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The Effect of Educational Games on Academic Achievement, Motivation, and Anxiety in the Solar System and Eclipses Unit

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Educational games can provide engaging learning environments that support active participation and the learning of abstract concepts. This study examined the effect of game-based learning on sixth-grade students' science learning motivation, science anxiety, and academic achievement in the Solar System and Eclipses unit. A quantitative, quasi-experimental, pre-test–post-test, control group design was employed. The study sample consisted of 48 sixth-grade students (26 in the experimental group and 22 in the control group) from a public school affiliated with the Ministry of National Education in Aksaray, Türkiye. Participants were selected using convenience sampling. The intervention lasted four weeks. Data were collected using the Solar System and Eclipses Achievement Test, the Motivation Scale for Science Learning and the Science Anxiety Scale. MANOVA was performed to examine differences between the groups. The findings revealed no statistically significant differences in pre-test scores between the groups. While there were no significant differences in post-test motivation scores, the experimental group the experimental group demonstrated significantly higher academic achievement. Although the experimental group had a descriptively lower mean score for science anxiety, this difference was not statistically significant after Bonferroni correction. Based on these findings, future studies could examine how different game settings and levels of in-game competition relate to students' learning outcomes.

Introduction

Astronomy draws on both observation and technological advances, yet its abstract concepts can complicate learning and increase student anxiety (Arıcı, 2013; Cheng et al., 2015; Duit, 1991; Jaeger & Dacorogna, 2024; Turner, 2014). When students perceive content as disconnected or fear errors, their attitudes toward science may decline, highlighting the need for engaging and accessible instructional strategies (Porozovs & Kristapsone, 2017). As traditional methods often prove insufficient (Pursell, 2009), educational games offer an engaging active-learning alternative by making abstract concepts more accessible while developing problem-solving and collaborative skills (Noemí & Máximo, 2014; Adachi &

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Willoughby, 2013; Sánchez & Olivares, 2011). Educational games can reduce fear of failure, encourage students to express ideas, and provide immediate feedback (Huizinga, 2018; Whelan, 2005; Small, 2000). Evidence across science education indicates that diverse formats, including card games, role-playing, LEGO-based activities, and digital games, can enhance scientific knowledge, problem-solving, motivation, and conceptual understanding (Morris et al., 2013; Cook, 2014; Lin et al., 2023; Muntean et al., 2017; Liu & Chu, 2010).

For the "Solar System and Eclipses" unit, dominoes and other game-based activities have been associated with higher academic achievement among sixth-grade students (Lisnani & Irzawati, 2019; Şensoy & Varzikioğlu, 2025). However, research on this unit remains limited (Güçhan Özgül, 2017; Halaç & Bozdoğan, 2021; Korkmaz, 2018; Özdemir, 2022; Şaşmaz Ören & Erduran Avcı, 2004; Topçuoğlu, 2024; Tüncaz, 2023; Varzikioğlu, 2023). Existing research primarily focuses on classroom-based matching games, with limited evidence on competitive, out-of-classroom activities addressing the full range of learning outcomes in the unit. This study, therefore, examines the effects of an enriched, game-based "Solar System and Eclipses" curriculum on sixth-grade students' science anxiety, motivation, and academic achievement.

The research questions are as follows:

(1) Does the game-enriched unit significantly affect students' science learning motivation?
(2) Does the game-enriched unit significantly affect students' science anxiety levels?
(3) Does the game-enriched unit significantly affect students' academic achievement?
(4) Is there a statistically significant difference between students' post-test scores and retention test scores?

Methodology

Research Design

This study employed a quasi-experimental pretest–posttest control group design with a quasi-experimental approach, which is well-suited to school settings where random assignment is often impractical (Küçük & Çepni, 2004). During game sessions, the researcher conducted continuous informal observations focusing on student engagement, group dynamics, collaboration and emotional reactions, such as excitement or performance anxiety. Unstructured interviews were also conducted immediately after the game sessions to capture students' spontaneous opinions and experiences.

Participants

The sample consisted of 48 sixth-grade students from a public middle school in central Aksaray during the 2024–2025 academic year. Because classroom assignments were predetermined, individual random assignment was not feasible. Therefore, a quasi-experimental design involving two intact classes (6/A and 6/B) was adopted. The participants were selected through convenience sampling, and the two intact classes were assigned to the experimental and control conditions. Class 6/A served as the experimental group (n = 26; 11 male, 15 female students), while 6/B as the control group (n = 22; 9 male, 13 female students).

Data Collection Tools

Data were collected using the Solar System and Eclipses Achievement Test (Altan et al., 2024; KR-20 = .837, average difficulty = .517, average discrimination = .54), the Science Learning Motivation Scale (Dede & Yaman, 2008; Cronbach's alpha = .80), and the Science Anxiety Scale (Şimşek & Hamzaoğlu, 2023; Cronbach's alpha = .92).

Development Process of the Games

The educational games (Let's Sequence, Don't Get Eclipsed, Word Hunter, The Last Word is Yours, Collect Points, Spin Around, and Hot Balls) were developed in alignment with the learning outcomes of the Solar System and Eclipses unit. Two science education specialists and five science teachers evaluated the games in terms of the clarity of the instructions and rules, the appropriateness of the materials, and their overall suitability, while a Turkish language educator reviewed the materials for linguistic accuracy and clarity. The alignment between the games and learning outcomes is presented in Table 1.

Table 1. Aligning educational games with learning outcomes

Learning Outcomes		**Educational Games**						
Main Learning Outcome	Sub-Learning Outcome	Let's Sequence	Spin Around	Collect Points	Don't Get Eclipsed	Hot Balls	The Last Word is Yours	Word Hunter
Compares the planets in the solar system with one another.	The basic characteristics of planets (terrestrial, gaseous, inner planet, outer planet) are addressed.		X			X	X	X
	It is mentioned that planets have satellites.		X			X	X	X
	The sizes of planets are addressed spatially.		X			X	X	X
	The order of the planets' distances from the Sun is mentioned.	X	X			X	X	X
	The concepts of meteor, meteorite, and asteroid are addressed.			X		X		
Creates a model by arranging the planets in the solar system according to their proximity to the Sun.						X		
Predicts how a solar eclipse occurs.	The phase of the Moon during a solar eclipse is mentioned.				X		X	
	It is mentioned that a solar eclipse does not occur every month.				X		X	

Predicts how a lunar eclipse occurs.	The phase of the Moon during a lunar eclipse is discussed.	X	X
	Every month, it is mentioned that there is no lunar eclipse.	X	X
Creates a model representing solar and lunar eclipses.		X	

Following expert review, the games were revised and pilot-tested with 57 students from three middle schools in central Aksaray under the supervision of science teachers. Semi-structured interviews with teachers and students were conducted to evaluate the feasibility of the games and identify implementation challenges. Pilot studies indicated that “Hot Balls” and “Word Hunter” were time-consuming and were therefore revised. “Hot Balls” was reduced from three to two true/false questions per turn, while “Word Hunter” was changed from a fill-in-the-blank format to a word-selection format. The games were then finalised for use both inside and outside the classroom. Schoolyard was used for selected activities to minimise classroom noise. “The Last Word Is Yours” and “Spin Around” consisted of a single stage, whereas the remaining five games consisted of two stages. Figure 1 presents their characteristics and structural flow.

Let’s Sequence

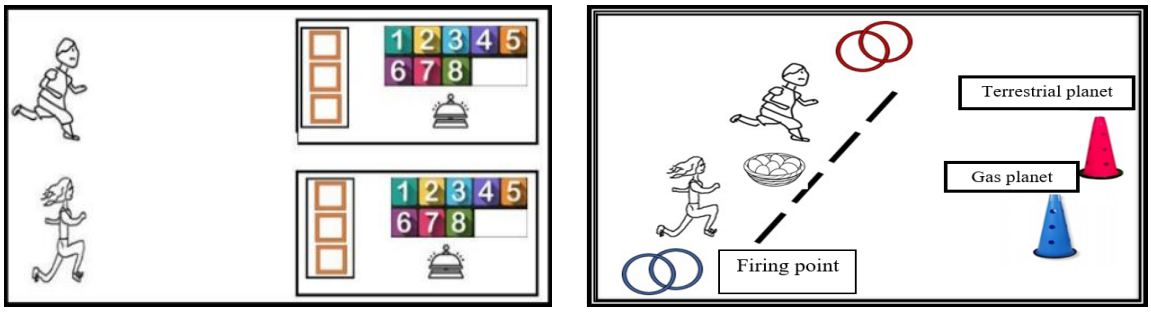


Figure 1. Structure and characteristics of the educational games

Game Procedure

(1) Sequence Task: The teacher selects a card listing three planets. Upon the "Start" command, students memorize the order of the planets based on their distance from the Sun and match them to the numbered desks.
(2) Categorization Task: In the second stage, students select a planet-themed egg and classify it as gaseous or terrestrial.
(3) Scoring: The first first student to provide the correct classification receives two rings, while the second student receives one.
(4) Physical Challenge: Students then race to place their rings on the corresponding gaseous or terrestrial cone.

Spin Around



Figure 2. Game Procedure

Game Procedure

Blue and red arrows indicate each team's route. After hearing a description of a planet and the teacher's whistle, contestants race from the starting point to the ring representing the correct planet

Data Collection Process

The study was conducted during the first semester of 2024–2025 over 14 instructional hours (4 hours per week). Following a parent meeting covering informed consent, voluntary participation, and student health considerations, the experimental (n = 26) and control (n = 22) groups were finalised. Pre-test measures of motivation (MSLM), anxiety (SAS), and achievement (SSEAT) were administered by the researcher to both groups within the same week.

Weekly lesson plans adhered strictly to the official curriculum for both groups. Several measures were taken to minimize potential researcher bias. Prior to implementation, weekly instructional procedures and game rules were standardised and peer-reviewed by science education specialists, ensuring adherence to predetermined lesson scripts and to ensure consistency across instructional procedures and adherence to the predetermined lesson plans. The researcher taught both groups to maintain procedural consistency and control for teacher effects. Finally, student data were coded before analysis to minimize expectancy effects. The control group received textbook-based instruction, whereas the experimental group participated in researcher-developed educational games. Materials and logistics were prepared in advance to minimise disruptions. Students were informed that students were informed that participation was voluntary and that game scores were symbolic and unrelated to their academic grades. Only data from the predefined study cohort were analysed. Symbolic rewards were provided to top-scoring students, and the weekly instructional schedule is presented in Table 2.

Table 2. Weekly Lesson Plan

Academic week	Class hour	Subject matter	Learning outcome	Method/ technique	Lesson implementation	Game-based experimental group
1	4	Solar System	1. Compares the planets in the solar system with each other.	Question-answer method, brainstorming technique	The concepts of "Planet and Satellite" are taught by questioning the characteristics that a celestial body should possess. The classification of planets is made, and their general characteristics are discussed.	Let's Sequence, Spin Around
2	4	Solar System	1. Compares the planets in the solar system with each other. 2. Creates a model by ordering the planets in the solar system according to their proximity to the Sun.	Question-answer method, Computer-assisted instruction, Model creation	The general characteristics of the planets in the solar system are discussed, indicating that not every planet has moons or rings. Videos are shown through the Education Information Network (EIN). Students are instructed to complete the model-making activity in the textbook using simple materials.	Hot Balls, Collect Points
3	4	Solar and Lunar Eclipses	1. Predicts how a solar eclipse forms. 2. Predicts how a lunar eclipse occurs.	Question-answer method, Prediction-Observation, Experiment	Images of eclipses are brought in and students' existing knowledge is questioned. Observations are made using an eclipse model and eclipse characteristics are predicted.	Don't get eclipsed, The last Word is yours
4	2	Solar and Lunar Eclipses	1. Creates a model representing solar and lunar eclipses	Model Creation	The eclipse model creation activity in the textbook is carried out using simple materials.	Word hunter

Following the intervention, the MSLM, SAS, and SSEAT were administered as post-tests, with the SSEAT re-administered two months later as a retention measure. Table 3 presents the distribution of SSEAT items by unit objective.

Table 3. Distribution of SSEAT Items According to Learning Outcomes

Learning Outcomes		Item number
Compares the planets in the solar system with each other.	a. Explains the basic characteristics of planets (terrestrial, gaseous, inner planet, outer planet)	1-4-8-9-12-13-26
	b. It gives prefixes to the satellites of the planets.	
	c. Compares the sizes of planets with each other.	
	d. Compares the order of planets based on their distances from the Sun.	
	e. Explains the difference between meteor, meteorite, and asteroid concepts.	
Creates a model by arranging the planets in the solar system according to their proximity to the Sun.		3-5-25-26
Predicts how a solar eclipse occurs.	a. Predicts in which phase the Moon is during a solar eclipse.	16-19-20-22-23-24
	b. It explains why there isn't a solar eclipse every month.	
Predicts how a lunar eclipse occurs.	a. Predicts which phase the Moon is in during a lunar eclipse.	16-20-22-24
	b. Every month, he/she explains that there is no lunar eclipse.	
Creates a model representing solar and lunar eclipses.		18-21-17

Data Analysis

To evaluate the effect of the game-enriched unit on academic achievement, science anxiety, and motivation, pretest-to-posttest gain scores (difference scores) were calculated, and a one-way Multivariate Analysis of Variance (MANOVA) was performed. Although MANCOVA was initially planned, the severe violation of the homogeneity of regression slopes assumption (Group x SAS pre-test, $F(1,40) = 7.096$, $p = .011$) warranted the use of gain-score MANOVA as a methodologically appropriate alternative. Retention scores were then compared using a paired-samples t-test. Given the three dependent variables in this study, the significance level was adjusted to $\alpha = .0167$. Data screening revealed no missing data for the achievement test; however, a total of four item-level missing data points were identified: one missing response in the science anxiety scale pre-test and three missing responses distributed across the motivation scale post-test. As the missing data were considered missing completely at random (Little's MCAR test, $p > .05$), a participant-specific subscale mean imputation strategy was implemented, replacing missing items with the individual's average score within that specific sub-dimension. The assumptions of MANOVA were then assessed using the Shapiro–Wilk test, Mahalanobis distance, Levene's test, and Box's M test (Shapiro-Wilk $p \geq .109$, $p > .05$), (Maximum Mahalanobis distance = 9.49 < 16.27, $p > .001$), (Levene's Test results for motivation gain $p = .396$, science anxiety gain $p = .566$, and academic achievement gain $p = .983$, (Box's M = 4.474, $F(6, 15152.2) = 0.697$, $p = .656$). These tests were used to evaluate univariate normality, multivariate normality, homogeneity of variances, and equality of covariance matrices, respectively.

Findings

Descriptive statistics were employed to compare pre-test and post-test scores descriptive statistics were used to compare pretest and posttest scores for all measures.

Furthermore, a one-way MANOVA on pretest to-posttest gain scores was conducted to evaluate to evaluate the effect of the game-enriched 'Solar System and Eclipses' unit on academic achievement, motivation, and science learning anxiety.

Descriptive Statistics

Table 4 presents descriptive statistics for the experimental and control groups, summarizing pretest and posttest scores for all measures

Table 4. Descriptive statistical values of the variables.

			N	Min.	Max.	$\overline{X}$	SD	Skewness	Kurtosis
MSLM	Pre-test	CG	22	67	102	84.95	9.35	-.485	-.389
		EG	26	68	102	87	9.54	-.502	-.396
	Post-test	CG	22	69	103	88.45	8.61	-.283	-.105
		EG	26	78	103	91.88	5.63	-.023	.541
SAS	Pre-test	CG	22	34	83	56.77	12.75	.216	.614
		EG	26	34	83	54.31	13.43	.342	-.506
	Post- test	CG	22	38	74	57.58	10.75	-.270	-.894
		EG	26	38	66	51.15	7.61	.278	-.326
SSEAT	Pre-test	CG	22	4	11	7.91	1.66	-.117	.562
		EG	26	3	13	7.38	2.53	.122	-.111
	Post- test	CG	22	3	19	11.27	4.30	.095	-.690
		EG	26	8	25	15.54	5.17	.302	-.996

As shown in Table 4, the experimental group showed increased motivation and academic achievement scores and decreased science learning anxiety scores compared with the control group.

Inferential Statistical Findings

Table 5 presents the independent-samples t-test results, evaluating whether significant baseline differences existed between the experimental and control groups across all dependent variables.

Table 5. T-test results of pre-test scores of dependent variables according to groups.

Variable	Groups	N	$\overline{X}$	SD	df.	t	p	Cohen's d
MSLM Pre-test	CG	22	84.95	9.35	46	.747	.458	.22
	EG	26	87.00	9.54				
SAS Pre-test	CG	22	56.78	12.75	46	-.648	.518	-.19
	EG	26	54.31	13.43				
SSEAT Pre-test	CG	22	7.91	1.66	46	-.832	.410	-.25
	EG	26	7.39	2.53				

* Alpha level α = 0.05

As shown in Table 5, no significant pretest differences were observed between groups in motivation ($t(46) = 0.747$, $p = .458$, $d = .22$), science anxiety ($t(46) = -0.648$, $p = .518$, $d = -.19$), or academic achievement ($t(46) = -0.832$, $p = .410$, $d = -.25$).

Table 6. Findings related to the homogeneity of regressions assumption.

Source	Dependent Variable	*df*	*F*	*p*	Partial η^2	Sum of Squares	Mean Square
Group	MSLM Post test	1	.276	.602	.007	9.691	9.691
	SAS Post test	1	1.505	.227	.036	24.151	24.151
	SSEAT Post test	1	6.108	.018	.132	60.192	60.192
MSLM Pre test	MSLM Post test	1	19.193	.001	.324	673.964	673.964
	SAS Post test	1	.125	.725	.003	2.008	2.008
	SSEAT Post test	1	1.228	.274	.030	12.106	12.106
SAS Pre test	MSLM Post test	1	.417	.522	.010	14.648	14.648
	SAS Post test	1	190.317	.001	.826	3053.499	3053.499
	SSEAT Post test	1	.934	.340	.023	9.200	9.200
SSEAT Pre test	MSLM Post test	1	.599	.443	.015	21.047	21.047
	SAS Post test	1	.139	.711	.003	2.237	2.237
	SSEAT Post test	1	36.550	.001	.477	360.189	360.189
Group * MSLM Pre test	MSLM Post test	1	.010	.920	.000*	.358	.358
	SAS Post test	1	1.168	.286	.028	18.741	18.741
	SSEAT Post test	1	2.899	.096	.068	28.573	28.573
Group * SAS Pre test	MSLM Post test	1	.386	.538	.010	13.540	13.540
	SAS Post test	1	7.096	.011	.151	113.857	113.857
	SSEAT Post test	1	1.428	.239	.034	14.068	14.068
Group* SSEAT Pre test	MSLM Post test	1	3.604	.065	.083	126.542	126.542
	SAS Post test	1	1.050	.312	.026	16.852	16.852
	SSEAT Post test	1	.023	.880	.001	.226	.226
Error	MSLM Post test	40				1404.591	1404.591
	SAS Post test	40				641.770	641.770
	SSEAT Post test	40				394.185	394.185
Total	MSLM Post test	48				393995.000	
	SAS Post test	48				144875.000	
	SSEAT Post test	48				10130.000	

* Alpha level α = .05

The Group × Anxiety pretest interaction was significant, $F(1, 40) = 7.096$, $p = .011$, partial $\eta^2 = .151$, violating the homogeneity of regression slopes assumption and therefore precluding the planned MANCOVA.

Findings Related to the Research Questions

A one-way MANOVA was conducted on pre-to-post gain scores to examine the effects of the intervention on motivation, science anxiety, and academic achievement (Table 7). To control for Type I error across the three dependent variables, the Bonferroni-adjusted significance level was set at α = .0167 (.05/3).

Table 7. MANOVA Results for Pretest-to-Posttest Gain Scores Across Dependent Variables

Source	Dependent Variable (Gain Scores)	*df*	*F*	*p*	Partial η²
Group	Multivariate Effect (Wilks' Λ)[a]	3.44	13.571	<.001	.498
	Motivation Gain	1	.356	.553	.008
	Anxiety Gain	1	4.541	.038	.090
	Academic Achievement Gain	1	22.767	<.001	.331
Error	Multivariate Error	44			
	Univariate Error (Within-groups)	46			

* [a] Wilks' Λ value = .502.
*Bonferroni correction was applied (adjusted alpha level α = .0167). Consequently, p-values lower than .0167 are considered statistically significant.

The omnibus multivariate test results revealed a statistically significant main effect of group membership on the combined dependent variables, Wilks' Λ = .502, $F(3, 44) = 13.571$, $p < .001$, and partial $\eta^2 = .498$. As shown in Table 7, no significant group differences were found in motivation gain, $F(1, 46) = 0.356$, $p = .553$, $\eta p^2 = .008$, or science anxiety, $F(1, 46) = 4.541$, $p = .038$, $\eta p^2 = .090$, based on the Bonferroni-adjusted threshold (α = .0167). In contrast, the experimental group showed significantly greater gains in academic achievement, $F(1, 46) = 22.767$, $p < .001$, $\eta p^2 = .331$.

Additionally, a follow-up paired-samples t-test was conducted to examine changes in science learning motivation within the experimental group. The analysis confirmed that the motivation scores within the experimental group increased significantly from pretest to posttest (t(25) = 2.448, p = .022).
The findings indicate that educational games significantly improved academic achievement but had no significant effects on motivation or science anxiety.

Findings Regarding the Impact of the Study on Retention

To evaluate the retention of academic achievement following the game-enriched unit, a paired - samples t-test was conducted to compare academic achievement post-test and retention test mean scores. Table 8 presents these results.

Table 8. Paired-samples t-test results for SSEAT posttest and retention-test scores

Group	Test	N	$\overline{X}$	SD	t	sd	p
EG	Post test	26	15.5385	5.1709	3.996	25	.001
	Retention test	26	14.4231	4.7089			
CG	Post test	22	11.2727	4.3004	2.723	21	.013
	Retention test	22	10.0455	2.7684			

* Alpha level α = .05

As shown in Table 8, scores declined significantly from posttest to retention test in both experimental and control groups ($t_{(25)} = 3.996, p < .05$; $\bar{x}_{post} = 15.54, \bar{x}_{ret} = 14.42$), ($t_{(21)} = 2.723, p < .05$; $\bar{x}_{post} = 11.27, \bar{x}_{ret} = 10.05$). To further investigate these differences, a two-factor ANOVA for repeated measures was conducted, with results presented in Table 9.

Table 9. Two-way repeated-measures ANOVA results for SSEAT posttest and retention-test scores

Source of Variance	Sum of Squares	df	Mean Square	F	p
Between Groups					
Intercept	15668.091	1			
Group (EG/CG)	445.133	1	445.133	12.046	.001*
Error	1699.867	46	36.954		
Within Groups					
Measurement (Post-test – Retention test)	32.700	1	32.700	20.817	.000*
Group* Measurement	.075	1	.075	.047	.828
Error	72.259	46	1.571		

* Alpha level α = .05

As shown in Table 9, the two-way repeated-measures ANOVA revealed no significant Group × Measurement interaction, $F(1, 46) = 0.047$, $p = .828$, indicating similar knowledge-retention patterns in the experimental and control groups. Thus, the game-enriched unit did not result in a significantly different retention pattern compared with traditional instruction under the Bonferroni-adjusted α = .0167.

Results, Discussion and Recommendations

No significant pre-test differences were found in science anxiety, indicating baseline equivalence between the groups. After the intervention, the experimental group reported a decrease in anxiety, but this was not statistically significant under the Bonferroni-adjusted threshold. The decrease in anxiety among students in the experimental group may be related to the development of more positive attitudes toward the course. Throughout the implementation, students who were initially less active became more willing to participate, take responsibility, demonstrate leadership and express themselves (Annetta et al., 2009). Furthermore, successfully answering questions, completing game stages and earning team points appeared to boost students' self-confidence.

These factors may help explain the downward trend in students' anxiety observed during the games, even though this change did not reach statistical significance after the Bonferroni correction. In some studies, examining the effect of educational games on anxiety towards learning science (Alp, 2016; Cohen et al., 1989; Lin & Hou, 2023; Mavridis & Tiatsos, 2017; Rocha & Dandio, 2021; Sarıkaya, 2019; Su, 2016; Yıldız et al., 2017), similar findings have been reported in previous studies. In fact, in their study examining the effects of three-dimensional games and traditional games on anxiety and exam success, Mavridis and Tiatsos (2017) found that educational games reduced anxiety in students and increased exam success. In the study conducted by Yıldız et al. (2017), they examined the effects of incorporating educational games into the cooperative learning model on students' anxiety towards science learning, attitudes towards school, and social skills. The study concluded that educational games improved students' social skills and reduced their anxiety towards science learning. In the literature, there are also studies (Asan and Çeliktürk Sezgin, 2020; Mirzakhani and Moradi, 2021; Vanbecelaere et al., 2020) showing that games do not create a statistically significant difference on students' anxiety levels towards the course. Competition in educational games may trigger negative attitudes, stress, anxiety, boredom and

disappointment (Hanna et al., 2021; Rocha & Dondio, 2021), which could limit reductions in students' anxiety. Asan and Çeliktürk Sezgin (2020) also proposed that the brief intervention period could account for the lack of notable differences in anxiety between groups. Therefore, longer-term studies are needed to clarify the effects of educational games on anxiety, particularly in light of the potential for peer pressure, the fear of making mistakes, and concerns about falling behind.

Students' experiences during implementation also support this interpretation. Peer warnings following consecutive incorrect answers appeared to reduce students' willingness to continue, while students reported that feeling excited and finding some questions difficult increased their anxiety. These experiences may help explain why educational games do not necessarily reduce anxiety for all students. To mitigate potential negative psychological outcomes, future educational games should prioritise cooperative or scaffolded reward structures over purely competitive mechanics. Collaborative, goal-oriented activities that emphasise collective progress may reduce peer accountability and evaluation anxiety (Plass et al., 2013). Private or anonymous feedback, rather than public leaderboards, can further minimise embarrassment and fear of failure. Additionally, safe-to-fail' features, such as multiple attempts and framing errors as part of learning, may foster a growth mindset and support students' psychological safety (Kapp, 2012).

Prior to the implementation, an academic achievement test was administered to the groups to measure students' prior knowledge of the "Solar System and Eclipses" unit. No significant difference was found between the groups at pretest. After the intervention, achievement scores increased in both groups, with significantly greater gains in the experimental group. After four weeks of implementation, an increase in academic achievement test scores was detected in both the experimental and control groups. This observed increase was found to be statistically significant in favor of the experimental group. Variables thought to have influenced this significant difference include students' enjoyment of games, their active participation in lessons, and their placement in an environment where they felt comfortable, away from the classroom setting. During the games, students carefully listened to each other's questions and discussed the answers given, which may have contributed to more durable learning. It was observed that incorrect answers given during games were not forgotten by students; in subsequent activities, they corrected their mistakes and provided the correct information. This supported the retention of knowledge. It is important to distinguish the effects of the educational game from those of the outdoor learning environment. Although outdoor settings may reduce academic stress and enhance situational attention (Plass et al., 2013), the acquisition of abstract astronomical concepts required systematic cognitive interaction, peer discussion, and formative feedback embedded in the game mechanics. Thus, while the outdoor environment may have reduced anxiety about science, improvements in conceptual understanding and academic achievement were more closely associated with the instructional design of the educational games. Similar findings have been reported in studies examining the effects of educational games on academic achievement in science courses (Ağırgöl et al., 2022; Anwer, 2019; Dadaylı & Pekbay, 2021; Nadolny & Halabi, 2016; Noreen & Rana, 2019; Şentürk, 2020). For example, Dadaylı and Pekbay (2021) determined that educational games used in their study on "Measurement of Force and Friction Force" positively affected the academic achievement of fifth-grade students. Similar results were also obtained by Ağırgöl et al. (2022) in a study examining the effect of educational games on achievement in the "Regulatory and Control Systems" unit for sixth-grade students. There are also studies in the literature where educational games were used in different courses with similar results (Erol et al., 2021; Işık & Semerci, 2016; Öğütveren & Akkuş, 2024; Soydan et

al., 2022; Toğru, 2020). Erol et al. (2021) used educational games in teaching Turkish to students aged 8-12; Işık and Semerci (2016) used them in teaching English vocabulary to third-grade primary school students; Öğütveren and Akkuş (2024) in social studies courses; and Soydan et al. (2022) in teaching integers in mathematics courses. All of these studies found a significant difference in favor of the experimental group at the end of the process. These results indicate that courses enriched with games have a significant effect on increasing students' academic achievement. At the same time, there are also studies in the literature (Altun, 2019; Bayram, 2015; Korkusuz & Karamete, 2017; Yavuzyılmaz, 2018) indicating that the use of educational games does not result in a significant difference in academic achievement. It is thought that factors such as high-achieving students being unable to concentrate during games, failure to maintain classroom control during games, students focusing on the entertainment aspect rather than the educational role of games, and students focusing only on their own questions while ignoring other questions or instructions contribute to this situation. Although educational games positively affect academic achievement in studies, the effect of the competition factor should not be ignored. In their research, Chen et al. (2018) stated that students who were not exposed to competitive conditions had higher academic achievement compared to students under competitive conditions. This suggests that the competition factor in educational games could be examined more deeply.

No significant pretest difference in science learning motivation was found between the groups. Following the intervention, the groups also did not differ significantly in posttest motivation scores. The lack of a statistically significant difference in science learning motivation between the groups warrants a critical examination of the intervention's structural design and inherent objectives. Although the developed educational games successfully fostered immediate classroom participation and student enjoyment, their core instructional architecture was heavily geared towards reinforcing curricular content and procedural academic achievement rather than explicitly targeting motivational outcomes (Whitton, 2011). Consequently, the activities stimulated situational interest and classroom dynamics but fell short of systematically altering students' deeply ingrained students' underlying intrinsic motivation. It is thought that the competition factor in games may affect students, resulting in no significant difference between the motivation scores of the experimental and control groups. It was observed in the study that the competitive environment can create peer pressure on students, resulting in students showing a tendency to avoid participating in games. While it motivated higher-achieving or more competitive students, it simultaneously introduced peer pressure and a fear of making mistakes among lower-performing students, thereby inducing performance anxiety and actively suppressing potential gains in overall learning motivation. Lam et al. (2004) investigated the impact of competition on motivation by conducting a two-hour classroom typing course. While competition improved performance in simple tasks, its effectiveness decreased with the complexity of the task, and it had a negative impact on students' self-evaluations and motivation. This negative trend is consistent with Hanus and Fox (2015), who found that competitive, reward-based classroom games may reduce intrinsic motivation over time by increasing external pressure and evaluation anxiety. The four-week intervention (14 instructional hours) also represents a limitation, as motivation is relatively stable and resistant to short-term change; thus, the intervention may have captured a temporary novelty effect rather than sustained changes in science learning motivation (Clark et al., 2016). Although no significant difference between groups was found, there was a significant increase in motivation scores within the experimental group. Even the more academically challenged students seemed more willing to participate when they knew games would be used in lessons. Similarly, Şengün (2021) reported findings that support the positive effect of gamification on student motivation in social science courses. Similar findings were

reported by Çilengir and İzmirli (2023) which investigated how the use of gamification in teaching block-based programming affected students' motivation levels. Hanus and Fox (2015) stated in their study on the effects of educational games on intrinsic motivation and student satisfaction that the experimental group experienced decreases in motivation and satisfaction levels, and at the end of the process, lower intrinsic motivation was associated with poorer exam performance. Although games are generally welcomed by students, they can be boring for some students (Kinzie and Joseph, 2008). In the research conducted by Cheung and Ng (2021), an educational game called "PaGamO" was implemented with students. As a result of the application, some students expressed that they found the game boring and were uncomfortable with the questions in the stages being consistently in multiple-choice exam format. Other studies have reported positive effects of educational games on motivation (Knobloch, 2005; Paino, 2001; Papastergiou 2009; Yavuzyılmaz, 2018; Yenice et al., 2019). For example, Gürbüz (2019) used educational games in the "Propagation of Light" unit in his study and indicated that there was a significant increase in the motivation of the experimental group students. In a similar study, Yavuzyılmaz (2018) implemented educational games combined with the team-game-tournament method in the fifth-grade "Electricity" unit and found that students' motivation increased. This increase may be attributed to the enjoyable nature of games. Similarly, Beker Baş and Karamustafaoğlu (2022) reported that students perceived educational games as enjoyable, found them helpful in making the subject more concrete, and said that they increased their attention, thus supporting our findings. Furthermore, games may boost motivation by fostering students' desire to win, their persistence, and their sense of belonging to a group (Boyraz & Serin, 2016). Clear game rules, prior practice and explicit explanations of the learning areas may have had a positive impact on students' learning. These findings emphasise the importance of incorporating educational games into the curriculum. As positive attitudes towards school can encourage engagement and responsibility, games could be a valuable part of effective educational processes.

Two months after the intervention, the SSEAT was reapplied to both groups to assess knowledge retention. Although scores declined significantly from posttest to retention test in both groups, the pattern of decline did not differ significantly between the experimental and control groups. This may be due to decreased student interest as the existing curriculum continued to be followed, interference from newly learned topics affecting previous learning, and a lack of review of the first unit. Students' reports of being unable to remember some of the topics covered by the questions provide further support for these explanations. Similar findings have also been reported in previous studies on educational games. In their study with 56 fifth-grade students, Torun and Duran (2014) found significant differences in achievement and attitude scores in favour of the experimental group. However, they found no significant difference between groups in the retention test. In contrast, several studies have reported the positive effects of educational games on knowledge retention. Demir (2016), Koç (2019), Yorulmaz and Göv (2019), Can and Aydın (2022) and Pınar and Akgül (2024), respectively, found statistically significant effects of educational games on retention in mathematics, electricity, religious studies, polygons and cell division.

Limitations of the Study

This study has several limitations. First, the relatively small convenience sample (N = 48) from a single public middle school limits the representativeness and generalizability of the findings. Future studies should employ larger, randomly selected, and geographically diverse samples. Second, the intervention focused exclusively on the "Solar System and

Eclipses" unit. Although this topic was selected because its abstract and spatial nature is well suited to game-based learning, the findings may not generalize to other science domains. Third, the games were implemented only in an outdoor setting, making it difficult to isolate the effects of the game mechanics from those of environmental novelty. Future research should compare identical game-based interventions across indoor and outdoor settings. Fourth, the four-week intervention (14 instructional hours) may have been insufficient to produce sustained changes in affective outcomes, such as motivation and science anxiety; thus, some effects may reflect novelty. Longitudinal studies are needed to examine their persistence. Finally, the intervention was delivered by the primary researcher, which may have introduced researcher or experimenter-expectancy effects despite standardized procedures and expert-validated lesson plans. Future studies should employ independent instructors to enhance objectivity and external validity.

Based on the results of the study, the following recommendations are presented to researchers:

- In future research, games could also be integrated into classroom instruction rather than being used only at the end of lessons.
- Future studies should use larger samples to enhance the generalizability of the findings
- Future studies should examine these educational games, across biology, physics, and chemistry to determine whether their cognitive and affective benefits are subject-specific or generalizable across science disciplines.
- Future studies should examine both the positive and negative effects of competition in educational games
- Game designers should prioritise private feedback and avoid public performance tracking or penalties to reduce students' fear of making mistakes.
- Game rules should be clearly defined to minimize potential peer pressure among students.
- The games in this study were implemented outside the classroom. Future studies could compare their implementation in classroom and outdoor settings.
- Future games could emphasize individual task completion rather than direct competition between pairs of students.
- The study was limited to a four-week implementation period. Future research should examine the longer-term effects of the intervention, as motivation, anxiety, interest and attitudes may change over time.
- Future studies should employ independent class teachers, rather than researchers, to deliver the educational games and minimise researcher bias.

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