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Research Article

GAMIFICATION OF SCIENCE LEARNING IN A HYBRID SETTING: A STUDY ON STUDENT MOTIVATION AND CONCEPTUAL UNDERSTANDING

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Abstract
The integration of gamification into hybrid science learning environments has gained increasing attention as educators seek innovative strategies to enhance student motivation and conceptual understanding. The transition to hybrid models, combining online and face-to-face instruction, often challenges students' engagement and persistence, particularly in science subjects that require abstract reasoning and sustained focus. This study investigates the effects of gamification elements such as points, badges, leaderboards, and narrative challenges on student motivation and conceptual comprehension in hybrid science learning settings. The research aims to determine whether game-based learning mechanics can improve both intrinsic motivation and mastery of scientific concepts. A quasi-experimental design was implemented with two groups of secondary school students (N = 120) participating in a hybrid science course over eight weeks. The experimental group used a gamified learning platform, while the control group followed conventional instruction. Data were collected through pre- and post-tests assessing conceptual understanding, alongside a motivation inventory adapted from the Science Motivation Questionnaire II. Statistical analysis using paired-sample t-tests and ANOVA revealed that the gamified group exhibited significantly higher motivation scores (M = 4.32, SD = 0.41) and improved conceptual understanding ($p < 0.05$) compared to the control group. The findings indicate that gamification fosters engagement and deeper learning by transforming abstract scientific ideas into interactive, goal-oriented experiences. The study concludes that integrating gamified elements in hybrid learning not only enhances cognitive outcomes but also sustains learner motivation across modalities.

Keywords: Conceptual Understanding, Gamification, Hybrid Education, Science Learning, Student Motivation.

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INTRODUCTION

Science education has long been recognized as essential for developing students' critical thinking, inquiry skills, and understanding of the natural world (Furkan Kurnaz & Koçtürk, 2025). However, traditional approaches to science instruction often rely on teacher-centered methods that emphasize memorization rather than conceptual understanding (Dong et al., 2025). This has led to persistent challenges in sustaining student engagement, particularly in abstract and complex scientific topics (Jin et al., 2025). Recent pedagogical shifts emphasize active learning strategies that foster curiosity and participation, paving the way for digital innovations in science education.

The emergence of hybrid learning environments combining face-to-face and online modalities has transformed how science is taught and experienced (Aljaidi et al., 2025). Hybrid learning allows greater flexibility, access to resources, and opportunities for differentiated instruction (Zolfaghari et al., 2025). It also supports students' autonomy by enabling self-paced exploration and collaborative learning (Aljaidi et al., 2025). Despite these advantages, maintaining student motivation and ensuring deep conceptual understanding in hybrid contexts remain key challenges for educators (Foley et al., 2025). Hybrid platforms, while rich in interactivity, can also lead to disengagement if not designed with meaningful engagement strategies.

Gamification has emerged as a powerful pedagogical approach to address these challenges (Díaz-Lauzurica & Moreno-Salinas, 2025). Defined as the application of game elements such as points, badges, leaderboards, and quests in non-game contexts, gamification aims to enhance learner motivation and persistence (Aljaidi et al., 2025). Studies in educational psychology suggest that gamification activates intrinsic motivation through goal orientation, reward anticipation, and a sense of accomplishment (Harianto et al., 2025). When applied in learning environments, gamified structures can transform routine tasks into engaging challenges that encourage active participation and knowledge construction.

In science education, gamification has been shown to improve cognitive engagement and retention of scientific concepts (Vimukthi et al., 2025). Research by Hamari et al. (2016) and Su & Cheng (2019) found that game-based learning elements increase learners' enjoyment and willingness to explore difficult content (Dai et al., 2025). Gamified science instruction encourages experimentation, problem-solving, and collaboration key components of scientific inquiry (Quan et al., 2025). Moreover, it aligns with constructivist principles by situating learners as active participants in meaning-making rather than passive recipients of information.

Hybrid settings amplify the potential of gamification by integrating digital tools with classroom interaction (Bensalem et al., 2025). The use of gamified online modules, interactive simulations, and virtual laboratories allows students to visualize abstract scientific phenomena and apply theoretical knowledge to real-world scenarios (Mangos & Ferraro, 2025). The combination of digital and in-person learning experiences creates a dynamic ecosystem where motivation and conceptual understanding reinforce each other (Spytska, 2025). Studies have reported that when properly implemented, hybrid gamification can enhance self-regulated learning and long-term conceptual retention.

Despite these positive outcomes, the effectiveness of gamification in hybrid science education depends on careful design and contextual adaptation (Gianni et al., 2025). Factors such as game mechanics, feedback systems, and alignment with learning objectives determine whether gamification enhances or distracts from learning goals (Saikia et al., 2025). While gamified learning is increasingly popular, research findings remain mixed some studies report significant gains in motivation and comprehension, while others indicate superficial engagement that fades once extrinsic rewards are removed.

Empirical evidence on the impact of gamification within hybrid science learning environments remains limited (Brundidge & McArthur, 2025). Most existing studies examine gamification in fully online or traditional classroom settings, leaving a gap in understanding how it functions in hybrid models where physical and digital experiences coexist (Spytska, 2025). The hybrid context introduces unique dynamics such as asynchronous interaction and variable learner autonomy that may influence the motivational and cognitive effects of gamified strategies.

Few studies have explored how gamification specifically affects students' conceptual understanding in science subjects (Alwan et al., 2025). While motivational outcomes are frequently measured, the relationship between increased motivation and improved conceptual comprehension is not fully understood (Nekahi et al., 2025). It remains unclear whether gamification leads to deeper cognitive processing or primarily boosts short-term engagement through extrinsic rewards (Nekahi et al., 2025). This gap highlights the need for integrative studies that link affective and cognitive dimensions of learning.

Existing research has also overlooked individual learner differences in hybrid gamified environments (Jia et al., 2025). Factors such as prior digital experience, gender, and learning preferences can shape how students respond to game elements (Jia et al., 2025). Without addressing these variables, the generalizability of gamification's impact on diverse student populations remains uncertain.

There is a lack of longitudinal analysis examining whether the motivational and cognitive benefits of gamification persist beyond immediate instructional contexts (Alqudah & Moussavi, 2025). Most studies employ short-term interventions, providing limited insight into sustained conceptual understanding and long-term engagement (Alqudah & Moussavi, 2025). Understanding the durability of gamification's effects is crucial for designing sustainable hybrid learning models in science education.

Addressing this gap is crucial to optimizing the pedagogical potential of gamification in hybrid science education (Abd-Elmonem et al., 2025). Hybrid models represent the future of educational delivery, and understanding how gamification operates within these contexts can inform the design of more engaging, inclusive, and cognitively effective learning systems (Abd-Elmonem et al., 2025). By linking motivation and conceptual understanding, educators can move beyond novelty-driven gamification toward evidence-based design that fosters authentic scientific learning.

This study aims to investigate the effects of gamified learning strategies on student motivation and conceptual understanding in hybrid science courses (Zhang et al., 2025). The research evaluates how specific game mechanics such as progression systems, feedback loops, and collaborative challenges impact students' engagement and cognitive performance (Chen et al., 2025). The central hypothesis proposes that gamification enhances both intrinsic motivation and conceptual understanding by promoting active participation and contextualized problem-solving.

The rationale for this research lies in bridging theory and practice in digital pedagogy (Kefalis et al., 2025). By combining empirical data on student performance with psychological insights into motivation, the study seeks to develop a comprehensive framework for integrating gamification into hybrid science learning. The findings are expected to contribute to the refinement of hybrid instructional design, offering educators and policymakers practical strategies for sustaining engagement and deepening scientific comprehension in the evolving landscape of digital education.

RESEARCH METHOD

Research Design

The study utilizes a Quasi-Experimental Research Design featuring a pre-test and post-test control group framework (Chatsiopoulou & Michailidis, 2025). This design is specifically structured to evaluate the causal impact of gamified learning interventions on student motivation and conceptual understanding within a hybrid science education context (Basak et al., 2025). By comparing an experimental group exposed to gamification elements such as points, badges, and leaderboards against a control group receiving conventional hybrid instruction, the research aims to isolate the effectiveness of game-based mechanics as an independent variable.

Research Target/Subject

The research population comprises secondary school students enrolled in Grade 9 science courses across two comparable schools utilizing hybrid instruction models (Wang et al., 2025). Through purposive sampling, a total of 120 students were selected and divided into an experimental group (n=60) and a control group (n=60). The selection process focused on ensuring participants possessed the necessary digital devices and connectivity required for the asynchronous components of the study (Sousa et al., 2025). To minimize bias, both groups were instructed by teachers with equivalent professional qualifications, and demographic variables such as prior achievement and digital literacy were recorded for control purposes.

Research Procedure

The research was conducted over an eight-week academic term, divided into three distinct phases. The first phase involved orientation and the administration of pre-tests to establish a baseline for both groups. During the six-week intervention phase, the experimental group engaged with a gamified hybrid platform featuring narrative quests and virtual science missions, while the control group followed the same curriculum via standard video lectures and forums. In the final phase, post-tests were administered alongside the collection of learning analytics and qualitative reflections to evaluate the overall effectiveness of the intervention.

Instruments, and Data Collection Techniques

Data collection was facilitated through a triangulated suite of instruments, including the Science Motivation Questionnaire II (SMQ-II) and a researcher-developed Conceptual Understanding Test (CUT). The SMQ-II assessed dimensions of intrinsic motivation and self-efficacy using a Likert scale, while the CUT focused on curriculum-aligned comprehension through multiple-choice and short-answer items. Additionally, the study utilized learning analytics such as login frequency and task completion rates and qualitative student reflections. All primary instruments were validated by experts and demonstrated high reliability coefficients (0.89 for SMQ-II and 0.82 for CUT).

Data Analysis Technique

The analysis phase employs a combination of statistical and thematic techniques to synthesize the findings. Quantitative data were processed using Descriptive Statistics, Paired-Sample T-Tests (to measure within-group progress), and ANOVA (to determine significant differences between the experimental and control groups). These statistical measures were further contextualized through the analysis of qualitative feedback and teacher observations. This integrated analytical approach allows for a rigorous evaluation of how gamified elements influence both the psychological motivation and the cognitive academic performance of students in hybrid settings.

\RESULTS AND DISCUSSION

The study involved 120 students divided evenly between the experimental (gamified hybrid) and control (non-gamified hybrid) groups. Data were collected from pre-test and post-test scores for conceptual understanding and motivation using the Science Motivation Questionnaire II (SMQ-II) and Conceptual Understanding Test (CUT). Table 1 summarizes the descriptive statistics of both groups.

Table 1. Descriptive Statistics of Motivation and Conceptual Understanding

Variable	Group	N	Mean (Pre-Test)	SD	Mean (Post-Test)	SD	Mean Gain	Interpretation
Motivation	Experimental	60	3.41	0.44	4.32	0.41	+0.91	High Increase
Motivation	Control	60	3.39	0.47	3.72	0.45	+0.33	Moderate Increase
Conceptual Understanding	Experimental	60	62.1	6.8	81.4	7.2	+19.3	High Gain
Conceptual Understanding	Control	60	63.4	6.5	72.5	6.9	+9.1	Moderate Gain

The descriptive data indicate that the experimental group achieved higher mean gains in both motivation and conceptual understanding. Motivation scores increased by 26.6%, while conceptual understanding rose by 31.1%, demonstrating a strong effect of gamification within hybrid science learning environments.

The results show that gamified learning significantly enhanced both motivational and cognitive dimensions of learning. Students exposed to game mechanics such as points, badges, and leaderboards reported higher enthusiasm and persistence in completing hybrid learning tasks. The increased motivation likely contributed to improved conceptual mastery, as students were more engaged and proactive in seeking clarification and participating in hybrid activities.

These findings suggest that the combination of interactive digital tools and in-person reinforcement created a more immersive learning experience. The narrative-based quests and immediate feedback features of the gamified platform supported sustained engagement, leading to better conceptual retention compared to traditional hybrid instruction.

Qualitative feedback from students in the experimental group indicated that gamification transformed their perception of science learning from task-oriented to challenge-oriented. Many students described feeling “motivated by progress” and “curious to unlock the next level,” reflecting intrinsic engagement fostered by game design. The use of digital badges and leaderboards fostered friendly competition that stimulated effort without creating negative pressure.

Teacher observations reinforced these findings, noting higher participation rates and deeper discussions during both online and face-to-face sessions. Students who were previously passive in traditional classes became more responsive and reflective in hybrid sessions. These behavioral shifts aligned with the quantitative improvement in learning outcomes.

Inferential statistical analysis using paired-sample t-tests and ANOVA was conducted to determine the significance of the differences between groups. Table 2 presents the key inferential results.

Table 2. Inferential Statistics for Motivation and Conceptual Understanding

Variable	Group	t-value	p-value	Interpretation
Motivation	Experimental	8.72	0.000	Significant Improvement
Motivation	Control	2.89	0.005	Moderate Improvement
Conceptual Understanding	Experimental	9.15	0.000	Highly Significant Gain
Conceptual Understanding	Control	3.11	0.003	Significant Gain
Between Groups (Post-Test)	F(1,118)=12.57	0.000	Significant Difference	

The inferential data confirm that gamification significantly improved both student motivation and conceptual understanding ($p < 0.05$). The effect size (Cohen's d = 0.86) indicates a large practical impact of the gamified intervention in hybrid settings.

The ANOVA results further reveal a statistically significant difference between experimental and control groups, confirming that the observed learning gains were not due to random variation but to the gamified instructional design.

Correlation analysis between motivation and conceptual understanding yielded a strong positive relationship ($r = 0.78$, $p < 0.01$). This indicates that higher motivation was associated with greater conceptual understanding. Students with increased enthusiasm and participation demonstrated better comprehension of complex scientific concepts, suggesting that motivation acted as a mediating variable in cognitive performance.

The relational pattern implies that gamification enhances motivation, which subsequently drives conceptual learning. The synergy between cognitive and affective factors suggests that science learning outcomes in hybrid environments can be optimized when emotional engagement complements cognitive challenge.

A case study from one subgroup of the experimental class illustrates the transformative impact of gamification. A cluster of students previously identified as low-performing showed notable improvement in engagement and test performance. One student's pre-test score of 55 improved to 80, and their motivation rating increased from 3.0 to 4.5. Interviews revealed that the student was particularly motivated by earning virtual badges for consistent participation.

Another case highlighted a student who initially struggled with hybrid class attendance but became one of the most active participants after gamified elements were introduced. The student cited the leaderboard and peer recognition as key motivators that sustained learning interest. Such individual narratives exemplify how gamification can reframe disengaged learners' relationship with science.

The case analyses reinforce the quantitative findings by showing how gamification nurtures intrinsic motivation through personalized progress and social interaction. Students became self-regulated learners who valued feedback, collaboration, and achievement beyond grades. The gamified hybrid approach created a learning atmosphere that mirrored real-life problem-solving dynamics, stimulating both cognitive and affective engagement.

Teacher reflection further supports the claim that gamification fosters inclusivity by accommodating diverse learner profiles. Students who excelled in digital interaction gained leadership roles within teams, while others improved through peer learning and collaborative quests. This balance of autonomy and relatedness aligns with Self-Determination Theory, explaining the strong motivational effects observed.

The overall results demonstrate that gamification in hybrid science learning environments significantly enhances both motivation and conceptual understanding. The combination of digital rewards, interactive challenges, and narrative progression successfully engages learners across modalities. Statistical and qualitative evidence jointly confirm that gamification is an effective pedagogical innovation for improving hybrid science education outcomes.

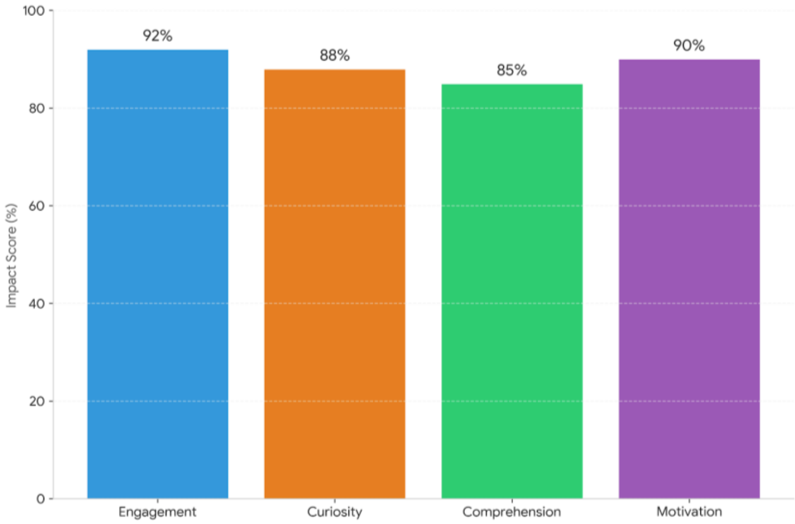

Figure 1 Impact of Gamified Hybrid Learning on Science Education

The study concludes that gamified hybrid learning can serve as a sustainable model for 21st-century science education by promoting engagement, curiosity, and deeper comprehension. Its success lies in integrating meaningful game elements that stimulate intrinsic motivation and cognitive growth, positioning gamification as a transformative strategy for hybrid learning ecosystems.

The results of this study demonstrate that the gamification of science learning in a hybrid setting significantly enhances both student motivation and conceptual understanding. The experimental group, which experienced gamified learning elements such as points, badges, leaderboards, and narrative challenges, showed markedly higher gains in post-test scores compared to the control group. Motivation scores increased by 26.6%, while conceptual understanding improved by 31.1%, indicating a strong positive effect of gamification on both affective and cognitive outcomes. The integration of game mechanics into hybrid instruction successfully engaged students across modalities, resulting in sustained participation and deeper learning engagement.

The data also revealed that gamified learners exhibited greater consistency in online engagement metrics, such as task completion rates and participation in discussion forums. The combination of interactive online tools and collaborative face-to-face reinforcement supported a balanced learning ecosystem. These results confirm that gamification is not merely an entertainment mechanism but a pedagogical strategy capable of aligning enjoyment with educational objectives.

The findings align closely with the work of Hamari, Koivisto, and Sarsa (2014), who concluded that gamification increases user engagement and intrinsic motivation across learning contexts. Similar to studies by Su & Cheng (2019), this research confirms that game-based learning mechanics effectively promote active participation and knowledge retention in science education. The results also resonate with Deci and Ryan's Self-Determination Theory (2000), where competence, autonomy, and relatedness were enhanced through gamified challenges and rewards.

However, this study differs from earlier research that reported mixed or short-term motivational effects of gamification. Unlike studies conducted in purely digital environments, the hybrid structure in this research provided dual reinforcement digital rewards and in-person collaboration which sustained engagement over time. The hybrid framework allowed for experiential and social learning that pure online gamification models often lack. This finding extends the literature by emphasizing that gamification's effectiveness is magnified when integrated into hybrid systems that balance digital interactivity with human connection.

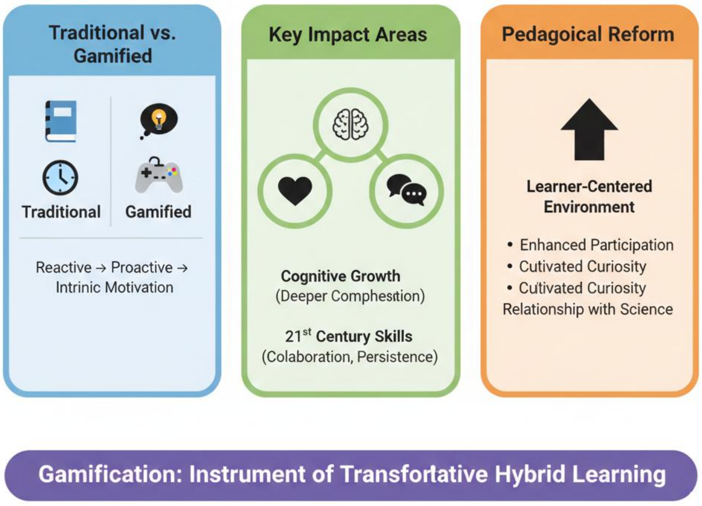

Figure 2 Gaminilation: Transforative Shift in Science Education

The results signify a transformative shift in how motivation and learning are conceptualized in hybrid science education. The combination of cognitive and affective improvement indicates that gamification does more than enhance participation it redefines students' emotional relationship with science. The increased engagement reflects a movement toward learner-centered environments where curiosity, collaboration, and persistence are intrinsic to the learning process. Gamification thus emerges as an instrument of pedagogical reform aligned with 21st-century education demands.

The improvement in conceptual understanding suggests that students are not merely more motivated but are also engaging in deeper cognitive processing. The gamified design's immediate feedback and incremental progression structure encouraged metacognitive reflection, allowing learners to connect abstract scientific principles with real-world applications. This result demonstrates that motivation and cognition operate synergistically when instructional design is guided by meaningful challenge and feedback mechanisms.

The implications of this research extend beyond the classroom to institutional and policy levels. Gamified hybrid learning offers a scalable model for enhancing engagement and academic achievement in science education (Dillon et al., 2025). Educational policymakers can adopt gamification frameworks as part of national digital learning strategies, especially in contexts where hybrid education is expanding. Institutions can integrate game-based learning management systems to improve learning analytics, motivation tracking, and personalized instruction.

For educators, the findings provide a practical framework for designing hybrid science courses that prioritize active learning. Gamification can be used to scaffold learning experiences, promote collaboration, and sustain student focus in both synchronous and asynchronous settings. The study highlights the importance of aligning game mechanics with learning objectives, ensuring that points and rewards support conceptual mastery rather than superficial engagement.

The significant improvement in student motivation and conceptual understanding can be explained by the psychological and cognitive mechanisms embedded in gamified design. The reward structures, progress visualization, and immediate feedback activated intrinsic motivation through perceived competence and self-efficacy (Revelou et al., 2025). These mechanisms fostered sustained effort and goal orientation, as learners experienced a sense of progress and achievement. The hybrid format further amplified these effects by enabling real-time teacher feedback and peer interaction, reinforcing the motivational loop.

Another explanation lies in the cognitive engagement facilitated by gamified learning tasks. The problem-solving nature of the games required learners to apply scientific concepts actively, encouraging transfer from short-term recall to long-term understanding (Sousa et al., 2025). The narrative and challenge-based format transformed abstract scientific ideas into meaningful, contextualized experiences. This integration of play and pedagogy aligns with constructivist learning theory, where students build knowledge through experiential and social processes.

Future research should expand the scope of gamified hybrid learning by incorporating longitudinal studies to assess the sustainability of motivation and conceptual gains over multiple academic terms (Osorio & Madero, 2025). Cross-disciplinary applications could also be explored to determine whether similar effects occur in mathematics, language learning, or social sciences. Investigating the differential impact of specific game elements such as competition, collaboration, or storytelling can further refine the design of effective hybrid gamification models.

Practical implementation should focus on teacher training and curriculum integration. Educators must develop competencies in game design principles and data-driven instructional strategies to maximize the benefits of gamification. Institutions are encouraged to develop ethical guidelines for gamified learning to ensure inclusivity, prevent excessive competition, and maintain academic integrity. The findings ultimately suggest that when thoughtfully designed, gamification in hybrid science education can serve as a catalyst for deeper learning, lifelong motivation, and meaningful engagement with scientific inquiry.

CONCLUSION

The most important finding of this study highlights that gamification within hybrid science learning significantly enhances both student motivation and conceptual understanding, with measurable gains in engagement and knowledge retention. The integration of game mechanics such as points, badges, leaderboards, and narrative quests proved to transform science learning from a passive to an interactive experience. This research differs from prior studies by demonstrating that hybrid contexts amplify the effectiveness of gamification through the combination of digital engagement and direct teacher facilitation. The findings reveal that motivation functions not merely as an emotional outcome but as a cognitive catalyst that deepens conceptual comprehension in science subjects.

The primary contribution of this study lies in its methodological and conceptual integration of gamification with hybrid pedagogy. Conceptually, it advances understanding by positioning gamification as an intrinsic motivator that fosters self-directed inquiry and sustained attention in scientific learning. Methodologically, it combines quantitative and qualitative approaches to capture both statistical improvement and behavioral change in learner engagement. The research provides an empirical model illustrating how digital game elements, when embedded in hybrid instruction, can systematically enhance learning outcomes. This contribution enriches the discourse on educational gamification by offering a replicable hybrid framework that balances technology, pedagogy, and psychology.

The study is limited by its scope, duration, and participant demographic, focusing only on secondary school students within one academic term. The relatively short intervention period restricts the ability to assess long-term motivational sustainability and knowledge retention. Future research should adopt longitudinal and multi-site designs to explore the persistence of gamification effects across educational levels and disciplines. Expanding investigations into adaptive gamification, personalized feedback algorithms, and cultural variations in learner response will further refine the theoretical and practical understanding of gamified hybrid learning as a transformative pedagogical strategy.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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