



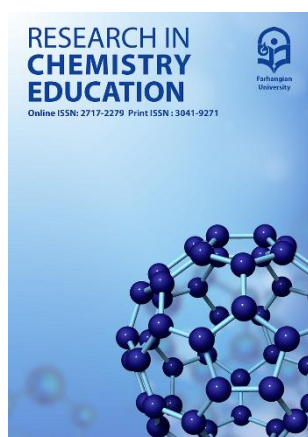
Investigating the impact of collaborative and individual educational games on eighth-grade Iranian students' learning in chemistry: A quasi-experimental study

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Abstract:

Background and Objective: Learning chemistry at the secondary level is often challenging for students due to the abstract and multi-representational nature of its concepts. Conventional teaching methods frequently lead to superficial learning and diminished motivation. Consequently, active instructional strategies, including game-based learning, have attracted growing scholarly attention. This study examined the impact of educational games on the understanding of chemistry concepts among eighth-grade female students. **Methods:** Using a quasi-experimental pretest–posttest control group design, 41 students were randomly assigned to either a control group ($n = 23$) or an experimental group ($n = 18$). The experimental group participated in six 90-minute sessions involving both collaborative and individual games, while the control group received traditional instruction. Data were collected through a researcher-developed achievement test and students' reflective notes. **Findings:** Analysis of covariance indicated that game-based learning significantly enhanced students' conceptual understanding ($F(1,39) = 40.35, p < 0.001, \eta^2 = 0.52$). Moreover, collaborative games yielded more significant effects on learning ($\eta^2 = 0.72$) than individual games ($\eta^2 = 0.23$). Qualitative analysis of students' reflections revealed that collaborative games promoted social interaction, teamwork, and collective learning, whereas individual games strengthened autonomy, self-regulation, and focused engagement. **Conclusion:** These findings suggest that game-based instruction—particularly collaborative formats—can enhance both motivation and the depth of students' learning in chemistry.

Keywords: Game-based learning, Chemistry education, Collaborative learning, Individual learning, Secondary education

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Introduction

Learning is an inherently complex process that requires not only cognitive engagement but also motivation, interaction, and enjoyment. Scholars argue that games offer powerful pedagogical tools that can make learning more student-centered and engaging (Xu et al., 2025; Prensky, 2003). Within this framework, Game-Based Learning (GBL) has emerged as an innovative approach that fosters active participation, exploration, and acceptance of intellectual challenges (Prensky, 2003; Wouters & van Oostendorp, 2013; Yu et al., 2020).

Although GBL encompasses a variety of formats and implementations, there is broad agreement regarding its educational value. By integrating interaction, clear goals, explicit rules, challenge, and feedback, GBL not only enhances students' conceptual understanding, but also increases motivation and interest (da Silva et al., 2025; Baek et al., 2015; Franco-Mariscal et al., 2016). Empirical studies have reported that GBL improves academic performance (Tokac et al., 2019; Karakoç et al., 2022), strengthens intrinsic motivation (Xu et al., 2025), and cultivates critical thinking (Noroozi et al., 2020; Wu et al., 2012). Nonetheless, mixed findings exist, with some studies reporting no significant impact on achievement (Sayan, 2015), underscoring the need for further research across diverse educational contexts.

Chemistry education is inherently complex due to its multi-level and abstract nature, which spans macroscopic, microscopic, and symbolic representations (Treagust et al., 2003). (Treagust et al., 2003). Teacher-centered approaches, which rely heavily on the unidirectional transmission of knowledge, are frequently insufficient to address these challenges, resulting in low motivation and surface-level understanding (Ahmad et al., 2023). This has prompted researchers to emphasize the adoption of innovative methods that foster active engagement and meaningful learning (Timilsena et al., 2022; Voska & Heikkinen, 2000, Seyfi & Rashidi, 2023). Consequently, educational games have gained increasing attention in chemistry education in recent decades. Beyond their motivational value, they foster autonomy, collaboration, and problem-solving skills (Li & Tsai, 2013).

Systematic reviews provide further evidence of the potential benefits of educational games. For example, Byusa et al. (2022) reviewed 57 studies published between 2010 and 2021 and concluded that games substantially improved students' conceptual understanding, motivation, and enjoyment of learning. Similarly, da Silva et al. (2025), in a review of 311 studies published over the past century, confirmed the broad application of educational games across various chemistry domains, consistently reporting positive learning outcomes. A meta-analysis by Xu et al. (2025), encompassing 14 studies with 36 effect sizes, demonstrated that GBL exerts a significant positive effect on students' motivation in chemistry, particularly in small-group, non-digital, and longer-duration interventions. Nouri and Rahimi Meroei (2021), in a narrative review, highlighted that while chemistry concepts can be challenging to understand due to their abstract nature, integrating educational games into instruction can make learning more engaging and enjoyable. These games also promote student collaboration and boost motivation, indicating that similar approaches could be valuable in teaching other chemistry topics. Ghalkhani et al. (2024) highlighted that the abstract nature of chemical bonding often leads to misconceptions among students. Importantly, these findings indicated that GBL more effectively fosters intrinsic rather than extrinsic motivation, suggesting that games can lead to deeper engagement with chemistry learning.

In addition to fostering intrinsic motivation, GBL's ability to engage students in active learning enhances their cognitive skills. Through motivating and interactive activities, GBL encourages self-regulation, active participation, and the development of higher-order thinking skills such as analysis and synthesis, which are essential for mastering complex chemistry concepts (Noroozi et al., 2020; Franco-Mariscal et al., 2016). The integration of games, which are designed with explicit educational purposes, supports students in grasping complex learning content while also fostering engagement and teamwork (Duggal et

al., 2021; Chen, 2025). These games not only help students better understand challenging concepts, but also enhance cognitive competencies such as problem-solving and communication skills (Martí-Parreño et al., 2019).

Collaborative and individual forms of GBL are grounded in different learning mechanisms, which justify examining their distinct effects on students' cognitive outcomes. Collaborative GBL promotes peer interaction, shared problem-solving, and co-construction of knowledge, allowing learners to clarify misunderstandings, negotiate meaning, and develop deeper conceptual understanding through social processes (Vygotsky, 1978; Johnson & Johnson, 2009). In contrast, individual GBL emphasizes self-regulation, autonomous decision-making, and personalized pacing, which can strengthen independent problem-solving and analytical skills (Zimmerman, 2000; Franco-Mariscal et al., 2016). Given these theoretically distinct pathways to learning, it is reasonable to expect that collaborative and individual GBL may lead to different levels or types of cognitive gains.

In Iran, however, research on GBL has been limited, with most studies focusing on computer-based applications. Bakhtiari et al. (2025) reported that out of 143 studies on educational games, 102 examined computer-based formats, while only 22 explored low-cost, non-digital alternatives. This highlights not only the limited focus on chemistry education in Iranian GBL research but also the significant gap in classroom-friendly, low-cost games developed from readily available materials.

Despite the growing body of research on digital GBL tools, a significant gap remains in studies focusing on low-cost, non-digital educational games, particularly in chemistry education. These low-tech, non-digital games offer a practical and affordable alternative, providing an engaging and accessible way to tackle the complex and abstract nature of chemistry concepts, especially in resource-constrained settings. Research on such non-digital games emphasizes their potential to promote equity in education, making science learning accessible to a broader range of students, even without extensive technological infrastructure (Namkeaw et al., 2025; Zainuddin et al., 2020).

Within this context, the present study examined the impact of low-cost educational games on the chemistry learning of Iranian eighth-grade female students. Specifically, the study addressed the following hypotheses:

1. Game-based learning has a significant positive effect on eighth-grade students' understanding of chemistry concepts.
2. Collaborative game-based learning exerts a greater positive impact on students' learning than traditional instruction.
3. Individual game-based learning leads to significantly higher student learning outcomes compared to traditional instruction.
4. Collaborative game-based learning has a greater positive effect on students' learning outcomes compared to individual game-based learning.

Methodology

This study used a quantitative approach to examine the effects of GBL on eighth-grade female students' understanding of chemistry concepts in the Iranian context. A quasi-experimental design was adopted, including pre-test and post-test measures for both control and experimental groups.

Population and Sampling

The study population comprised all eighth-grade students enrolled in Shahriar city, Tehran province, Iran, during the 2024–2025 academic year. Participants were selected through convenience sampling. A total of 41 eighth-grade female students participated, with 23 students in the control group and 18 students in the experimental group. All participants were aged 13–14 years at the time of the study.

Data Collection Instruments

1. Achievement Test

To evaluate students' academic achievement and conceptual understanding, a researcher-designed test was developed based on the eighth-grade chemistry curriculum. The test items were aligned with Bloom's cognitive taxonomy and administered as both pre-test and post-test.

- **Pre-test:** The pre-test consisted of 21 questions, including knowledge (2 questions), comprehension (9 questions), application (6 questions), and analysis (4 questions). The primary purpose of the pre-test was to establish students' baseline understanding and to assess their initial mastery of these cognitive levels before the intervention.
- **Post-test:** The post-test contained 19 questions distributed across all levels of Bloom's taxonomy: knowledge (1 question), comprehension (5 questions), application (6 questions), and analysis (7 questions). The post-test was designed to measure the effects of the intervention, with an emphasis on the assessing of higher-order thinking skills gained through the GBL activities.

Each test item was scored dichotomously, with one point awarded for a correct response and zero for an incorrect response. To assess the effects of cooperative and individual games separately, post-test items were categorized according to the game format they addressed, and scores were computed for each category. This approach enabled us to assess the impact of each game format while keeping the groups combined. Content validity was confirmed by five experts, including three faculty members in chemistry education and two experienced science teachers. The internal consistency reliability was calculated using Cronbach's alpha ($\alpha = 0.87$), indicating high level of reliability.

The experimental intervention consisted of six instructional sessions (90 minutes each), which incorporated both collaborative and individual GBL activities.

2. Educational Games

A set of six researcher-designed games was developed to align with the eighth-grade chemistry curriculum and to foster conceptual understanding, student engagement, and active participation. The games and their implementation formats were as follows:

Collaborative Games

- *Dice and Electrons Game:* Designed to teach atomic structure and electron distribution by rolling dice to generate atomic numbers, followed by arranging protons, neutrons, and electrons accordingly.
- *Snakes and Ladders—Chemistry Edition:* Adapted to address chemical reactions, oxidation, and reduction through content-based questions.
- *Atom Card Game:* Utilized element cards containing atomic numbers, mass numbers, and symbols, enabling students to construct atomic models.

Individual Games

- *Card and Empty Squares Game:* Focused on atomic models, requiring students to match cards with appropriate spaces on the game board.
- *Concept Puzzle Game:* Targeted the understanding of mixtures and separation methods through puzzle-based card arrangements.
- *Each Change in Its Place Game:* Facilitated the distinction between physical and chemical changes by categorizing examples.

Procedure and Session Structure

The study began with the administration of the pre-test to both groups. Over a period of three weeks, the experimental group participated in six 90-minute sessions of GBL, while the control group received traditional textbook-based instruction through lectures. Each GBL session included a combination of collaborative and individual activities. Collaborative games required peer interaction, discussion, and joint problem-solving, whereas individual games emphasized self-paced learning, focus, and autonomous engagement. Students were organized into small groups of 3–4 participants for collaborative games, and these groups remained consistent throughout the intervention to foster stable peer collaboration and social learning. The pre-test was conducted in the first session, and the post-test was administered in the final session, allowing for the evaluation of learning progress and the differential effects of collaborative versus individual game formats.

Pilot Testing

The reliability of the games as instructional tools was evaluated through a pilot test with 10 randomly selected students. The pilot results demonstrated consistent performance across conditions, supporting their appropriateness for classroom use.

3. Student Reflection Notes

At the conclusion of each session, students were asked to submit written reflections on their experiences with both collaborative and individual games. These notes captured students' emotions, perceptions, and evaluations of chemistry learning through games. Reflections were analyzed qualitatively using open and axial coding, allowing for the identification of recurring themes and the comparative contributions of different game formats.

To ensure the trustworthiness and consistency of the coding process, two researchers independently coded a subset of the reflection notes. Inter-rater reliability was assessed using Cohen's kappa, yielding a high level of agreement ($\kappa = 0.87$). Any discrepancies were discussed and resolved through consensus, ensuring that the final codes and themes accurately represented the students' perspectives.

Inclusion and Exclusion Criteria

Students were eligible if they were enrolled in the eighth grade and had obtained written informed consent from their parents or legal guardians. Confidentiality and voluntary participation were assured. Students absent for more than two sessions or those who chose to withdraw were excluded; however, all participants completed the study.

Data Analysis

Quantitative data from achievement tests were analyzed using descriptive and inferential statistics. Assumptions of homogeneity of variance were tested before conducting a one-way Analysis of Covariance (ANCOVA) to determine group differences. To isolate the effects of collaborative and individual games, post-test items were categorized according to the game format they addressed. Separate ANCOVA analyses were conducted for collaborative games (Dice and Electrons Game, Snakes and Ladders—Chemistry Edition, Atom Card Game) and individual games (Each Change in Its Place Game, Card and Empty Squares Game, Concept Puzzle Game), controlling for pre-test scores. SPSS version 26 was used for all statistical analyses.

Ethical Considerations

All ethical guidelines were adhered to, and written informed consent was obtained from the participating students and their parents or legal guardians. Participation was voluntary, and confidentiality was guaranteed. Students retained the right to withdraw at any time without penalty. To ensure fairness, students in the control group were given access to the educational games after the study concluded.

Results

a) Distribution of Pre-test and Post-test Questions by Cognitive Level

Table 1 presents the distribution of pre-test and post-test questions across Bloom's cognitive levels. The pre-test items were weighted toward lower-order skills, particularly comprehension (42.9%). In contrast, the post-test placed greater emphasis on higher-order thinking, with analysis accounting for 36.8% of the questions. These revisions were undertaken in consultation with subject-matter experts to ensure that the assessments captured both students' baseline knowledge and their subsequent progress in developing higher-order cognitive skills in chemistry.

Table 1- Distribution of Bloom's cognitive levels across pre-test and post-test questions

Learning level	Pre-test (%)	Post-test (%)
Knowledge	9.5	5.3
comprehension	42.9	26.3
Application	28.6	31.6
Analysis	19.0	36.8

b) Descriptive statistics of pre-test and post-test results

Descriptive statistics for both groups are summarized in Table 2. The experimental group achieved higher post-test scores ($M = 16.65$, $SD = 1.74$) than the control group ($M = 13.37$, $SD = 3.51$). Within the experimental group, a descriptive comparison of item subsets showed larger pre- to post-test gains for items aligned with collaborative game activities (pre-test: $M = 5.20$; post-test: $M = 9.05$) than for items aligned with individual game activities (pre-test: $M = 5.15$; post-test: $M = 7.60$). Overall, these descriptive results suggest that both game formats supported learning, with more pronounced gains observed for collaborative-related items.

Table 2- Mean and standard deviation of pre-test and post-test scores

Test	Group	Mean	SD	N
Pre-test	Control	10.78	2.13	23
	Experimental	10.35	2.45	18
Post-test	Control	13.37	3.51	23
	Experimental	16.65	1.74	18

c) Effect of GLB on students' chemistry achievement

To evaluate the first hypothesis, one-way ANCOVA was performed, controlling for pre-test scores. Assumption testing confirmed the homogeneity of variances (Levene's test, $p = 0.44 > 0.05$) and regression slopes ($p = 0.27 > 0.05$).

ANCOVA results (Table 3) revealed a statistically significant effect of GBL on post-test performance ($F(1,39) = 40.35$, $p < 0.001$). The intervention explained 52% of the variance ($\eta^2 = 0.52$). Cohen's $d = 2.61$ further indicated a notable practical effect, underscoring the considerable impact of GBL on students' chemistry achievement (Cohen, 1992).

Table 3- ANCOVA of post-test scores

Source	SS	df	MS	F	Sig.	η^2
Pre-test	61.43	1	61.43	57.22	<.001	0.37
Group	62.64	1	62.64	40.35	<.001	0.52
Error	47.23	39	1.88			
Total	109.87	41				

d) Effect of cooperative and individual games on chemistry learning

Cooperative Games

For the second hypothesis, ANCOVA assumptions were met (Levene's test, $p = 0.063 > 0.05$). Results (Table 4) demonstrated that cooperative games had a highly significant effect on student learning ($F(1,39) = 55.2$, $p < 0.001$), with a considerable effect size ($\eta^2 = 0.72$). Cohen's $d = 4.45$ reflected a very extremely effect of cooperative gameplay.

Table 4- ANCOVA of post-test scores; cooperative games

Source	SS	df	MS	F	Sig.	η^2
Pre-test	38.65	1	38.65	3.77	0.00	0.45
Group	126.00	1	126.00	55.20	0.00	0.72
Error	46.80	39	1.20			
Total	172.80	41				

Individual Games

The third hypothesis assessed the effect of individual games. Assumptions of homogeneity were satisfied (Levene's test, $p = 0.437 > 0.05$; regression slopes test, $p = 0.67 > 0.05$). ANCOVA results (Table 5) indicated a significant effect ($F(1,39) = 11.60$, $p = 0.002$), with a medium-to-large effect size ($\eta^2 = 0.23$). Cohen's $d = 2.53$ suggested a substantial practical impact, albeit weaker than that of cooperative games.

Table 5- ANCOVA of post-test scores; individual games

Source	SS	df	MS	F	Sig.	η^2
Pre-test	12.54	1	12.54	4.76	0.000	0.59
Group	11.10	1	11.10	11.60	0.001	0.23
Error	36.30	39	0.35			
Total	47.40	41				

In summary, both cooperative and individual games enhanced student achievement in chemistry; however, cooperative formats exerted a notably significantly influence.

e) Qualitative Analysis of Student Reflections

Many students reported that collaborative games fostered peer discussion, teamwork, and knowledge-sharing, which deepened their comprehension of chemistry concepts. For example, one student noted: "*Working in a group helped me understand difficult concepts better because my friends' explained things to me.*" Collaborative approaches were additionally associated with enhanced social skills, increased motivation, and a greater sense of shared responsibility for learning.

In contrast, individual games were appreciated for promoting autonomy, personal focus, and self-paced learning. Some students, particularly those identifying as introverted, expressed a preference for this format: "*I am an introvert, and I enjoyed individual games more because I could focus deeply on the concept and learn at my own pace.*" Others highlighted both the strengths and limitations of individual work, appreciating the opportunity for concentrated effort while noting the absence of peer support.

Table 6 summarizes examples of reflective statements beside the corresponding open codes, axial codes, and emergent themes. Together, these findings indicate that while both approaches contributed positively to learning, they did so through different mechanisms: collaborative games strengthened the social dimension of learning, whereas individual games emphasized autonomy and independent problem-solving.

Table 6- Examples of students’ reflective notes and derived themes from qualitative analysis

Type of Game	Selected Student Reflections	Key Insights (Open Codes)	Broader Themes (Axial Codes)	Main Theme
Collaborative	“The concept puzzle game was really fun! I felt I understood chemistry much better. Playing with my friends, I learned things I didn’t know before.” – Student #3	Engagement, deeper understanding, peer collaboration, learning new ideas	Learning through collaboration	Social and collaborative e-learning
	“Group games helped me grasp chemistry concepts more clearly. I realized that each of us had knowledge that complemented the others.” – Student #7	Peer discussion, knowledge sharing, complementing each other	Collective knowledge building	
	“Working in a group strengthened my social skills. Discussing with classmates made learning chemistry easier.” – Student #16	Social skill development, group discussion, improved comprehension	Social learning and skill enhancement	
	“Group games felt enjoyable. Working together made learning easier and more effective.” – Student #11	Positive feelings, collaboration, team success	Teamwork and cohesion	
	“Group games helped me understand complex chemistry concepts. Collaborating with classmates made problem-solving easier.” – Student #5	Understanding complex ideas, collaborative thinking, facilitated learning	Peer-assisted conceptual understanding	
	“In group games, I felt we all shared responsibility. This motivated me and made learning feel more successful.” – Student #2	Shared responsibility, motivation, learning success	Responsibility and group motivation	
Individual	“Playing alone made me rely on myself. This helped me learn the atomic structure thoroughly.” – Student #16	Self-reliance, focus, mastering concepts independently	Self-efficacy and personal focus	Independent and autonomous learning
	“The individual game was helpful because I could go at my own pace, even though playing with others is more exciting.” – Student #14	Learning at personal pace, preference for group play	Autonomy with social awareness	
	“Playing alone let me focus on details, but when I got stuck, there was no one to help.” – Student #7	Focus on details, lack of peer support, sense of isolation	Benefits and limitations of individual learning	
	“I wish we could play this game in groups too. I really enjoy teamwork.” – Student #8	Desire for collaboration, interest in group learning	Missing peer interaction	

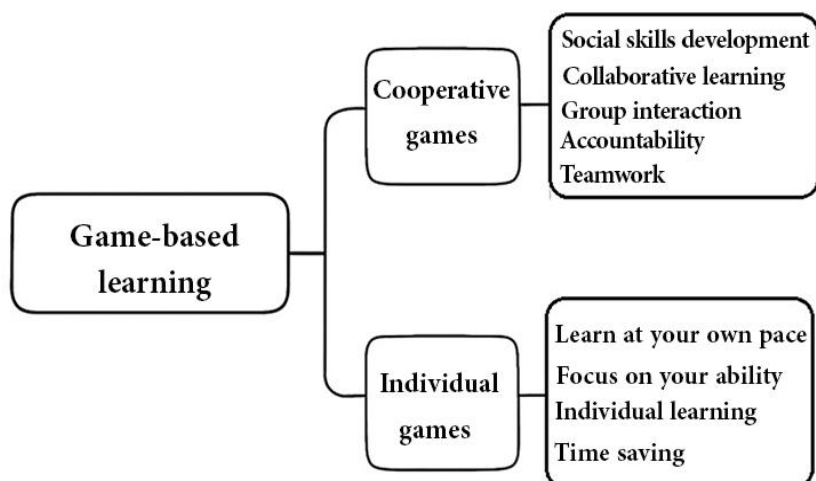


Figure 1- Comparison of students' perspectives on collaborative versus individual educational games

Figure 1 illustrates the conceptual map of learning features associated with the two approaches. Collaborative games were linked to enhanced social skills, responsibility, group interaction, teamwork, and shared learning. In contrast, individual games were associated with personal focus, self-paced learning, time management, and learner autonomy.

In Figure 2, students are shown engaging in collaborative group games. The purpose of these activities was to strengthen chemistry learning through social interaction and cooperation. Participation in group games enabled students to jointly explore chemistry concepts, engage in peer discussions, and develop a deeper understanding of the subject. Additionally, group-based activities enhanced social skills, responsibility, teamwork, and motivation, reinforcing the collaborative dimension of learning. These findings, particularly the students' reflections in Table 6, affirm the effectiveness of collaborative games in promoting social and cooperative learning. Figure 2b shows a student who engaged individually in a puzzle related to the properties of chemical compounds. This type of game allowed the learner to focus on personal abilities, progress at their own pace, and manage Discussion and Conclusion.

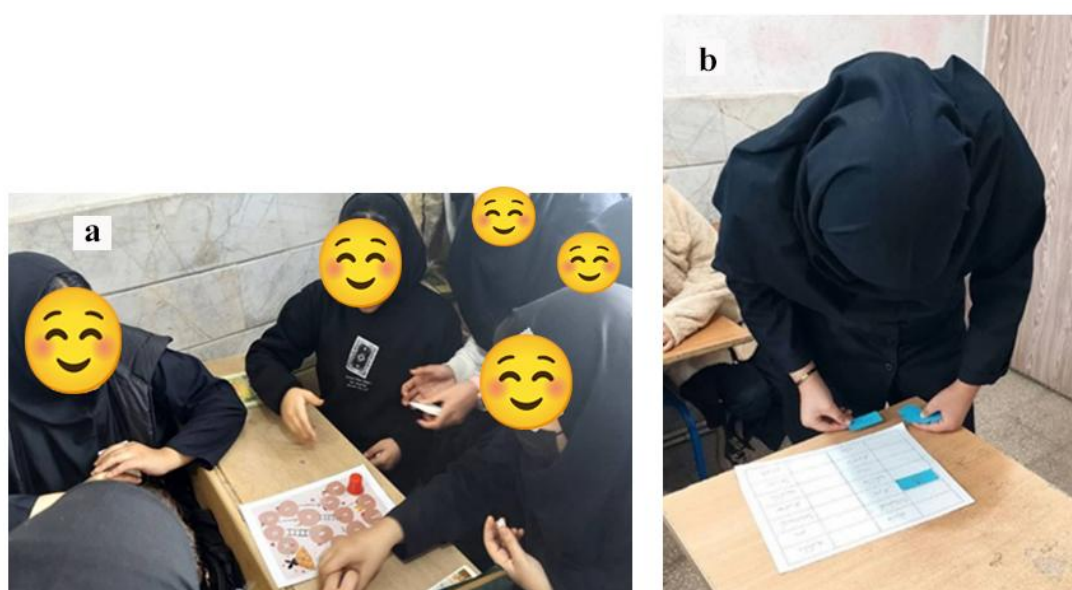


Figure 2- Illustration of student engagement in educational games. (a) Collaborative group games. (b) Individual game activity

Discussion and Conclusion

This study examined the impact of educational games on the learning of chemistry concepts among eighth-grade female students in Iran. The results demonstrated that games designed with low-cost, readily available materials significantly enhanced students' conceptual understanding of chemistry, with collaborative games exerting particularly strong effects. ANCOVA results revealed that the post-test mean score of the experimental group ($M = 16.65$) was significantly higher than that of the control group ($M = 13.37$), $F(1,39) = 40.35$, $p < 0.001$, $\eta^2 = 0.52$. These findings highlight the pedagogical value of active, interactive methods in teaching complex and abstract chemistry concepts. The considerable effect size (Cohen's $d = 2.61$) further underscores the educational potential of GBL, supporting prior research that has shown improvements in both academic achievement and conceptual understanding through such approaches (Tokac et al., 2019; Karakoç et al., 2022; Byusa et al., 2022).

Similar results were also reported by Ghalkhani et al. (2024), who demonstrated that visualization and GBL effectively improved students' understanding of ionic and molecular compounds while preventing misconceptions. Likewise, Seyfi and Rashidi (2023) found that using games to teach periodic properties significantly enhanced motivation and deep learning among 10th-grade students. In a review study, Nouri and Rahimi (2021) highlighted the role of games in organic chemistry instruction, emphasizing their potential to make abstract content more engaging and collaborative.

A more detailed analysis revealed differential effects of game types. Collaborative games produced very strong learning outcomes ($\eta^2 = 0.72$, Cohen's $d = 4.45$), while also fostering social skills, responsibility, and teamwork. These outcomes were supported by qualitative analysis of students' reflection notes. Through open and axial coding, themes related to social interaction, peer support, autonomous learning, and self-efficacy were identified, providing evidence of the differential contributions of collaborative and individual games to non-cognitive learning outcomes. The reflection notes revealed that students viewed collaborative games as valuable for peer support, social interaction, and shared problem-solving, which contributed to the stronger learning outcomes observed. Similarly, while individual games had a more modest impact on achievement, they were particularly effective in promoting learner autonomy and self-regulation, a theme also reflected in the students' qualitative feedback.

These results are consistent with the findings of Noroozi et al. (2020) and Franco-Mariscal et al. (2016), who emphasized the value of peer interaction, group problem-solving, and cooperative learning in promoting deeper and more enduring knowledge acquisition. By contrast, individual games also had a positive, though less pronounced, effect on learning ($\eta^2 = 0.23$, Cohen's $d = 2.53$). They were particularly effective in cultivating learner autonomy, focused engagement, and self-efficacy, aligning with studies that emphasize the role of GBL in enhancing intrinsic motivation and independence (Xu et al., 2025). However, the absence of peer feedback and limited opportunities for social interaction were notable drawbacks, echoing the principles of social constructivist theories (Vygotsky, 1978; Johnson & Johnson, 2009), which stress the central role of collaboration in both cognitive and social development.

The qualitative findings complemented the quantitative results by providing insights into how students experienced the two formats. Students perceived collaborative games as opportunities for interaction, peer support, and shared problem-solving, leading to increased motivation and group cohesion. In contrast, individual games were appreciated for allowing students to work at their own pace, strengthen self-regulation, and focus on personal skill development. These findings resonate with previous work (Partovi & Razavi, 2019; da Silva et al., 2025), which similarly identified motivation and deep engagement as outcomes of game-based approaches, with variations in effectiveness depending on the degree of social interaction involved.

A noteworthy contribution of this study lies in its use of simple, low-cost, classroom-friendly materials to design educational games. This approach addresses challenges in resource-limited contexts, where access to digital tools may be restricted. The

findings are consistent with Byusa et al. (2022) and Câmara Olim et al. (2024), who emphasized that even low-technology instructional games can provide active, multisensory, and engaging learning opportunities.

While collaborative games encouraged shared responsibility and collective success, and individual games emphasized independence and self-directed learning, the evidence suggests that integrating both approaches may provide the most balanced instructional strategy. A blended approach could simultaneously support conceptual mastery, social skills, and self-efficacy. This conclusion aligns with previous research (Choi et al., 2013; Sung et al., 2012), which recommended combining individual and group-based activities to optimize science learning outcomes.

Recommendations

This study demonstrated that educational games significantly enhance the learning of chemistry concepts among eighth-grade students, particularly when implemented in collaborative formats. Beyond improving academic achievement, collaborative games fostered social interaction, teamwork, and motivation, while individual games complemented this process by promoting autonomy, focused engagement, and self-regulated learning. The results indicate that students' understanding of chemistry concepts significantly improved through the use of educational games, with collaborative games having a greater impact on learning outcomes compared to individual games.

Nevertheless, several limitations of the study should be acknowledged. One limitation is the unequal number of students in the control and experimental groups. This imbalance was due to fixed class sizes and scheduling constraints set by the school, which prevented the formation of fully equivalent groups. Other limitations include the relatively small sample size, the focus on a single school in Shahriar, and the short duration of the intervention, all of which restrict the generalizability of the findings. Future research should involve larger and more diverse student populations, extend the intervention period, and explore the interplay between digital and non-digital game formats. Furthermore, investigating how gender, personality traits, and learning styles influence the effectiveness of GBL would provide a more comprehensive understanding of its role in chemistry education. Also, future studies should also systematically explore the combination of collaborative and individual game-based learning approaches and investigate their potential combined effects on learning outcomes.

Overall, the findings suggest that integrating both collaborative and individual game-based activities offers a promising pedagogical approach for fostering active, meaningful, and inclusive learning in chemistry, especially in contexts with limited resources.

Conflict of Interest

The authors have declared no conflicts of interest.

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