.006
		Post-test	16	3.95	0.86		
	Motivation for Performance	Pre-test	16	3.65	0.90	$t(15) = -1.14$	.274
		Post-test	16	3.98	0.80		
	Motivation for Communication	Pre-test	16	3.14	1.11	$t(15) = -1.19$	.254
		Post-test	16	3.54	0.82		
	Motivation for Collaborative Work	Pre-test	16	3.97	0.83	$t(15) = -1.14$	.272
		Post-test	16	4.30	0.61		
	Motivation for Participation	Pre-test	16	3.79	1.29	$t(15) = -1.63$	.124
		Post-test	16	4.40	0.65		
	Science Learning Motivation Scale	Pre-test	16	3.49	0.65	$t(15) = -2.31$	.035
		Post-test	16	3.98	0.47		
Control	Motivation for Research	Pre-test	15	3.19	1.38	$t(14) = -0.61$	.551
		Post-test	15	3.40	1.44		
	Motivation for Performance	Pre-test	15	2.93	1.28	$t(14) = 0.68$	.508
		Post-test	15	2.64	1.35		
	Motivation for Communication	Pre-test	15	3.52	1.03	$t(14) = -1.30$	.215
		Post-test	15	3.75	0.98		

Motivation for Collaborative Work	Pre-test	15	3.93	0.94	$t(14) = 0.90$	.385
	Post-test	15	3.72	0.87		
Motivation for Participation	Pre-test	15	3.31	1.07	$t(14) = 0.16$	.877
	Post-test	15	3.24	1.47		
Science Learning Motivation Scale	Pre-test	15	3.35	0.90	$t(14) = 0.03$	.978
	Post-test	15	3.34	0.97		

Note. t = paired-samples t -test; Z = Wilcoxon signed-rank test.

As presented in Table 5, between-group comparisons indicated no statistically significant differences in any pre-test motivation sub-dimension (motivation for research, performance, communication, collaborative work, or participation) or in the overall science learning motivation scale ($p > .05$). These findings indicate no significant differences in motivation among the groups prior to the intervention. As presented in Table 6, paired-samples t -tests and Wilcoxon signed-rank tests revealed statistically significant increases in motivation scores from pre-test to post-test in Experimental Group 1 across all sub-dimensions and in the overall Science Learning Motivation Scale ($p < .05$).

In this group, post-test mean scores were consistently higher than pre-test scores, indicating a substantial improvement in students' motivation levels. In Experimental Group 2, statistically significant increases were observed in the Motivation for Research sub-dimension ($p < .01$) and in the overall Science Learning Motivation Scale ($p < .05$), whereas no significant changes were found in the other sub-dimensions ($p > .05$). In contrast, no statistically significant differences were observed between pre-test and post-test scores in the control group for any motivation sub-dimension or for the overall scale ($p > .05$), indicating that students' motivation levels remained largely unchanged.

Effect sizes were calculated for statistically significant comparisons only, using d_z for paired-samples t -tests and $r = |Z|/\sqrt{N}$ for Wilcoxon signed-rank tests. The results indicated large effect sizes for all significant comparisons in Experimental Group 1 (d_z and r values ranging from 0.59 to 1.18) and large-to-medium effect sizes for the significant comparisons in Experimental Group 2 (Motivation for Research: $d_z = 0.81$; overall scale: $d_z = 0.58$), suggesting practically meaningful improvements in motivation.

Table 7. Comparison of post-test motivation scores across groups

	Group	n	Mean	SD
Motivation for Research	Exp-1	20	4.03	0.74
	Exp-2	16	3.95	0.86
	Control	15	3.40	1.44
Motivation for Performance	Exp-1	20	4.35	0.65
	Exp-2	16	3.98	0.80
	Control	15	2.64	1.35
Motivation for Communication	Exp-1	20	4.26	0.60
	Exp-2	16	3.54	0.82
	Control	15	3.75	0.98
Motivation for Collaborative Work	Exp-1	20	4.24	0.68
	Exp-2	16	4.30	0.61
	Control	15	3.72	0.87
Motivation for Participation	Exp-1	20	4.50	0.54
	Exp-2	16	4.40	0.65
	Control	15	3.24	1.47
Science Learning Motivation Scale	Exp-1	20	4.25	0.44
	Exp-2	16	3.98	0.47
	Control	15	3.34	0.97

Note. Motivation for Research: Welch's $F(2, 27.58) = 1.19$, $p = .32$, $\eta^2 = .08$; Motivation for Performance: $\chi^2(2) = 13.84$, $p = .001$, $\varepsilon^2 = .25$ (Exp-1 > Control); Motivation for Communication: Welch's $F(2, 27.63) = 4.87$, $p = .015$, $\eta^2 = .26$ (Exp-1 > Exp-2); Motivation for Collaborative Work: $\chi^2(2) = 4.26$, $p = .12$, $\varepsilon^2 = .05$; Motivation for Participation: $\chi^2(2) = 7.95$, $p = .02$, $\varepsilon^2 = .12$ (Exp-1 > Control); Science Learning Motivation Scale: Welch's $F(2, 27.42) = 5.94$, $p = .007$, $\eta^2 = .30$ (Exp-1 > Control). Welch's F was applied for Motivation for Research, Communication, and the overall Science Learning Motivation Scale; χ^2 = Kruskal–Wallis test. Post-hoc comparisons were conducted using the Games–Howell test following Welch's ANOVA and Dunn's test with Bonferroni adjustment following the Kruskal–Wallis test. Effect sizes were calculated using η^2 for Welch's ANOVA and ε^2 for Kruskal–Wallis tests.

As presented in Table 7, statistically significant differences were observed among the groups in Motivation for Performance ($\chi^2(2) = 13.84$, $p = .001$, $\varepsilon^2 = .25$), Motivation for Communication (Welch's $F(2, 27.63) = 4.87$, $p = .015$, $\eta^2 = .26$), Motivation for Participation ($\chi^2(2) = 7.95$, $p = .02$, $\varepsilon^2 = .12$), and the overall Science Learning Motivation Scale (Welch's $F(2, 27.42) = 5.94$, $p = .007$, $\eta^2 = .30$), whereas no significant differences were found for Motivation for Research or Motivation for Collaborative Work ($p > .05$).

Post-hoc comparisons indicated that Experimental Group 1 scored significantly higher than the Control Group in Motivation for Performance ($p = .001$), Motivation for Participation ($p = .023$), and the overall scale ($p = .009$). In Motivation for Communication, Experimental Group 1 scored significantly higher than Experimental Group 2 ($p = .017$). The difference between Experimental Group 1 and Experimental Group 2 on the overall scale was not significant ($p = .21$). These effects were of medium to large magnitude, indicating practically meaningful differences between groups. Therefore, the second research question was answered affirmatively, primarily in favour of the AR-enriched gamification group.

Results and Discussion

The mean achievement score of experimental group 1 was 38.85 on the pretest and 70.68 on the posttest. The mean score of experimental group 2 increased from 36.77 at pretest to 69.15. In the control group, the mean score increased from 36.26 to 62.41. Although the increases in the experimental groups were larger than those in the control group, inferential analyses indicated no statistically significant differences among the groups in posttest achievement scores ($p > .05$). Therefore, although the experimental groups had higher post-test means, the present findings do not provide sufficient evidence that either gamification condition was more effective than textbook-based instruction in improving astronomy achievement.

The absence of statistically significant differences in achievement between groups may be associated with the intervention's relatively short duration and the limited sample size, which may have reduced statistical power. Benli Özdemir (2023) examined the effect of AR applications on seventh-grade students' astronomy literacy and reported significant improvements. Similarly, Ferrari et al. (2024) reported that AR-based astronomy instruction significantly improved secondary school students' academic performance compared with traditional instruction. This finding suggests that the increase in achievement observed in experimental group 1 may be partially attributable to AR. Similar results were reported in a study conducted in China, which emphasized that AR offers strong support for science education but noted unresolved challenges that may hinder large-scale implementation (Zhang & Yao, 2025).

The effect of gamification on academic achievement has also been widely studied. Positive impacts of gamification on students' science achievement have been reported by Karagöz (2023) and Şahin and Namlı (2016). In gamified lessons, instructional planning is goal-oriented, and expectations, objectives, and intended learning outcomes are typically made explicit. Systematic planning and providing students with information about the learning process may have contributed to the achievement gains observed in the experimental groups. In terms of motivation, significant improvements, particularly in Experimental Group 1, were observed across all sub-dimensions. In contrast, no significant changes were identified in the control group, indicating that the observed improvements in motivation were primarily associated with the intervention.

These results can be explained by the characteristics of the instructional design implemented in the experimental groups. The integration of game elements such as feedback, rewards, and progression structures appears to have increased student engagement and sustained attention throughout the learning process. Additionally, augmented reality in Experimental group 1 provided interactive, hands-on learning experiences that likely supported active participation and deeper processing of scientific concepts. These findings are consistent with Self-Determination Theory, which emphasizes the roles of autonomy, competence, and relatedness in motivation.

Comparisons between the experimental groups showed no statistically significant differences in the performance and participation subdimensions or on the overall scale ($p = .21$). However, Experimental Group 1 scored significantly higher than Experimental Group 2 in Motivation for Communication ($p = .017$). These results suggest that integrating AR into gamification may provide additional benefits for some motivational outcomes, particularly motivation for communication; however, further research with larger samples is needed to confirm this interpretation. This difference may be related to the use of digital tools that support more interactive learning experiences. The findings are consistent with previous studies (Kapp, 2012; Razali et al., 2020).

Similarly, Bağrıyanık (2025) reported that gamification has a moderate and statistically significant effect on motivation in science education. A recent meta-analysis of K-12 studies similarly found a moderate-to-strong effect of gamification on student motivation, with the largest effect among secondary school students (Kurnaz & Koçtürk, 2025). Recent studies also indicate that integrating these technologies with self-regulated learning strategies can improve student engagement in science learning environments (Ateş & Şahin Kölemen, 2025; Ateş & Polat, 2025). These findings support earlier research showing that combining gamification elements with interactive technologies can raise student engagement and motivation (Kalogiannakis et al., 2021; Ateş & Polat, 2025).

This study examines these approaches within astronomy education. Although no statistically significant between-group differences were found in academic achievement, higher mean scores in the experimental groups, together with gains in motivation, indicate potential learning benefits that should be examined in larger and more diverse samples. The interactive and three-dimensional features of AR applications, when integrated with the motivational elements of gamification, can increase students' interest and attention while reducing learning-related anxiety (Chiang & Liu, 2023; Özeren & Top, 2023).

The findings show that both gamification and AR-enriched gamification were associated with higher motivation and improved academic performance in astronomy-related topics. Although statistically significant differences in achievement between groups were not observed, higher mean scores in the experimental groups and clear improvements in motivation indicate the contribution of technology-supported instructional approaches. The integration of augmented reality with gamification is likely to create more engaging and interactive learning conditions that support students' motivation, participation, and communication.

Several limitations should be considered when interpreting these findings. First, the study involved a relatively small sample of 51 female students from three intact classes in a single selective middle school, which limits the generalizability of the findings. Second, the intervention lasted four weeks, and longer-term motivational and achievement effects were not examined. Third, although the two experimental conditions followed comparable instructional sequences, some activities differed in modality as well as in the use of AR; therefore, differences between the experimental groups cannot be attributed exclusively to the presence of AR. Future studies with larger and more diverse samples, longer interventions, and more tightly controlled instructional conditions are needed to isolate the specific contribution of AR within gamified learning environments.

Recommendations

The findings of this study provide implications for educational practice and future research. The recommendations are presented under two categories: implications for practice and directions for future research.

Implications for Practice

Astronomy includes abstract concepts that are often difficult for students to visualize; therefore, AR technologies can be integrated into the curriculum to provide three-dimensional representations. This may support the development of students' spatial reasoning skills. Effective use of AR and gamification in science classrooms requires practical pedagogical training. Teachers should be supported in managing technology-enhanced learning environments. Schools need adequate technological infrastructure, including tablets, stable internet access, and user-friendly AR applications aligned with the curriculum, to reduce technical disruptions during implementation.

Directions for Future Research

This study focused on short-term effects. Future research should use longitudinal designs to examine how AR-enriched gamification influences knowledge retention over time. Further studies can examine the effects of AR-enriched gamification at different educational levels, and across other science topics. To better interpret quantitative findings, future research should include qualitative data, such as student interviews or teacher observations, to identify underlying motivational factors and implementation challenges.

Scientific Ethics Declaration

* The authors declare that the scientific, ethical, and legal responsibility for this article published in JESEH journal rests with the authors.

* Ethical approval for this research was obtained from the Scientific Research and Ethics Committee of Gazi University (Meeting date: September 5, 2023; Meeting no: 15; Research Code No: 2023-10).

Conflict of Interest

* The authors declare that they have no conflicts of interest

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