

DIGITAL GAME-BASED LEARNING IN SCIENCE EDUCATION: ADVANCING MOTIVATION AND DEEP UNDERSTANDING AMONG MIDDLE SCHOOL GIRLS

Alghaliya Al-Muqbali , Zamzam Al-Nabhani , Mohamed A. Shahat* 

Sultan Qaboos University (Oman)

s147997@student.squ.edu.om, s147852@student.squ.edu.om

**Corresponding author: m.shahat@squ.edu.om*

Received September 2025

Accepted March 2026

Abstract

Persistent challenges in science education, notably weak conceptual comprehension and declining student motivation, hinder the achievement of deeper learning objectives. This is particularly critical in rapidly developing nations like Oman, where educational outcomes are directly tied to the strategic goals of Oman Vision 2040. To address this need, this study investigates the value of integrating digital educational games as an innovative strategy to promote deeper understanding and enhance motivation among eighth-grade female students in Omani science classes. Employing a quasi-experimental design with 146 students divided into experimental and control groups, the study consisted of a two-week intervention in which the experimental group was taught using platforms such as *Kaboot*, *Wordwall*, and *Quizizz*. The findings make a significant contribution to the field by demonstrating that game-based learning yielded statistically significant improvements, with a large effect on learner motivation ($\eta^2 = 0.796$) and a moderate effect on deep understanding ($\eta^2 = 0.066$). Specifically, the study adds nuanced insight by showing that while digital games strongly enhanced knowledge acquisition, application, and classroom enthusiasm through interactive and competitive features, the development of higher-order reasoning skills may require longer-term exposure. Based on these outcomes, the study provides practical recommendations for integrating digital games into pedagogy and calls for future research to explore their long-term impact on higher-order thinking, thereby offering a valuable pathway for creating more engaging and meaningful science learning experiences aligned with 21st-century educational goals.

Keywords – Game-based learning, Digital educational games, Deep understanding, Student motivation, Science education.

To cite this article:

Al-Muqbali, A., Al-Nabhani, Z., & Shahat, M. A. (2026). Digital game-based learning in science education: Advancing motivation and deep understanding among middle school girls. *Journal of Technology and Science Education*, 16(2), 423–445. <https://doi.org/10.3926/jotse.3839>

1. Introduction

Education in the modern era is witnessing profound transformations that necessitate a critical re-examination of traditional teaching methods. Rapid technological advancements, changing learner characteristics, and the increasing demand for equipping students with higher-order thinking skills and the ability to address complex problems have reshaped the goals of education (Shahat et al., 2026). Contemporary educational research increasingly emphasizes learner-centred environments in which students actively construct knowledge, engage in inquiry, and apply concepts in authentic contexts supported by digital technologies. Education is therefore no longer limited to the transmission of knowledge or rote memorization; rather, it now emphasizes the development of deep understanding, enabling learners to analyse, connect, and apply concepts in novel contexts and to construct knowledge independently rather than passively consuming it (Ohle-Peters et al., 2024, Shahat & Al-Maamari, 2025; Zhang & Linn, 2022).

In science education, deep understanding is the cornerstone of meaningful learning. Because science is inherently cumulative and interconnected, a deep understanding requires bridging the gaps between phenomena, concepts, and evidence. When topics are presented superficially or in isolation, learners often struggle to comprehend the material or gain the ability to apply it to real-world contexts (Arifin et al., 2025). To address this, recent research highlights the importance of instructional environments that utilize active inquiry and technology-enhanced experiences to promote conceptual integration (Sun et al., 2024). Ultimately, prioritizing deep understanding cultivates systematic and holistic thinking and empowers students to see the direct relevance of scientific knowledge in their daily lives (National Research Council, 2012).

Achieving this depth of learning, however, requires strong intrinsic motivation. Motivation drives students to actively engage with content, inquire, experiment, and participate in learning activities. It is not merely a psychological state but a dynamic internal force that shapes the willingness to learn and the effort invested in attaining meaningful comprehension (Howard et al., 2025). Research consistently demonstrates that higher motivation leads to greater engagement, persistence, and improved levels of understanding (Soriano-Sánchez et al., 2026). Recent scholarship (e.g., Howard et al., 2025; Reeve & Cheon, 2024; Schunk & DiBenedetto, 2020) has highlighted that motivational processes are strongly influenced by the design of learning environments, particularly those that incorporate interactivity, autonomy, and meaningful challenges. Thus, there appears to be a reciprocal relationship between deep understanding and motivation: motivation enables learners to persevere with challenging concepts and sustain active engagement, while deep understanding enhances learners' sense of competence and achievement, thereby reinforcing motivation in a positive cycle (Oga-Baldwin & Ryan, 2025).

Digital game-based learning (GBL) has emerged as a promising pedagogical approach capable of strengthening both motivational and cognitive dimensions of learning. By integrating elements such as challenge, feedback, competition, and exploration, educational games create interactive environments that stimulate curiosity and sustained engagement while simultaneously supporting conceptual learning (Hamari et al., 2016). Recent meta-analyses and empirical studies indicate that well-designed digital games can enhance student engagement, improve motivation, and promote deeper learning across different educational contexts (Barz et al., 2024; Pan et al., 2025; Soriano-Sánchez et al., 2026). Research also suggests that digital game environments can foster collaboration, problem-solving, and active learning processes that contribute to improved academic achievement and engagement in science classrooms (Zhou, 2024). Consequently, GBL has increasingly been recognized as a strategy capable of bridging affective and cognitive aspects of learning, particularly in science education where sustained engagement is essential for conceptual development.

With these considerations in mind, the present action research was designed to explore the effectiveness of integrating digital educational games into science instruction. This comes in light of classroom observations and TIMSS 2023 results indicating that Omani eighth-grade students continue to face challenges in achieving deep conceptual understanding and maintaining motivation

toward science learning (Mullis et al., 2024). Despite growing international evidence on the benefits of GBL, empirical research examining its combined effects on deep understanding and motivation within Middle Eastern science classrooms remains limited. By combining technology-driven play with meaningful learning experiences, the study seeks to improve conceptual understanding and motivation, thereby contributing to innovative practices in science education. Moreover, this initiative aligns with the broader objectives of Oman Vision 2040, which advocates for interactive, technology-enhanced, and competency-based education as a foundation for sustainable human capital development (Oman Vision 2040, 2019).

2. Theoretical Framework

2.1. Science Teaching in Light of Contemporary Educational Developments

Science education plays a critical role in preparing students to understand and interpret natural phenomena while developing essential competencies such as problem-solving, critical thinking, and evidence-based reasoning. In contemporary knowledge-based societies, these competencies are increasingly viewed as being the more important outcomes of science education over the mere acquisition of factual knowledge (Arifin et al., 2025).

In response to these evolving expectations, educational reforms have increasingly moved away from traditional teacher-centred instruction toward learner-centred pedagogies that emphasize inquiry, collaboration, and active knowledge construction. These approaches encourage students to explore scientific ideas, engage in problem-solving, and apply concepts within authentic learning contexts (Zhang & Linn, 2022). This shift is reflected in international curriculum frameworks such as the Next Generation Science Standards (NGSS), which promote three-dimensional learning through the integration of disciplinary core ideas, science and engineering practices, and crosscutting concepts (NGSS Lead States, 2013). Such frameworks emphasize that meaningful science learning emerges when students actively engage in scientific practices rather than passively memorizing isolated facts.

Within this evolving educational landscape, digital technologies are increasingly viewed as tools capable of enriching science learning environments and supporting interactive engagement with scientific concepts. Several studies (Arifin et al., 2025; Sun et al., 2024; Zhang & Linn, 2022) have shown that technology-enhanced learning environments can improve conceptual understanding and facilitate knowledge transfer across contexts by enabling interactive exploration and visualisation of scientific phenomena. Such digital learning environments provide opportunities for learners to actively engage with content, which can strengthen conceptual connections and support deeper scientific understanding. In Oman, these developments align closely with the goals of Oman Vision 2040, which emphasizes innovation, digital transformation, and learner-centred education as key pillars of national development (Oman Vision 2040, 2019). Consequently, integrating digital and interactive learning approaches has become an important priority for enhancing both conceptual understanding and student engagement in science classrooms.

2.2. Digital Game-Based Learning (GBL)

GBL refers to the use of digital games designed specifically to support learning objectives while maintaining high levels of learner engagement. Educational games typically incorporate mechanics such as challenge, feedback, progression, and reward systems that encourage sustained participation and active interaction with learning content (Soriano-Sánchez et al., 2026).

Recent literature highlights the importance of distinguishing GBL from gamification, as the two approaches represent different instructional strategies. While GBL involves learning through complete educational games designed around specific learning goals, gamification refers to the incorporation of selected game elements, such as points, badges, or leaderboards, into non-game learning environments to enhance engagement (Sailer & Homner, 2020). In contrast, GBL embeds learning activities directly within the structure of a game environment in which learners interact with content through challenges,

simulations, or narrative scenarios (Plass et al., 2020). Because the present study focuses on learning through digital educational games rather than the gamification of traditional instruction, the theoretical framework draws primarily on research related to digital game-based learning and its impact on both cognitive and motivational processes.

A growing body of research indicates that GBL can support meaningful learning by combining interactive engagement with opportunities for exploration, experimentation, and immediate feedback (Pan et al., 2025). Empirical studies and meta-analyses have reported that well-designed digital games can enhance students' motivation, collaboration, and problem-solving abilities across diverse educational contexts (Barz et al., 2024; Soriano-Sánchez et al., 2026). In addition to improving affective outcomes such as engagement and motivation, game-based environments have also been associated with improved knowledge retention and conceptual understanding (Zhou, 2024). When carefully aligned with curriculum objectives, digital game-based learning can transform science classrooms into interactive learning environments that encourage active knowledge construction. However, the effectiveness of GBL depends largely on thoughtful instructional design, ensuring that game mechanics are meaningfully integrated with learning objectives and support the cognitive processes required for conceptual understanding (Plass et al., 2020).

2.3. Deep Understanding

Deep understanding refers to a learner's ability to construct meaningful connections among scientific concepts, apply knowledge to new situations, and engage in analytical reasoning rather than relying on rote memorization. It reflects a shift from surface learning – where information is temporarily recalled – to deeper cognitive engagement in which knowledge is integrated, applied, and transferred across contexts (Sun et al., 2024). In the present study, deep understanding is reflected in students' performance on an achievement test designed to assess their ability to analyse relationships among scientific concepts and apply them to real-life situations.

Theoretical perspectives on meaningful learning provide a foundation for understanding this construct. Ausubel's theory of meaningful learning emphasizes the integration of new knowledge with learners' existing cognitive structures, while research in the learning sciences highlights the importance of conceptual models that enable reasoning, problem-solving, and knowledge transfer (Ausubel, 1968; Bransford et al., 2000). From this perspective, deep understanding emerges when learners actively engage with ideas, evaluate evidence, and apply knowledge in different contexts.

Recent research on technology-enhanced learning environments further supports this view. For example, Zhang and Linn (2022) demonstrated that digital scaffolds in inquiry-based environments help students build stronger conceptual connections and improve the transfer of learning to new tasks. Similar conclusions have been reported in systematic reviews and meta-analyses of digital and game-based learning environments, which indicate that interactive digital learning features can promote deeper engagement, motivation, and conceptual understanding in science education (Alotaibi, 2024; Barz et al., 2024; Widayanti et al., 2026). Together, these findings suggest that instructional strategies emphasizing active knowledge construction and interactive engagement are strongly associated with improved deep learning outcomes in STEM education.

2.4. Motivation for Learning

Motivation plays a central role in students' engagement with academic tasks and their persistence in learning activities. It refers to the psychological processes that initiate, direct, and sustain behaviour toward achieving learning goals (Ryan & Deci, 2000). In educational contexts, motivation influences the effort students invest in learning, the strategies they employ, and their willingness to persist when facing challenging tasks (Schunk & DiBenedetto, 2020).

Self-Determination Theory (SDT) provides a widely used framework for understanding motivation in learning environments. According to this theory, students are more likely to demonstrate sustained

engagement when their psychological needs for autonomy, competence, and relatedness are supported (Deci & Ryan, 2017). Therefore, instructional environments that promote choice (autonomy), provide constructive feedback (competence), and encourage collaboration (relatedness) can therefore enhance intrinsic motivation and promote deeper engagement in learning activities (Oga-Baldwin & Ryan, 2025). Recent research (Howard et al., 2025; Oga-Baldwin & Ryan, 2025; Reeve & Cheon, 2024) emphasizes that instructional environments supporting students' psychological needs for autonomy, competence, and relatedness play a central role in fostering motivational engagement, persistence, and sustained participation in learning activities.

In technology-enhanced learning environments, motivational processes are often influenced by design features such as interactivity, feedback, progressive challenge, and learner control. These elements can create engaging learning experiences that stimulate situational motivation and encourage active participation (Hamari et al., 2016; Schunk & DiBenedetto, 2020). Improvements in game-based learning approaches (e.g., self-efficacy, motivation, and academic achievement) have been consistently demonstrated across educational contexts (Soriano-Sánchez et al., 2026; Zhou, 2024). However, recent empirical and meta-analytic studies caution that care must be taken in digital game-based learning environments to meaningfully align game mechanics with instructional objectives (Barz et al., 2024; Pan et al., 2025; Widayanti et al., 2026).

Based on all this evidence, motivation should be understood not as a fixed learner trait but as a dynamic process shaped by instructional design and learning experiences. Interactive learning environments such as digital game-based learning can therefore play an important role in fostering motivational engagement that supports deeper cognitive involvement in learning tasks.

To clarify the relationships among the main constructs guiding this study, Table 1 summarizes the theoretical foundations and learning mechanisms associated with digital game-based learning, motivation, and deep understanding.

Construct	Theoretical Basis	Learning Mechanism	Key References
Digital Game-Based Learning	Game-based pedagogy	Interactive tasks and feedback	Gee (2003); Hamari et al. (2016)
Motivation	Self-Determination Theory	Autonomy, competence, relatedness	Deci and Ryan (2017)
Deep Understanding	Constructivist learning theory	Conceptual integration and transfer	Bransford et al. (2000)

Table 1. Theoretical Foundations of the Study

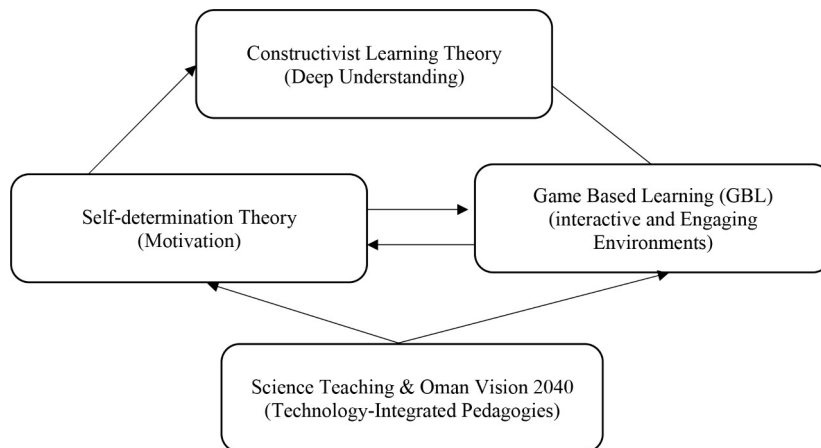
2.5. Linking the Constructs: The Guiding Framework

The present study is guided by a conceptual framework that integrates insights from constructivist learning theory, self-determination theory, and research on digital game-based learning. Rather than reintroducing these perspectives independently, the framework focuses on how their key principles interact to explain the relationships among the study variables.

Within this framework, digital game-based learning is expected to enhance students' motivation toward science learning by supporting the psychological needs for autonomy, competence, and relatedness, which are central to self-determination theory and have been shown to promote sustained engagement and persistence in learning activities (Deci & Ryan, 2017; Howard et al., 2025; Reeve & Cheon, 2024).

Accordingly, the framework guiding this study assumes that digital game-based learning contributes to deep understanding in two ways: directly, through interactive learning experiences that promote active knowledge construction, and indirectly, by enhancing students' motivation and engagement in science learning activities. The interaction between motivational engagement and cognitive processing therefore forms the conceptual basis of the present research. Figure 1 illustrates the relationships among digital

game-based learning, motivation, and deep understanding and summarizes the conceptual framework guiding the study.



Note. The framework integrates constructivist learning theory (deep understanding), self-determination theory (motivation), and principles of GBL within the context of Oman Vision 2040. GBL enhances motivation through autonomy, challenge, and feedback, which in turn fosters deep understanding of scientific concepts. The cyclical relationship between motivation and deep understanding reinforces sustainable learning outcomes.

Figure 1. The Guiding Theoretical Framework Linking GBL, Motivation, and Deep Understanding

2.6. Aims and Research Questions

The present study aims to:

1. Examine the effect of digital game-based learning on students' deep understanding of scientific concepts.
2. Assess its impact on students' motivation toward learning science.
3. Provide evidence-based insights to inform innovative and technology-driven teaching strategies in science education.

Accordingly, the central research questions guiding this study are:

RQ1. What is the effect of digital game-based learning on improving the *deep understanding* of scientific concepts among eighth-grade female students in Oman?

RQ2. What is the effect of digital game-based learning on enhancing *motivation* toward learning science among eighth-grade female students in Oman?

3. Methodology

3.1. Research Design

This study employed a quasi-experimental design with two groups (experimental and control) and pre- post measurements, a design widely used in educational interventions to assess treatment effects while maintaining ecological validity (Creswell & Creswell, 2018). Such designs have been frequently applied in science education and game-based learning research to examine the impact of digital educational games on motivation and conceptual understanding (Soriano-Sánchez et al., 2026).

3.2. Sample

The study population comprised all eighth-grade students in the Sultanate of Oman, as reported in the Ministry of Education's official statistics for the 2024–2025 academic year. From this population, the study sample consisted of 146 female students enrolled in four intact eighth-grade classes at a girls' school

(Grades 7–10) located in (blinded for review process). The study was conducted in a girls' school due to the gender-segregated structure of public schooling in Oman, where boys and girls are typically educated in separate schools at the middle and secondary levels. Data collection was conducted during the second semester of the academic year, between March and April 2025.

To form the study groups, the four classes were randomly assigned to either the experimental condition ($n = 73$) or the control condition ($n = 73$). The experimental group received science instruction supported by digital educational games, while the control group was taught using traditional instructional methods without digital games. Random assignment at the class level ensured that each group represented similar learning contexts within the same school environment (Creswell & Creswell, 2018).

3.3. Treatment

To ensure clarity and consistency in the intervention, a teacher's guide was developed to structure the instructional process for both the experimental group (EG) and the control group (CG). The guide aligned with the Grade 8 science curriculum (Unit: *Sound*) and was designed to support lesson delivery, learning activities, and assessment practices.

3.3.1. Experimental Group (EG): Digital Game-Based Learning

Students in the experimental group ($n = 73$) received science instruction using interactive digital game-based strategies. The teacher implemented four structured lessons from the *Teacher's Guide for Science – Grade 8, Part II*, integrating digital games, simulations, and virtual experiments. Each lesson followed a clear sequence—1) interactive warm-up, 2) game-based activity (guided exploration, collaborative practice), and 3) formative assessment. Examples (with the sequence numbered as above) include:

- Lesson on “Changing Sounds”: Students identified sound sources together through *Wordwall* (1). Then they manipulated frequency and amplitude using *Chrome Music Lab*, and analysed voice recordings through *Voice Spice Recorder* (2). The lesson concluded with a competitive quiz on *Kaboot* or *Quizizz* (3).
- Lesson on “Vibrations”: Students were introduced to concepts interactively (1) and then conducted real and simulated experiments on the relationship between mass and frequency, supported by digital games such as *Bamboozle* and *PhET Sound Simulation* (2). Collaborative concept games on *Quizlet* were used for reinforcement (3).
- Lesson on “How Sound Travels”: Students did a group concept check (1). Then they explored the transmission of sound in different media (air, water, solids) using *PhET* simulations, *LabXchange* virtual experiments, (2) finally completed real-life problem-solving tasks gamified through *Prodigy* (3).
- Lesson on “Representing Sound on an Oscilloscope”: Following a warm-up (1), students used *PhET* and *Audacity* to analyse waveforms and matched sounds to wave shapes with *Wordwall* (2). Then they completed interactive assessments on *Quizizz* (3).

Throughout the intervention, the teacher applied structured game-based activities that emphasized conceptual understanding, active exploration, and peer interaction. Homework assignments were also digitized, requiring students to record or analyse environmental sounds and share results via Google Classroom. Assessments were embedded within the games, ensuring continuous formative evaluation.

3.3.2. Control Group (CG): Traditional Instruction

Students in the control group ($n = 73$) were taught the same science unit (Sound) by another teacher with the same teaching experience over the same two-week period (12 lessons). Instruction followed the standard Ministry of Education textbook and teaching practices, relying on teacher explanations, textbook exercises, note-taking, and whole-class questioning. Lessons were delivered in a lecture–recitation format, accompanied by occasional paper-based worksheets. No digital games, simulations, or interactive

technologies were used. Homework was assigned through traditional written tasks aligned with the unit objectives.

To ensure consistency, both the experimental and control groups studied the same sequence of lessons and content coverage, as outlined in the Ministry’s instructional guide. The only systematic difference was the mode of delivery: the control group received traditional instruction, while the experimental group engaged in structured digital game-based strategies. The same teacher taught both groups in the same school setting, with equal instructional time (12 lessons of 40–45 minutes each). Furthermore, instructional quality in both groups was monitored using a standardized observation instrument (Clausen, 2002), which assessed dimensions such as time-on-task, use of materials, teacher–student interactions, and classroom behaviours. This verification confirmed that instructional quality was comparable across groups, apart from the intended difference in pedagogical approach. An independent-samples t-test also confirmed that there were no statistically significant differences between the groups on pre-intervention achievement and motivation measures (Table 2), thereby establishing group equivalence and supporting the study’s internal validity.

Variable	Control (n = 73) Mean (SD)	Experimental (n = 73) Mean (SD)	t value	Sig.
Achievement (pre-test)	8.49 (2.10)	8.03 (1.70)	0.143	> .05
Motivation (pre-test)	47.38 (4.19)	46.62 (6.43)	0.419	> .05

Table 2. Independent Samples t-test Results for Pre-Test Achievement and Motivation

3.4. Instruments

Two instruments were employed to measure the impact of the independent variable (digital educational games) on students’ motivation and deep understanding:

3.4.1. Motivation Scale

Students’ motivation toward learning science was assessed using a modified version of the questionnaire originally developed by Tuan et al. (2005). The original instrument comprised six dimensions and demonstrated high internal consistency (Cronbach’s $\alpha = .89$). For the purposes of this study, the instrument was adapted and shortened to better align with the study objectives and the characteristics of the target population.

The adapted version consisted of 22 items, distributed across four dimensions: self-efficacy (7 items), value of learning science (5 items), performance goals (4 items), and learning environment stimulation (6 items) (see Appendix A). Responses were recorded on a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Negatively worded items were reverse-coded prior to analysis to ensure scoring consistency.

To establish reliability after adaptation, the revised scale was pilot-tested with a group of eighth-grade students who were not part of the experimental or control groups. The Cronbach’s α coefficients for the four dimensions were as follows: self-efficacy (0.78), value of learning science (0.72), performance goals (0.74), and learning environment stimulation (0.76). The overall reliability of the scale was 0.75, which is considered acceptable to very good for educational research (George & Mallery, 2019). The slightly lower value compared to the original instrument can be attributed to the younger age group of the respondents and the adapted item structure.

3.4.2. Deep Understanding Test

To assess students’ deep understanding of scientific concepts, the researchers of this study developed an achievement test based on the Grade 8 science curriculum (Sound Unit, Second Semester). The instrument was comprised of 20 items designed to measure three levels of cognitive engagement: knowledge, application, and reasoning. To ensure comprehensive assessment, the test included both

objective items (multiple-choice questions) and short constructed-response questions, thereby capturing a range of cognitive skills from factual recall to higher-order reasoning. A full version of the test items is provided in Appendix B.

Validity was established through expert review. A panel of eighth-grade science teachers examined the test items and confirmed their alignment with the intended learning outcomes and curriculum standards, ensuring both content validity and face validity.

Item analysis was conducted to examine psychometric properties. Item difficulty indices ranged from 0.36 to 0.72, indicating that the items were of moderate difficulty and therefore appropriate for distinguishing between lower- and higher-achieving students (George & Mallery, 2019). Item discrimination indices ranged between 0.32 and 0.61, which exceeded the commonly accepted threshold of 0.30 and demonstrated that the test items effectively differentiated between students with higher and lower levels of achievement.

Reliability of the instrument was assessed using Cronbach's alpha, which produced a coefficient of 0.82, indicating excellent internal consistency (George & Mallery, 2019). This level of reliability suggests that the test is a stable and dependable measure of students' deep understanding across the three targeted domains.

3.5. Procedures and Data Analysis

The study was implemented in five stages. First, the science content was delivered using two formats: a digital game-based format for the experimental group, incorporating platforms such as Wordwall, Kahoot, and Quizizz, and a traditional format for the control group, following standard teaching practices in Omani public schools. The study instruments - a motivation scale and a deep understanding test - were adapted, validated, and pilot-tested prior to use (Tuan et al., 2005).

In the second stage, both instruments were administered as pre-tests to ensure equivalence between the experimental and control groups. The third stage consisted of conducting the intervention over two weeks (12 sessions), during which the experimental group ($n = 73$) received instruction using digital educational games, while the control group ($n = 73$) received traditional instruction. For the fourth stage, the post-tests were administered to both groups following the intervention.

Finally, data were analysed using the Statistical Package for the Social Sciences (SPSS), with reliability confirmed through Cronbach's alpha (George & Mallery, 2019). Descriptive statistics (means and standard deviations) were calculated for pre- and post-test scores. To examine group differences, an Independent Samples t-test was applied to post-test scores, and a Multivariate Analysis of Covariance (MANCOVA) using Wilks' Lambda was conducted to test for significant differences in post-test achievement and motivation while controlling for pre-test scores (Creswell & Creswell, 2018). This procedure provided a rigorous assessment of the impact of digital game-based learning compared to traditional instruction.

4. Results

4.1. Post-Test Results After the Intervention

To examine the impact of digital game-based learning, post-test scores on both the achievement test and the motivation scale were analysed using Multivariate Analysis of Covariance (MANCOVA), controlling for pre-test scores. The results are summarized in Table 3.

The analysis revealed statistically significant differences between the groups in both post-test achievement and motivation. For post-test achievement, $F(1, 141) = 10.071$, $p = .002$, partial $\eta^2 = .066$, indicating a medium effect size. For post-test motivation, $F(1, 141) = 555.53$, $p < .001$, partial $\eta^2 = .796$, indicating a large effect size. These findings suggest that the digital game-based learning intervention substantially enhanced students' motivation and produced measurable gains in their achievement. Figure 2 illustrates the comparison between the control and experimental groups in post-test achievement and motivation

scores after the intervention. The experimental group demonstrates higher mean scores for both variables, with a particularly substantial increase in motivation, reflecting the strong impact of digital game-based learning.

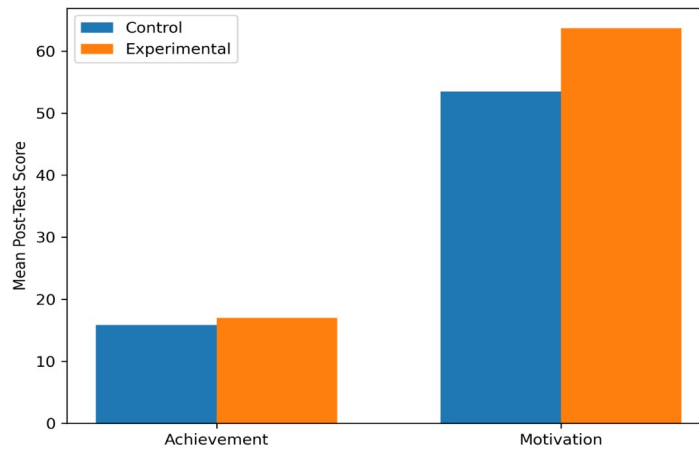


Figure 2. Post-Test Achievement and Motivation Scores for the Control and Experimental Groups

4.1.1. Analysis by Levels of Understanding

When analysed according to the three levels of learning assessed in the Omani science curriculum (knowledge, application, and reasoning), significant differences were observed in knowledge ($p < .001$) and application ($p = .004$), favouring the experimental group. However, no significant differences were found in reasoning ($p = .174$), suggesting that higher-order inferential skills may require more extended exposure to the intervention (Table 3).

Level	% Weight	Control Mean (SD)	Experimental Mean (SD)	p value
Knowledge	40%	6.51 (1.17)	7.12 (0.85)	.000
Application	40%	6.21 (1.40)	6.85 (1.29)	.004
Reasoning	20%	3.15 (0.74)	3.33 (0.83)	.174

Table 3. Independent Samples *t*-test for Post-Test Achievement Levels

Figure 3 illustrates the comparison between the control and experimental groups across the three levels of understanding assessed in the achievement test: knowledge, application, and reasoning. The experimental group achieved higher mean scores in the knowledge and application levels, whereas the difference between the two groups in the reasoning level was smaller and not statistically significant.

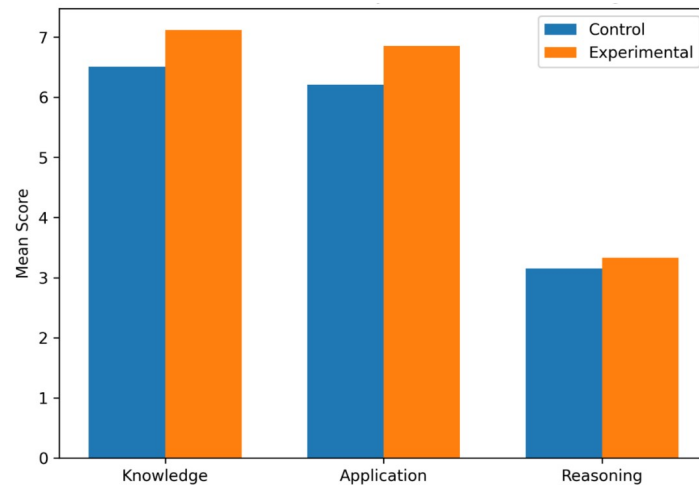


Figure 3. Post-Test Motivation Comparison Between Control and Experimental Groups

4.1.2. Analysis by Motivation Sub-Dimensions

Further analysis of motivation subscales demonstrated statistically significant improvements in all four dimensions - self-efficacy, value of learning science, performance goals, and learning environment stimulation - for the experimental group compared to the control group (all $p < .001$), as shown in Table 4.

Dimension	Control Mean (SD)	Experimental Mean (SD)	p value
Self-efficacy	17.55 (3.46)	23.53 (3.33)	.000
Value of Science Learning	11.45 (2.60)	17.33 (2.88)	.000
Performance Goal	9.55 (1.99)	13.29 (2.38)	.000
Learning Environment Stimulation	14.95 (2.63)	19.77 (2.84)	.000

Table 4. Independent Samples *t*-test for Motivation Sub-Dimensions (Post-Test)

As illustrated in Figure 4, the experimental group demonstrated higher scores across all four motivation dimensions - self-efficacy, value of science learning, performance goal orientation, and learning environment stimulation - compared with the control group. This indicates that digital game-based learning significantly enhanced multiple aspects of motivation toward science learning

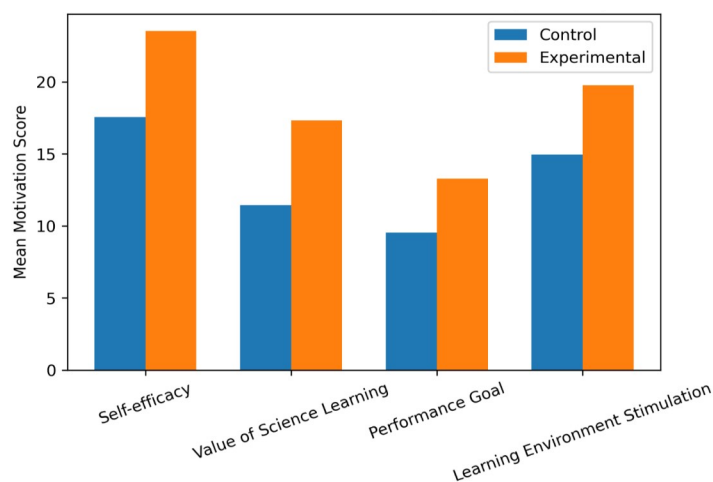


Figure 4. Post-Test Motivation Sub-Dimensions in Control and Experimental Groups

Overall, the results indicate a significant combined effect of the instructional method on both motivation and deep understanding ($p = .013$ for the overall model). The findings confirm that digital game-based learning not only enhances students' cognitive outcomes but also strengthens affective and motivational dimensions of learning. This supports the view that game-based approaches represent an effective, integrated pedagogical strategy for fostering both academic achievement and student engagement in science education.

4.2. Effect of Digital Game-Based Learning on Deep Understanding

The results indicated a statistically significant difference between the experimental and control groups in post-test achievement, with $p = .002$ and a medium effect size (partial $\eta^2 = .066$). This finding suggests that the use of digital game-based learning contributed to the improvement of students' deep understanding of scientific concepts, although the effect was not as large as that observed for motivation.

An analysis of the achievement test across three sub-levels of learning - knowledge, application, and reasoning - provided further insights. At the knowledge level (40% of test items), the experimental group ($M = 7.12$) significantly outperformed the control group ($M = 6.51$), indicating that digital games enhanced students' ability to recall and recognize scientific information ($p < .001$). At the application level (40% of test items), the experimental group ($M = 6.85$) also scored higher than the control group ($M = 6.21$), suggesting that game-based instruction helped students transfer knowledge to practical problem-solving contexts ($p = .004$). By contrast, at the reasoning level (20% of test items), no statistically significant difference was found between the groups, ($p = .174$), even though the experimental group's mean ($M = 3.33$) was slightly higher than that of the control group ($M = 3.15$). Figure 5 presents the effect sizes (Cohen's d) for the impact of digital game-based learning on the three levels of deep understanding assessed in the achievement test: knowledge, application, and reasoning. The largest effects were observed in the knowledge and application levels, while the effect at the reasoning level was comparatively small.

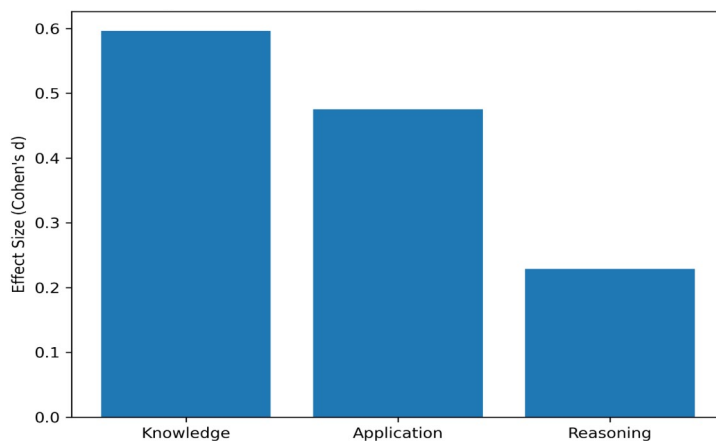


Figure 5. Effect Sizes of Digital Game-Based Learning Across Levels of Deep Understanding

Two factors may explain the lack of significance at the reasoning level. First, reasoning items accounted for only 20% of the test, thereby reducing statistical power. Second, reasoning skills typically require extended practice and sustained instructional exposure before measurable gains become evident. Accordingly, it may be concluded that while the intervention significantly enhanced knowledge and application skills, a longer implementation period would likely be necessary to yield substantial improvements in reasoning.

4.3. Effect of Digital Game-Based Learning on Motivation

The MANCOVA results further revealed a highly significant difference between the experimental and control groups in post-test motivation, $p < .001$, with a very large effect size (partial $\eta^2 = .796$). This finding highlights the significant impact of digital games on enhancing students' motivation to learn science.

The magnitude of this effect can be attributed to the interactive and engaging nature of game-based learning, which combines entertainment with instruction, situates students in realistic learning contexts, and promotes positive competition. Such elements have been shown to increase enthusiasm and sustained participation. Recent research provides strong empirical support for this interpretation. For instance, Barz et al. (2024) reported in a large meta-analysis that digital game-based learning interventions produce significant positive effects on students' cognitive and affective-motivational learning outcomes in school contexts. Similarly, Soriano-Sánchez et al. (2026) found that game-based learning significantly enhances students' motivation, self-efficacy, and academic achievement in science education. Other studies also indicate that the interactive and challenge-based features of digital games can foster engagement and persistence by creating immersive learning experiences that stimulate learners' interest and sustained participation (Pan et al., 2025; Zhou, 2024).

Analysis of the four motivation sub-dimensions further confirmed these results:

- Self-efficacy: The experimental group ($M = 23.53$) outperformed the control group ($M = 17.55$), indicating that digital games enhanced students' confidence in their ability to learn science.
- Value of science learning: The experimental group scored higher ($M = 17.33$) than the control group ($M = 11.45$), reflecting stronger recognition of the importance of science when taught through games.
- Performance goal orientation: Students in the experimental group ($M = 13.29$) scored much higher than those in the control group in this sub-dimension ($M = 9.55$), suggesting that game-based instruction fostered greater motivation to achieve academic success.
- Learning environment stimulation: The experimental group had a higher mean ($M = 19.77$) compared to the control group ($M = 14.95$), showing that digital games created a more stimulating and motivating classroom environment.

Figure 6 illustrates the effect sizes (Cohen's d) of digital game-based learning across the four motivation dimensions: self-efficacy, value of science learning, performance goal orientation, and learning environment stimulation. The results indicate large positive effects across all dimensions, demonstrating the strong impact of the intervention on students' motivation toward science learning.

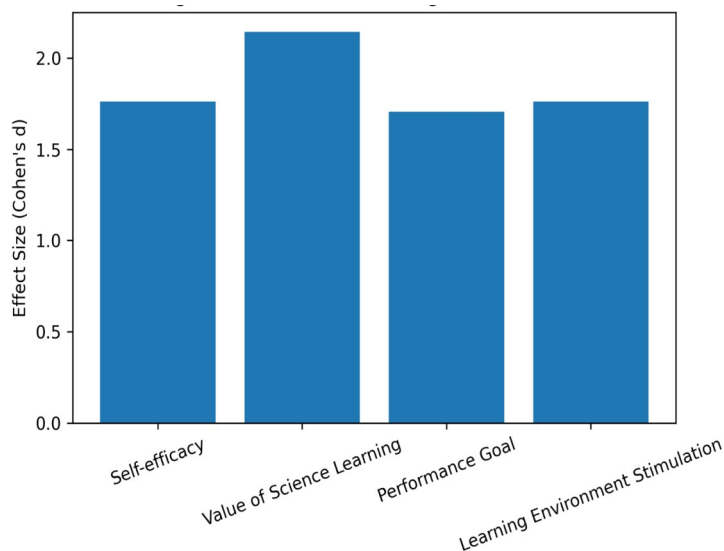


Figure 6. Effect Sizes of Digital Game-Based Learning Across Motivation Dimensions

Taken together, these results demonstrate that digital game-based learning not only improves students' academic achievement but also provides a substantial boost to their motivation, making it a powerful pedagogical strategy for promoting both cognitive and affective learning outcomes.

5. Discussion

This study aimed to investigate the impact of GBL on deepening understanding and motivation among eighth-grade students in science. Guided by constructivist learning theory, self-determination theory, and principles of game-based pedagogy, the findings provide strong evidence that GBL has the potential to foster both cognitive and motivational gains. However, these findings should be interpreted within the specific instructional context and duration of the intervention, which may influence the magnitude and stability of the observed effects. The discussion below is organized around the two research questions.

For RQ1: *What is the effect of digital game-based learning on developing deep understanding of scientific concepts?* The results indicated that students in the experimental group obtained significantly higher post-test scores than their counterparts in the control group, with a medium effect size (partial $\eta^2 = .066$). This demonstrates that GBL effectively enhanced students' conceptual understanding of science, particularly at the knowledge and application levels. These outcomes align with constructivist perspectives, which emphasize that meaningful learning occurs when learners actively engage in exploring, applying, and restructuring knowledge (Bransford et al., 2000). The results also mirror recent research suggesting that by challenging students to solve problems, make decisions, and interact continuously with content, interactive game-based learning environments support deeper conceptual engagement and meaningful learning processes (Sun et al., 2024; Barz et al., 2024). These findings have shown to be robust across school contexts particularly when games require learners to actively interact with concepts and apply knowledge in problem-solving situations (Barz et al., 2024). Similar results were obtained in a science education context by Soriano-Sánchez et al. (2026), who reported that game-based learning significantly improves academic achievement and conceptual understanding.

Looking at more fine-grained results, GBL significantly improved performance in knowledge and application. In other words, GBL improves learners' ability to interpret concepts and apply them in new contexts – two key markers of deep understanding. Recent research emphasizes that meaningful learning occurs when students actively engage with content through interactive and exploratory learning environments that promote conceptual integration and knowledge transfer (Sun et al., 2024; Wang et al., 2025). However, the lack of statistically significant differences in reasoning suggests that inferential thinking requires more sustained exposure and instructional scaffolding. This finding may also reflect the relatively

short duration of the intervention, as higher-order reasoning skills typically develop through extended engagement with inquiry-oriented and technology-supported learning experiences (Arifin et al., 2025).

This improvement can also be explained by the active learning nature of digital games, which require students to make decisions, solve problems, and interact continuously with the content. Such features promote deeper cognitive engagement and reduce reliance on rote memorization. Contemporary research has similarly emphasized that game-based environments can enhance higher-order learning processes by integrating interaction, feedback, and exploratory learning activities (Pan et al., 2025; Sun et al., 2024). Digital games also support integrated learning by presenting information in visually and experientially engaging formats that facilitate conceptual integration and knowledge transfer (Arifin et al., 2025). Gee (2003) describes educational games as offering “rich” learning environments that facilitate simulation and repeated practice needed for fostering deep understanding.

The study’s findings are also consistent with research highlighting the role of educational games in improving individual and group outcomes. For instance, Al-Ghamdi (2021) and Al-Shehhi (2023) reported that digital games significantly enhanced reading comprehension and cognitive flexibility among primary school students in the UAE. Similarly, Samara and Sawalha (2018) found that electronic games improved multiple levels of reading comprehension - including literal, inferential, and critical - in Jordanian schools. More recent studies also confirm that digital game environments can promote collaborative problem-solving and conceptual engagement in educational settings (Pan et al., 2025; Zhou, 2024).

From a theoretical perspective, these results affirm Ausubel’s (1968) theory of meaningful learning, which posits that new knowledge must be anchored to existing cognitive structures for deep learning to occur. The digital games used in this study provided interactive, multimodal contexts that facilitated such anchoring by presenting science concepts visually, experientially, and socially. Contemporary research (Barz et al., 2024; Sun et al., 2024) on digital game-based learning similarly indicates that game environments can function as situated learning contexts in which simulation, interaction, and repeated practice support conceptual integration and deeper understanding.

For RQ2: *What is the effect of digital game-based learning on increasing students’ motivation toward learning science?* The findings also revealed a highly significant effect of GBL on students’ motivation, with a very large effect size (partial $\eta^2 = .796$). Students in the experimental group reported higher self-efficacy, stronger recognition of the value of science learning, greater performance goal orientation, and greater stimulation from the learning environment.

These results can be explained through the application of self-determination theory (Deci & Ryan, 1985, 2017), which highlights autonomy, competence, and relatedness as key drivers of intrinsic motivation. The design of digital games in this study directly addressed these needs (Nadeem et al., 2023). Autonomy was enhanced by allowing students to make choices and progress at their own pace; competence was reinforced through immediate feedback and progressively challenging tasks; and relatedness was fostered through the social and competitive dynamics embedded in the gameplay. Similarly, Pan et al. (2025) demonstrated that digital game-based learning environments support motivation through mechanisms explained by expectancy-value and flow theories, particularly when games incorporate meaningful challenges and interactive feedback.

Recent research further confirms that digital game-based environments can significantly enhance students’ motivation and engagement. For example, Widayanti et al. (2026) found in their meta-analysis that digital games consistently improve students’ motivational engagement in science learning environments. Comparable results have also been reported in international research. Zhou (2024) found that digital game-based learning significantly increased learners’ motivation and engagement by integrating interactive tasks and progress-based feedback mechanisms. These findings align with the present study, where students demonstrated heightened motivation when exposed to well-structured digital games that balanced challenge, feedback, and exploration.

Nevertheless, the motivational improvements observed in this study should be interpreted cautiously. Because the intervention was relatively short, the results may partly reflect situational engagement or novelty effects associated with the introduction of digital games rather than long-term changes in students' motivational dispositions toward science learning. Longitudinal research would therefore be valuable in determining whether such motivational gains can be sustained over time.

The motivational outcomes also suggest a cyclical relationship between motivation and deep understanding. Motivated students are more willing to persist in cognitively demanding tasks, while success in knowledge and application can reinforce their sense of competence and further sustain engagement. This dynamic reflects the study's guiding framework, where GBL functions as a catalyst that simultaneously enhances motivation and deepens conceptual learning. Recent research similarly indicates that digital game-based learning environments can create mutually reinforcing cognitive and motivational processes that support meaningful learning (Pan et al., 2025).

Importantly, the stronger motivational effect observed compared with the cognitive gains may indicate that game-based environments influence affective engagement more rapidly than deeper conceptual change. This was found by Barz et al. (2024), who investigated digital game-based learning interventions in school contexts and found that measurable changes in conceptual understanding often requires longer instructional exposure compared to increases in motivation and attitude.

Taking the Omani context into consideration, the outcomes of this study align with the goals of Oman Vision 2040, which emphasizes digital empowerment and learner-centred pedagogies as pathways for enhancing educational quality and preparing students for participation in a global knowledge economy. More broadly, the results underscore the potential of digital game-based learning to provide science education with an integrated strategy that cultivates both conceptual mastery and motivation - two pillars essential for sustainable and meaningful learning.

5.1. Implications for Science Education

The findings of this study carry important implications for both theory and practice in science education. From a theoretical perspective, the results validate the study's guiding framework, which integrates constructivist learning theory, self-determination theory, and the principles of game-based learning. The observed gains in deep understanding confirm the constructivist assumption that knowledge is best acquired through active engagement, problem-solving, and interaction with meaningful contexts. At the same time, the substantial motivational effects provide empirical support for self-determination theory, demonstrating how digital games can satisfy students' needs for autonomy, competence, and relatedness. By highlighting the reciprocal relationship between motivation and deep understanding, the study makes a conceptual contribution to the literature, illustrating how the affective and cognitive domains reinforce each other in digitally mediated environments. This integrated evidence strengthens the theoretical case for considering GBL as more than a motivational tool; it is also a mechanism for conceptual growth.

From a practical perspective, the study offers clear guidance for science educators. The evidence that GBL significantly enhances motivation suggests that teachers should incorporate game-based platforms, such as Kahoot, Wordwall, and Quizizz, into their classroom practice to create more engaging and stimulating environments. These tools foster self-efficacy, enhance the perceived value of science, and strengthen performance-oriented goals, thereby counteracting declining motivation often observed in middle school science classrooms. The improvement in knowledge and application further indicates that digital games can serve as pedagogically valuable complements to traditional instruction, supporting conceptual integration and transfer of learning. However, the modest impact on reasoning suggests that GBL should be implemented for longer durations and potentially combined with inquiry-based or argumentation-based strategies to develop higher-order cognitive skills.

At a systemic and policy level, the findings match with the explicitly stated goals of *Oman Vision 2040*, which aims to promote digital empowerment, learner-centred pedagogies, and innovation in education.

Incorporating GBL into the national science curriculum could help prepare students for participation in a global knowledge economy by cultivating curiosity, resilience, and problem-solving skills. To achieve this, professional development programs must equip teachers not only with technical skills but also with pedagogical strategies for effectively designing, adapting, and implementing digital games. Such capacity-building would ensure that GBL is integrated meaningfully into instruction rather than used superficially as entertainment.

In summary, this study advances the field of science education by making two key contributions: it strengthens theoretical understandings of how motivation and deep learning interact within game-based environments, and it provides actionable recommendations for teachers, schools, and policymakers seeking to transform science classrooms into dynamic, interactive spaces for twenty-first-century learning.

5.2. Limitations and Future Research

While the findings of this study provide valuable insights into the impact of GBL on students' motivation and deep understanding in science, several limitations should be acknowledged. First, the study was limited to a relatively short intervention period of two weeks (12 sessions). Although significant gains were observed in knowledge and application, the absence of significant improvement in reasoning may be partly attributable to the limited duration. Extended interventions may yield stronger effects on higher-order cognitive skills.

Second, the sample consisted of eighth-grade female students from a single school in Muscat, Oman. The inclusion of only female students reflects the structural organization of the Omani public education system, where schooling is typically gender-segregated at the middle and secondary levels. Consequently, the study was conducted in a girls' school, which represents the practical realities of the local educational context rather than an intentional exclusion of male students. Nevertheless, this sampling context may limit the generalizability of the findings due to the exclusion of male students or mixed-gender educational settings. Previous research indicates that students' motivational responses to digital game-based learning may vary depending on learner characteristics, including gender and classroom dynamics. Therefore, future research should replicate similar interventions in boys' schools and in mixed-gender environments to examine whether the observed effects of digital game-based learning on motivation and conceptual understanding are consistent across different student populations. At the same time, focusing on female students provides meaningful insights, particularly in light of the increasing global emphasis on supporting girls' engagement and participation in STEM-related learning environments. Examining how innovative pedagogical approaches such as digital game-based learning influence motivation and conceptual understanding among female learners contributes to broader efforts aimed at promoting inclusive and equitable science education.

While this focus allowed for a controlled investigation, it also limits the generalizability of the findings across different grade levels, genders, schools, and cultural contexts. Future studies should include more diverse and representative samples to strengthen external validity.

Third, the study relied on paper-based tests and self-report scales to measure deep understanding and motivation. While these instruments demonstrated reliability and validity, they may not fully capture the richness of students' cognitive processes or the dynamic nature of motivational engagement during gameplay. Incorporating qualitative methods, such as classroom observations, interviews, or learning analytics from digital platforms, could provide deeper insights into how students interact with games and construct their understanding.

Finally, the study examined GBL as a single strategy without comparing its effects to other innovative approaches such as inquiry-based learning, flipped classrooms, or augmented reality applications. Future research could explore comparative designs or hybrid models that combine GBL with other pedagogies to maximize learning outcomes.

Future research should therefore focus on (a) longitudinal studies to investigate the long-term impact of GBL on reasoning and higher-order thinking, (b) expanding the scope to include diverse student populations across different cultural and educational contexts, (c) employing mixed-method approaches for a more comprehensive understanding of learning processes, and (d) exploring the integration of GBL within broader instructional frameworks that align with twenty-first-century skills and national educational reform goals.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Authors' contributions

Alghaliya Al-Muqbal: Conceptualization, methodology, investigation, data collection, and writing – original draft.

Zamzam Al-Nabhani: Data curation, data processing, validation, literature review, and writing – original draft.

Mohamed A. Shahat: Supervision, methodology, formal analysis, project administration, and writing – review and editing.

Data availability

Data included in the article itself or supplementary material

Use of Artificial Intelligence

The authors declare that the text of this manuscript is original. Generative artificial intelligence and AI-assisted tools were used solely to support language editing, improve readability, and enhance academic style in selected sections. Specifically, ChatGPT was used for linguistic correction, clarity, grammar, and style improvement. The authors reviewed, verified, and approved all AI-assisted revisions and take full responsibility for the final content of the manuscript. ChatGPT was not used in the research design, data collection, data analysis, or interpretation of the findings.

References

- Al-Ghamdi, S. A. M. (2021). Using digital educational games to develop reading comprehension among primary school female students. *International Journal of E-Learning*, 3(1), 63–87. <https://search.emarefa.net/detail/BIM-1464267> (in Arabic)
- Al-Shehhi, F. A. M. R. (2023). The effect of using electronic educational games on reading comprehension and cognitive flexibility among basic education students. *Arab Journal for Specific Education*, 7(29), 211–238. <https://doi.org/10.21608/ejev.2023.320298> (in Arabic)
- Alotaibi, M. S. (2024). Game-based learning in early childhood education: A systematic review and meta-analysis. *Frontiers in Psychology*, 15, 1307881. <https://doi.org/10.3389/fpsyg.2024.1307881>
- Arifin, Z., Sukarmin, Saputro, S., & Kamari, A. (2025). The effect of inquiry-based learning on students' critical thinking skills in science education: A systematic review and meta-analysis. *Eurasia Journal of Mathematics, Science and Technology Education*, 21(3), em2592. <https://doi.org/10.29333/ejmste/15988>
- Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. Holt, Rinehart and Winston.

- Barz, N., Benick, M., Dörrenbächer-Ulrich, L., & Perels, F. (2024). The Effect of Digital Game-Based Learning Interventions on Cognitive, Metacognitive, and Affective-Motivational Learning Outcomes in School: A Meta-Analysis. *Review of Educational Research*, 94(2), 193-227. <https://doi.org/10.3102/00346543231167795>
- Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school*. National Academy Press.
- Clausen, M. (2002). *Unterrichtsqualität: eine Frage der Perspektive?* [Instructional quality: A question of perspective?]. Waxmann.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.
- Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Springer. <https://doi.org/10.1007/978-1-4899-2271-7>
- Deci, E. L., & Ryan, R. M. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Press.
- Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. Palgrave Macmillan. <https://doi.org/10.1145/950566.950595>
- George, D., & Mallery, P. (2019). *IBM SPSS statistics 26 step by step: A simple guide and reference* (16th ed.). Routledge. <https://doi.org/10.4324/9780429056765>
- Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow, and immersion in game-based learning. *Computers in Human Behavior*, 54, 170–179. <https://doi.org/10.1016/j.chb.2015.07.045>
- Howard, J. L., Bradshaw, E. L., & Ryan, R. M. (2025). Future directions for self-determination theory: Introduction to the special issue. *Motivation and Emotion*, 50, 1–12. <https://doi.org/10.1007/s11031-025-10160-y>
- Mullis, I. V. S., Martin, M. O., Foy, P., Fishbein, B., Centurino, V. A. S., & Drucker, K. T. (2024). *TIMSS 2023 International Results in Mathematics and Science*. Boston College, TIMSS & PIRLS International Study Center. <https://doi.org/10.6017/lse.tpisc.tr2103.kb5342>
- Nadeem, M., Oroszlanyova, M., & Farag, W. (2023). Effect of digital game-based learning on student engagement and motivation. *Computers*, 12(9), 177. <https://doi.org/10.3390/computers12090177>
- National Research Council (NRC) (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. <https://doi.org/10.17226/13165>
- NGSS Lead States (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.
- Oga-Baldwin, W. L. Q., & Ryan, R. M. (2025). Competence need satisfaction in language learning (and beyond): Current state of the evidence and directions for exploration. *Studies in Second Language Learning and Teaching*, 15(2), 279–299. <https://doi.org/10.14746/ssl.48236>
- Ohle-Peters, A., Shahat, M. A., & Ambusaidi, A. K. (2024). Text-Picture-Material in science education: A comparison of Omani and German teachers' attitudes, motivational orientations and self-regulatory skills. *Educational Studies*, 50(1), 103–122. <https://doi.org/10.1080/03055698.2022.2117542>
- Oman Vision 2040 (2019). *Vision 2040: Education and learning sector strategy*. Oman Vision 2040 Implementation Follow-Up Unit.

- Pan, Y., Shao, X., & Shakibaei, G. (2025). Influence of digital game-based learning on social collaboration, problem-solving skills, and motivation: An integrative approach of expectancy-value theory and flow theory. *Learning and Motivation*, 90, 102123. <https://doi.org/10.1016/j.lmot.2025.102123>
- Plass, J. L., Mayer, R. E., & Homer, B. D. (2020). *Handbook of game-based learning*. The MIT Press.
- Reeve, J., & Cheon, S. H. (2024). Learning how to become an autonomy-supportive teacher begins with perspective taking: A randomized control trial and model test. *Teaching and Teacher Education*, 148, 104702. <https://doi.org/10.1016/j.tate.2024.104702>
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68–78. <https://doi.org/10.1037/0003-066X.55.1.68>
- Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. *Educational Psychology Review*, 32(1), 77–112. <https://doi.org/10.1007/s10648-019-09498-w>
- Samara, A. F., & Sawalha, M. A. (2018). The impact of educational electronic games on reading comprehension among seventh graders at UNRWA schools in Jordan. *Journal of Al-Quds Open University for Educational & Psychological Research & Studies*, 8(23), 45–56. <https://search.emarefa.net/detail/BIM-839287> (in Arabic)
- Schunk, D. H., & DiBenedetto, M. K. (2020). Motivation and social-emotional learning: Theory, research, and practice. *Contemporary Educational Psychology*, 60, 101830. <https://doi.org/10.1016/j.cedpsych.2019.101830>
- Shahat, M. A., Al-Balushi, S. M., Alawi, K. A., Bahri, K. A., & Seikkula-Leino, J. (2026). Fostering entrepreneurial mindsets and future skills: Innovative educational units for enhancing creative problem-solving in tenth-grade students. *Thinking Skills and Creativity*, 60, 102084. <https://doi.org/10.1016/j.tsc.2025.102084>
- Shahat, M. A., & Al-Maamari, S. (2025). Cultural Contexts and Global Challenges: Integrating Science and Social Sciences in Omani Teacher. In J. Kreps Frisch, D. M. Alston, A. Feldman, R. Hagevik, & M. Schpakow (Eds.), *Wicked Problems in PreK-12 Science Education* (pp. 147–156). Routledge. <https://doi.org/10.4324/9781003508793-17>
- Soriano-Sánchez, J. G., Quijano López, R., & Airado Rodríguez, D. (2026). The Impact of Game-Based Learning on Motivation, Self-Efficacy, and Academic Achievement in the Natural Sciences: A Meta-Analysis. *Education Sciences*, 16(1), 122. <https://doi.org/10.3390/educsci16010122>
- Sun, L., Kangas, M., & Ruokamo, H. (2024). Game-based features in intelligent game-based learning environments: A systematic literature review. *Interactive Learning Environments*, 32(7), 3431–3447. <https://doi.org/10.1080/10494820.2023.2179638>
- Tuan, H. L., Chin, C. C., & Shieh, S. H. (2005). The development of a questionnaire to measure students' motivation towards science learning. *International Journal of Science Education*, 27(6), 639–654. <https://doi.org/10.1080/0950069042000323737>
- Wang, X. M., Wang, J. L., Xu, S. Y., & Xu, S. J. (2025). Concept mapping in STEM education: A meta-analysis of its impact on students' achievement in STEM disciplines (2004–2023). *International Journal of STEM Education*, 12, 30. <https://doi.org/10.1186/s40594-025-00554-2>
- Widayanti, Istiyono, E., Haryanto, & Retnawati, H. (2026). How Digital Games Impact Student Motivation in Science: A Meta-Analysis. *Journal of Teaching and Learning*, 20(1). <https://doi.org/10.22329/jtl.v20i1.9331>
- Zhang, L., & Linn, M. C. (2022). Designing technology-enhanced science instruction to support deep learning. *Journal of Research in Science Teaching*, 59(3), 365–392. <https://doi.org/10.1002/tea.21740>

Zhou, S. (2024). Gamifying language education: The impact of digital game-based learning on Chinese EFL learners. *Humanities and Social Sciences Communications*, 11, 1518.
<https://doi.org/10.1057/s41599-024-04073-3>

Appendix

Appendix A

Motivation Scale for Learning Science among Eighth-Grade Students

Student’s Name: Class:

Dear Student,

This questionnaire aims to understand your perspective on learning science. There are no right or wrong answers; we are only interested in your personal opinion. Please place a check mark (✓) in the box that best reflects your level of agreement with each statement according to the following scale:

1 = Strongly Disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly Agree

Section 1: Self-Efficacy

No.	Item	1	2	3	4	5
1	Whether science content is easy or difficult, I am confident that I can understand it.					
2	I am not confident in my ability to understand difficult science concepts (-).					
3	I am confident that I can achieve good results in science tests.					
4	No matter how hard I try, I cannot learn science. (-)					
5	When science activities are difficult, I give up or only do the easy parts. (-)					
6	During science activities, I prefer to ask others for help instead of thinking for myself. (-)					
7	When I find science content difficult, I do not try to learn it. (-)					

Section 2: Value of Learning Science

No.	Item	1	2	3	4	5
8	I believe learning science is important because I can use it in my daily life.					
9	I believe learning science is important because it stimulates my thinking.					
10	I believe learning science helps me solve problems.					
11	I believe it is important to participate in inquiry activities in science.					
12	It is important for me to satisfy my curiosity when learning science.					

Section 3: Performance Goal Orientation

No.	Item	1 2 3 4 5
13	I participate in science classes only to get a good grade. (–)	
14	I participate in science classes to outperform my classmates. (–)	
15	I participate in science classes so that my classmates think I am smart. (–)	
16	I participate in science classes because I want the teacher to notice me. (–)	

Section 4: Learning Environment Stimulation

No.	Item	1 2 3 4 5
17	I am willing to participate in this class because the content is interesting and varied.	
18	I am willing to participate because the teacher uses a variety of teaching methods.	
19	I am willing to participate because the teacher does not put too much pressure on us.	
20	I am willing to participate because the teacher cares about me and notices me.	
21	I am willing to participate because the subject matter is challenging for me.	
22	I am willing to participate because other students take part in the discussions.	

Note. Items marked with (–) are reverse-coded.

Appendix B

Achievement Test – Sound Unit

Grade 8 – Science

Name: _____ Class: _____ Date: _____

Introduction

Dear Student,

This test is designed to measure your understanding of the concepts in the Sound Unit. The questions are structured to assess your ability to recall basic information, apply it in new contexts, and draw inferences.

Objective of the Test:

The aim of this test is to evaluate the extent to which you have acquired knowledge and skills related to the properties of sound, both before and after studying the unit.

Part A – Fill in the blanks with the appropriate answer

1. If a ruler vibrates 70 times in 10 seconds, the frequency of the sound is _____ Hz. (*Application*)
2. If a tuning fork vibrates 300 times per second, the frequency equals _____ Hz. (*Application*)
3. Sound is produced by _____. (*Knowledge*)

4. When a sound carrier is brought closer to the source, the loudness of the sound _____.
(Application)
5. Sound waves travel through _____, _____, and _____. (Knowledge)
6. The frequency of sound is _____. (Knowledge)
7. Amplitude is the distance between _____ and _____ in a sound wave. (Knowledge)
8. On an oscilloscope graph, if the distance from crest to trough increases, this indicates an increase in _____. (Application)
9. If two waves have the same frequency but different amplitudes, the wave with the greater amplitude is _____ in sound. (Application)
10. If no wave appears on the oscilloscope, this indicates _____. (Reasoning)
11. If you notice that the sound becomes sharper (higher pitch) gradually, the frequency _____.
(Reasoning)
12. Sound cannot travel through _____. (Knowledge)
13. High-frequency sounds are described as _____ pitched. (Knowledge)
14. The sound of a guitar is higher than that of a drum because _____. (Application)
15. When the ruler vibrates faster, the resulting sound is _____. (Knowledge)
16. If the frequency is 500 Hz, the number of vibrations in 2 seconds is _____. (Application)
17. As amplitude increases, the loudness of sound _____. (Knowledge)
18. If the wave is longer but has the same amplitude, the pitch _____. (Reasoning)
19. If a sound wave repeats more quickly on the screen, this means that the sound source _____.
(Reasoning)
20. On an oscilloscope, if more waves appear within the same time period, the frequency _____.
(Application)

Published by OmniaScience (www.omniascience.com)

Journal of Technology and Science Education, 2026 (www.jotse.org)



Article's contents are provided on an Attribution-Non Commercial 4.0 Creative commons International License.

Readers are allowed to copy, distribute and communicate article's contents, provided the author's and JOTSE journal's names are included. It must not be used for commercial purposes. To see the complete licence contents, please visit <https://creativecommons.org/licenses/by-nc/4.0/>.