IJMR E-ISSN: 3109-9777
INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEACH

EFFECTIVENESS AND DESIGN OF DIGITAL GAME-BASED LEARNING FOR SCIENCE PROCESS SKILLS IN HIGHER EDUCATION: A SYSTEMATIC LITERATURE REVIEW

Rohmani
Universitas Muhammadiyah Kotabumi, Indonesia
Email: rohman.orgos@gmail.com

E-ISSN : 3109-9777

Received: August 2026	Accepted: August 2026	Published: August 2026

Abstract :

Mastery of Science Process Skills (SPS) is a foundational competency in STEM higher education; however, conventional instructional methods consistently fail to facilitate deep engagement with complex and abstract scientific phenomena. This study aimed to evaluate the effectiveness of Digital Game-Based Learning (DGBL) in developing undergraduate students' science process skills, and to identify the instructional design elements most critical to achieving these outcomes. A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 protocol. Empirical articles were retrieved from Scopus and ScienceDirect (2021–2025) and appraised using the Mixed Methods Appraisal Tool (MMAT). A final corpus of 33 articles was synthesised. DGBL produced consistently positive and significant effects on higher-order science process skills, with synthesised effect sizes of Hedges' g ≈ 0.65–0.82 for problem-solving, critical thinking, and scientific reasoning. Effects on lower-order skills were more modest (g ≈ 0.38–0.45). Adaptive scaffolding, immediate formative feedback, and precise Learning Mechanics–Game Mechanics (LM–GM) alignment were identified as the most influential design variables. Stealth assessment frameworks provided more objective and process-oriented evaluations than conventional instruments. DGBL grounded in robust pedagogical design effectively bridges the gap between abstract scientific theory and authentic inquiry-based practice. Future research should prioritise Generative AI integration, immersive technologies, and longitudinal studies tracking long-term SPS retention.

Keywords : Digital Game-Based Learning; Science Process Skills; Higher Education; Systematic Literature Review; Instructional Design; Serious Games

INTRODUCTION

Scientific literacy is a core requirement of twenty-first-century higher education, and science process skills (SPS) constitute its operational foundation in STEM programmes (Turiman et al., 2012). These skills span systematic observation, hypothesis formulation, experimental design, multivariate data interpretation, and analytical problem-solving. Undergraduate mastery of them is consistently associated with stronger academic performance, sharper critical thinking, and readiness for the complexities of contemporary industry and research.

Conventional lecture-centred instruction has nonetheless proved persistently inadequate for teaching phenomena that are abstract, dynamic, or inaccessible to direct observation. Students frequently struggle to visualise microscopic processes or systems operating across extreme timescales, while institutional constraints such as limited laboratory access, equipment costs, and safety risks further narrow opportunities for authentic exploration (Li & Tsai, 2013). These conditions create a clear need for technology-mediated interventions capable of bridging abstract theory and experiential scientific practice safely and affordably.

Digital Game-Based Learning (DGBL) has emerged as one of the most promising responses to that need (Clark et al., 2016). By embedding rigorous educational content within interactive game architectures, DGBL mobilises challenge, autonomy, narrative, and immediate feedback to sustain cognitive engagement and intrinsic motivation. Unlike passive multimedia, serious games offer reactive simulation environments in which students iteratively experiment, manipulate variables, and test hypotheses without the risks inherent in physical laboratory work, supporting the pedagogical transition from knowing science to doing science.

Despite this potential, prior systematic reviews have concentrated on K–12 settings or have measured holistic science achievement without differentiating the sub-dimensions of SPS (Clark et al., 2016; Li & Tsai, 2013). A synthesis examining DGBL effectiveness and evidence-based design principles specifically for SPS development in higher education therefore remains absent, leaving curriculum designers and institutional decision-makers at risk of adopting commercial games that are misaligned with advanced scientific learning objectives.

This review pursues four objectives: to evaluate systematically the effectiveness of DGBL on undergraduate students' science process skills in higher education; to identify the instructional game design elements most critically associated with the development of those skills; to synthesise recent empirical evidence published between 2021 and 2025 under the PRISMA 2020 protocol; and to derive actionable design guidelines for curriculum developers, science educators, and serious game designers.

RESEARCH AND METHODS

This study employed a Systematic Literature Review (SLR) design, guided by the PRISMA 2020 (Preferred Reporting Items for Systematic reviews and Meta-Analyses) protocol (Page et al., 2021) to ensure methodological transparency, reproducibility, and rigour in synthesising evidence on DGBL and SPS in higher education.

Data Sources and Search Strategy

A systematic search was conducted in Scopus and ScienceDirect, selected for their indexing coverage of educational technology and science education. Boolean strings combined three conceptual clusters, namely the DGBL intervention, science process skill outcomes, and the higher education context, and were applied to title, abstract, and keyword fields: ("digital game" OR "educational game" OR "serious game" OR "game-based learning") AND ("science process skill" OR "scientific process" OR "scientific inquiry" OR "experimental skill") AND ("higher education" OR "university" OR "college" OR "undergraduate"). The search was completed in January 2026, with database filters restricting publication year and document type.

Eligibility Criteria

A structured PICOS framework covering population, intervention, comparison, outcomes, and study design was established before screening in order to minimise selection bias. Eligible records were peer-reviewed empirical journal articles published in English between 2021 and 2025 that reported primary data on undergraduate or postgraduate students in STEM disciplines at higher education institutions. Studies had to employ interactive digital or serious games as the principal instructional medium and to report either a measurable impact on science process skills, such as observation, hypothesis formulation, or experimentation, or an evaluation of the alignment between learning mechanics and game mechanics. Reviews, book chapters, conference proceedings, theses, and editorials were excluded, as were publications issued before 2021, works without an official English translation, studies of pre-school, primary, or secondary school populations, interventions confined to non-digital board games or to gamification elements such as points, badges, and leaderboards without a full simulation environment, and studies measuring only general conceptual achievement or motivation without addressing science process skills.

Study Selection Process

All retrieved metadata were exported to a reference manager for deduplication and then screened blind by title and abstract on a systematic review platform to reduce subjective bias. Selection followed the four PRISMA phases: identification (n = 673), title and abstract screening (n = 327), full-text eligibility assessment (n = 89), and final inclusion (n = 33). Reasons for exclusion at the full-text stage, such as wrong population, wrong outcome, or insufficient empirical data, were documented systematically, and Figure 1 presents the complete flow.

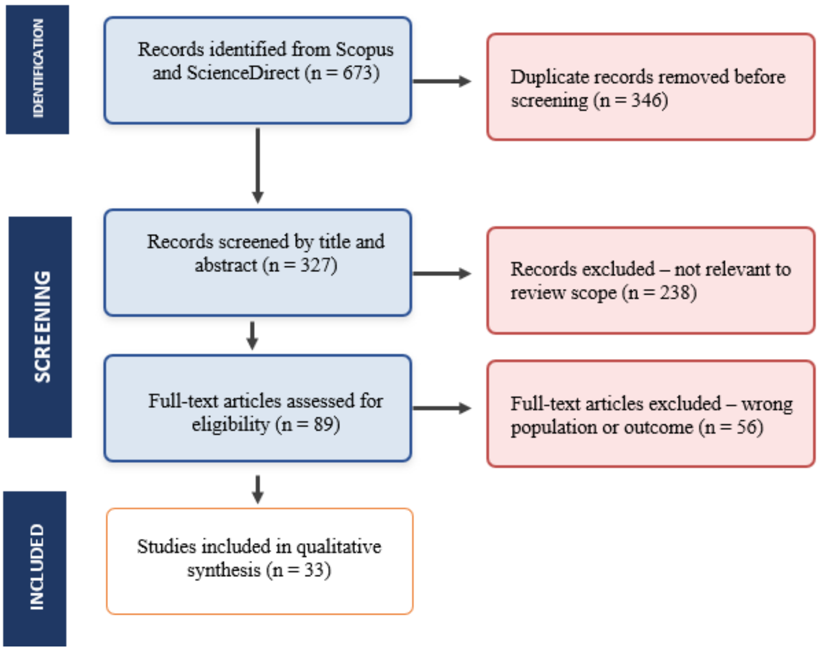

Figure 1. PRISMA 2020 flow of the article selection process. The systematic

screening sequence yielded a final corpus of 33 empirical studies for qualitative synthesis.

Quality Appraisal

Methodological quality was appraised with the Mixed Methods Appraisal Tool, version 2018 (Hong et al., 2018), selected for its capacity to evaluate quantitative, qualitative, and mixed-methods designs within a single framework, which matches the heterogeneity of this corpus. Appraisal covered research question clarity, appropriateness of data collection, and sample representativeness, and only studies rated medium to high in quality were retained.

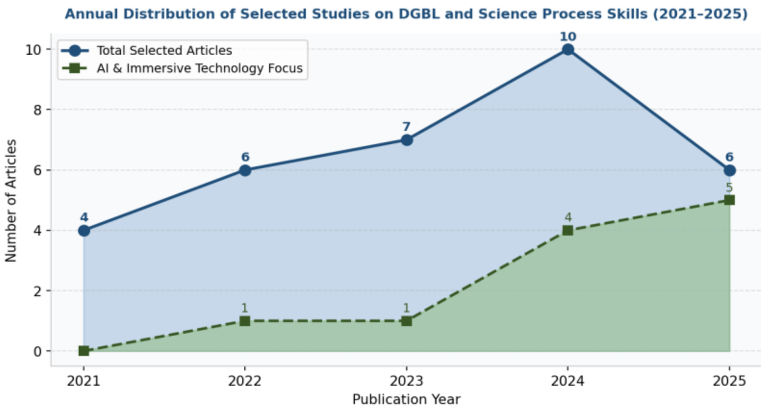

Figure 2. Annual Distribution of Selected Studies on DGBL and Science Process Skills (2021–2025). A progressive increase in AI and immersive technology-focused studies is evident from 2023 onward.

Data Extraction and Synthesis

Data from all 33 articles were extracted into a structured matrix capturing authorship and year, country, research design and sample size, game name and genre, embedded learning and game mechanics, the SPS sub-dimensions measured, and the principal effectiveness findings. Given the heterogeneity of designs and outcome measures, a narrative synthesis was adopted, supplemented by effect size data drawn from the included meta-analyses.

RESULTS AND DISCUSSION

Thematic Mapping of the Literature

Analysis of the 33 included studies identified five thematic clusters that structure the findings reported below: the effectiveness of DGBL on STEM achievement and cognitive outcomes; instructional design, encompassing adaptive scaffolding, feedback, and the alignment of learning mechanics with game mechanics; learner cognition and engagement, including prior knowledge, cognitive load, and metacognition; game-based assessment through stealth measurement and learning analytics; and innovation driven by artificial intelligence and immersive technologies.

Effectiveness of DGBL on Science Process Skills

The synthesised evidence from meta-analyses and longitudinal studies converges on a clear finding: DGBL consistently produces positive, measurable effects on undergraduate students' SPS in higher education. Multiple large-scale meta-analyses report effect sizes for cognitive outcomes, particularly problem-solving, in the range of Hedges' g ≈ 0.54 to 0.65 (Cai et al., 2025; Gui et al., 2023; Wang et al., 2022). Figure 3 presents a synthesis of effect sizes across SPS dimensions derived from the included meta-analyses.

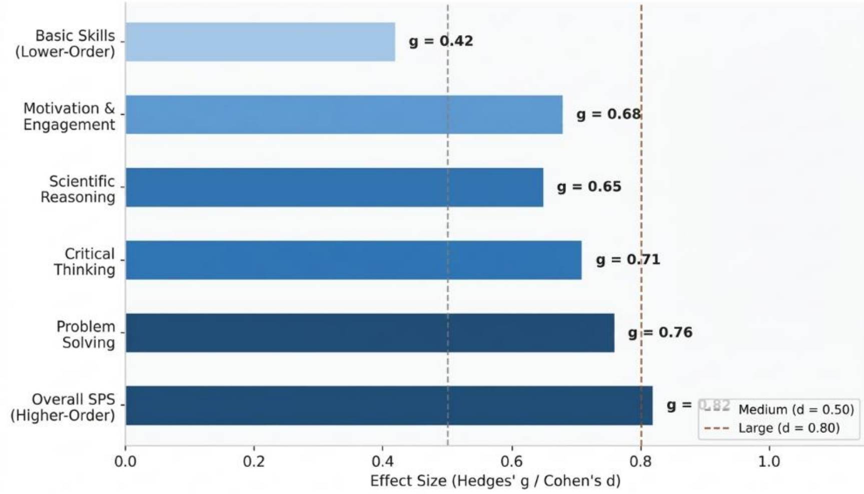

Figure 3. Synthesised Effect Sizes of DGBL on Science Process Skill Dimensions. (Barz et al., 2024; Cai et al., 2025; Gui et al., 2023; Wang et al., 2022)

From a longitudinal perspective, multi-semester studies show that retention and transfer of SPS improve markedly when DGBL is sustained and integrated with self-regulated learning strategies (Barz et al., 2024), and Hussein et al. (2025) confirm that continuous engagement produces more durable and transferable scientific skills than single-session interventions. Instructional sequencing is equally consequential: deploying DGBL after foundational conceptual instruction yields greater gains in collaborative problem-solving and conceptual understanding than pre-instruction gameplay (C.-H. Chen & Chen, 2025).

The comparative advantage of DGBL over conventional instruction is most pronounced for Higher-Order Thinking Skills (HOTS) including critical thinking, complex problem-solving, and scientific reasoning. By contrast, for Lower-Order Thinking Skills (LOTS) such as basic observation, classification, and measurement, the advantage of DGBL is more variable and less consistently reported (Barz et al., 2024; Gui et al., 2023). Figure 4 provides a direct visual comparison of DGBL and conventional instruction across both skill categories.

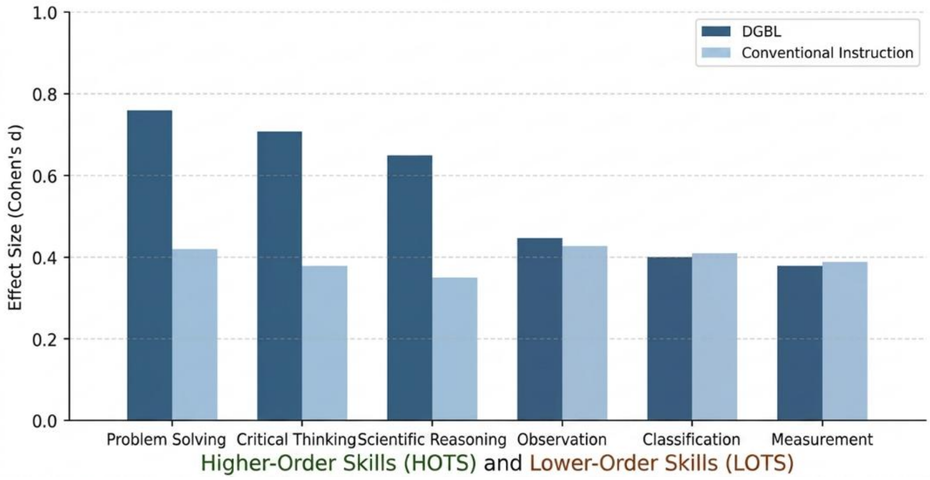

Figure 4. Comparative Effect Sizes of DGBL vs. Conventional Instruction on Higher-Order Skills (HOTS) and Lower-Order Skills (LOTS).

Differences in motivation and active engagement consistently favour DGBL, although achievement differences on lower-order dimensions occasionally fail to reach statistical significance (Li & Tsai, 2013). The comparative value of DGBL is therefore domain-specific, concentrated in higher-order scientific reasoning rather than in rote skill acquisition.

DGBL effectiveness is not uniform across disciplines. In engineering and computer science, purpose-designed games strengthen computational thinking, design skills, and innovation competencies, whereas in biology and chemistry the emphasis shifts towards experimental design, data analysis, and hypothesis testing (Gui et al., 2023). Across fields, discipline-specific adaptations rather than generic educational games yield consistently superior outcomes.

Instructional Design Elements: LM–GM Alignment, Scaffolding, and Feedback

A foundational finding of this review is that game mechanics without explicit pedagogical grounding are insufficient for the cognitive targets of science education (Caparoso & Orleans, 2024). Table 1 presents an evidence-based mapping of SPS sub-dimensions to the game mechanics and corresponding learning mechanics that proved most effective in the included interventions.

Table 1. Evidence-Based Mapping of Game Mechanics (GM) to Learning Mechanics (LM) per SPS Dimension

Science Process Skill Dimension	Game Mechanics (GM)	Learning Mechanics (LM)	Example Games	Key Reference(s)
Observation & Classification	Exploration & Discovery	Pattern Recognition, Data Collection	Minecraft Edu, SimCity	Gui et al. (2023)
Hypothesis Formulation	Puzzle Sequencing, Decision Tree	Hypothesis Testing, Prediction	DragonBox, Labster	Caparoso & Orleans (2024)

Experimentation & Variable Control	Sandbox Simulation, Resource Management	Variable Isolation, Experimental Design	PhET Simulations, Labster	Caparoso & Orleans (2024); Gui et al. (2023)
Data Interpretation	Analytics Dashboard, Feedback Loops	Data Analysis, Inference Making	Zoombinis, Science Birds	Dever et al. (2024); Erhel & Jamet (2013)
Scientific Communication	Collaborative Quest, Role-Play	Peer Discussion, Argumentation, Report Writing	STEM Quest, Digital Escape Room	Udeozor et al. (2024); Ramirez-Montoya et al. (2025)

Adaptive scaffolding emerges as the single most influential mediating element in DGBL design. The three-level meta-analysis of Cai et al. (2022) demonstrates that appropriately implemented scaffolding significantly amplifies achievement across diverse game contexts. Two modalities prove effective: hard scaffolding, comprising structured prompts and hints available at designated stages, and soft scaffolding, comprising adaptive assistance triggered by specific student behaviours during gameplay. Both achieve optimal outcomes when faded systematically over time to promote scientific autonomy (C.-H. Chen et al., 2023).

The design of in-game assessment mechanics equally requires careful deliberation. Over-integration of assessment elements, or poorly designed evaluation mechanics, demonstrably reduces learning gains by redirecting students' cognitive resources from authentic scientific exploration toward score optimisation (Dever et al., 2024). Striking a principled balance between challenge and evaluation in game design is, therefore, a critical consideration that practitioners frequently overlook in DGBL implementation.

Constructive immediate feedback helps students recalibrate their data interpretation and adjust cognitive strategies in real time (Erhel & Jamet, 2013; Ramirez-Montoya et al., 2025), while environments that embed metacognitive prompts such as reflective questioning and review of prior decision steps foster deeper self-regulation of learning (Lin et al., 2025). Figure 5 maps the pedagogical impact scores and literature frequency of eight key design elements across the 33 included studies.

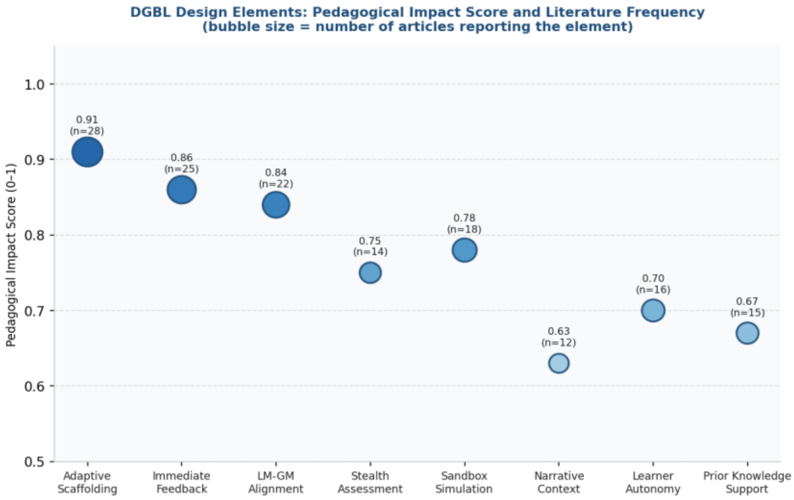

Figure 5. DGBL Design Elements: Pedagogical Impact Score vs. Literature Frequency (n = 33 articles). Adaptive scaffolding and LM-GM alignment dominate as simultaneously the most impactful and most consistently reported design variables.

Contextual Factors Moderating DGBL Effectiveness

Students' prior knowledge is the primary moderator of DGBL effectiveness. Learners with a higher baseline gain more in motivation and achievement, yet environments equipped with adaptive scaffolding meaningfully support low prior knowledge learners as well (Lin et al., 2025). S. Y. Chen and Hsiao (2024) show that providing an electronic book as a pre-game preparatory resource equalises comprehension across heterogeneous cohorts. Initial motivation, learning style, and prior gaming experience moderate outcomes further, underscoring the need for flexible, personalised design.

Course level and disciplinary context also moderate outcomes. Entry-level undergraduates typically derive the greatest benefit, although games with adaptive complexity successfully support advanced learners, and the disciplinary field determines which mechanics are contextually relevant. Vocational and professional programmes benefit substantially where game content authentically reflects workplace scenarios.

Assessment design itself acts as a further moderator, since an excess of evaluative elements redirects students' cognitive resources from scientific exploration toward score optimisation. Figure 6 profiles the principal moderating factors identified across the included studies.

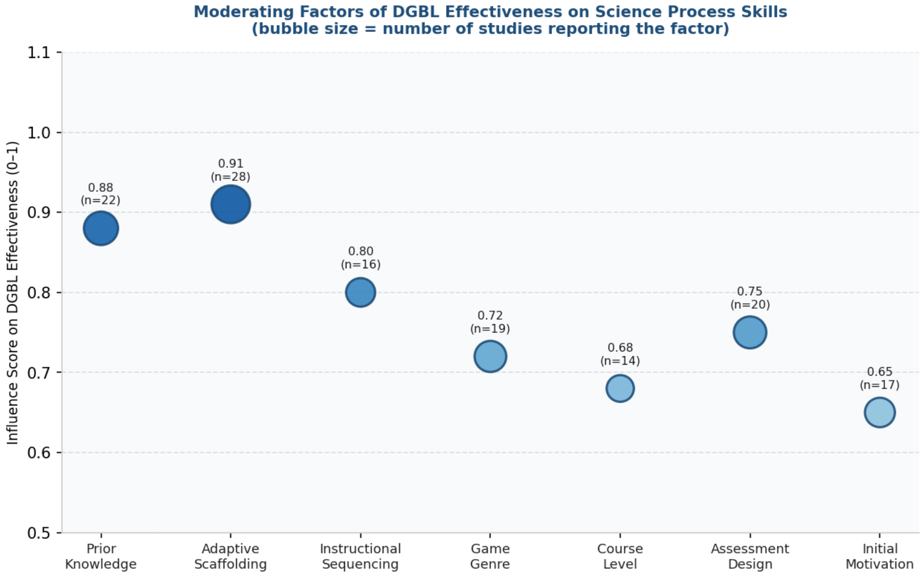

Figure 6. Moderating Factors of DGBL Effectiveness on Science Process Skills: Impact Score and Number of Reporting Studies. Adaptive scaffolding and prior knowledge emerge as the most influential contextual moderators.

Game-Based Assessment and Evaluation Innovation

A central challenge in higher education science assessment is achieving objectivity and richness of evaluative data. Stealth assessment embedded within game mechanics offers a more authentic solution: students are evaluated based on decision-making patterns, response latency, and problem-solving strategies captured in real time during gameplay, rather than solely on final test scores (Dever et al., 2024). This approach aligns with the principles of formative assessment, which emphasise continuous, actionable feedback as the engine of learning (Ramirez-Montoya et al., 2025).

AI-driven adaptive feedback opens further possibilities for personalisation, and Gong et al. (2026) map the potential of large language model integration to generate contextually responsive feedback. Challenges of algorithmic transparency and the risk of over-reliance on automated systems nonetheless warrant careful consideration before large-scale implementation.

Discussion

The synthesised findings confirm that the effectiveness of DGBL in higher education is not an artefact of technological novelty but a function of rigorous pedagogical design, appropriate implementation context, and precise alignment between game mechanics and higher-order scientific learning objectives. The discussion below addresses the theoretical basis of these findings, their implications for instructional design, equity considerations, and directions for future inquiry.

Theoretical Foundations: Why DGBL Effectively Develops SPS

The effectiveness of DGBL for science process skills can be explained through three complementary frameworks. Constructivist learning theory (Vygotsky, 1978) accounts for the authentic, contextualised space that games provide for scientific practice, where students do not merely read about hypothesis formulation but construct, test, and revise hypotheses within dynamic simulations (Caparoso & Orleans, 2024). Cognitive load theory (Sweller, 1988) explains why effective design minimises extraneous load through adaptive scaffolding and clear sequencing, channelling working memory toward intrinsic processing of the scientific content (Cai et al., 2022; C.-H. Chen et al., 2023). Self-regulated learning theory (Zimmerman, 2000) accounts for the metacognitive elements embedded in games, such as reflective prompts, adaptive feedback loops, and strategy revision opportunities, which build students' capacity to monitor and regulate their own learning (Lin et al., 2025).

Collectively, the studies reviewed here challenge the longstanding dichotomy between play and higher-order cognitive learning. Barz et al. (2024) demonstrate that DGBL triggers a shift from surface-level content acquisition toward metacognitive awareness, whereby students become conscious of their own thinking within the context of scientific inquiry, a level of cognitive transfer that passive instruction rarely achieves.

Practical Implications: Evidence-Based Instructional Design Guidelines

For curriculum developers, science faculty, and serious game designers, this synthesis converts into a small set of design commitments. Sequencing comes first: positioning DGBL after initial conceptual instruction maximises higher-order gains, whereas deploying games as opening activities without a conceptual foundation tends to amplify cognitive overload rather than support inquiry (C.-H. Chen & Chen, 2025; Erhel & Jamet, 2013). Alignment comes second: each science process sub-dimension requires purpose-designed mechanics, and the DiGIBST model provides a validated framework for ensuring that every in-game action corresponds explicitly to a scientific skill target, precluding superficial point-and-click interaction (Caparoso & Orleans, 2024).

Support structures follow. Scaffolding should be designed to withdraw progressively as competence increases, so that game-facilitated assistance gives way to genuine scientific autonomy (Cai et al., 2022; C.-H. Chen et al., 2023), while pre-learning modules such as electronic books or two-tier diagnostic instruments level the knowledge baseline before gameplay, a step that is particularly critical in heterogeneous cohorts (S. Y. Chen & Hsiao, 2024). Feedback loops should explain why a scientific strategy succeeds or fails in context rather than merely marking responses correct or incorrect (Ramirez-Montoya et al., 2025), and instructors themselves require pedagogical and technical preparation to lead post-game debriefing that connects gameplay experience with formal scientific concepts and vocabulary.

Equity and Accessibility Considerations

One frequently overlooked dimension of the DGBL discourse concerns equity and accessibility. The present review reveals that the majority of included studies originate from countries with advanced technological infrastructure, substantially limiting the generalisability of findings to developing-country higher education contexts (Hussein et al., 2025). If not purposefully designed with access in mind, DGBL risks exacerbating existing digital divides by assuming reliable internet connectivity, high-specification hardware, and adequate digital literacy. Context-responsive DGBL design, incorporating offline compatibility, low-bandwidth optimisation, and intuitively navigable interfaces, constitutes an essential prerequisite for realising the inclusive potential of game-based learning across diverse institutional settings.

Future Research Directions

Five priorities emerge for the next phase of research. The DGBL ecosystem is approaching an artificial-intelligence-driven inflection point, in which embedding large language models within game environments allows non-playable characters to function as adaptive science tutors capable of dynamic Socratic dialogue that stimulates metacognitive development in real time (Gong et al., 2026). Immersive virtual and augmented reality environments similarly open the way to embodied laboratory simulation at molecular or cellular scale, although their cognitive and affective outcomes still require validation through controlled experimental designs (Mitsea et al., 2025). Beyond these technological frontiers, the field requires greater methodological standardisation in controlling exposure duration and instructor bias, systematic validation of DGBL under the limited technological infrastructure typical of developing-country institutions (Hussein et al., 2025), and multi-semester tracking of skill retention and of the long-term consequences of scaffolding fading (Barz et al., 2024).

Limitations and Methodological Cautions

Several limitations qualify these conclusions. The corpus is likely subject to publication bias, since null and negative findings remain systematically underrepresented in indexed journals, and the exclusive reliance on Scopus and ScienceDirect may have excluded relevant work indexed elsewhere. The evidence base is also dominated by research conducted in well-resourced settings, which constrains generalisability to lower-resource higher education systems. Wide variability in game genre, intervention duration, and outcome instrumentation complicates direct cross-study comparison, longitudinal evidence beyond a single semester remains scarce, and instructor effects are rarely controlled, representing a persistent confound in the reported effectiveness estimates.

CONCLUSION

This systematic review of 33 peer-reviewed empirical studies, conducted in accordance with the PRISMA 2020 guidelines, establishes that Digital Game-Based Learning is an evidence-based and pedagogically effective instrument for developing higher-order science process skills, particularly complex problem-solving, critical thinking, and scientific reasoning, among undergraduate students. Effect sizes for these dimensions are large and consistent (Hedges' $g \approx 0.65–0.82$), whereas effects on lower-order skills such as observation, classification, and measurement are more modest and context-dependent.

The effectiveness of DGBL rests on four interlocking pillars: precise alignment between learning mechanics and game mechanics, adaptively implemented and systematically faded scaffolding, constructive real-time formative feedback, and deliberate management of students' prior knowledge through supplementary instructional support. DGBL also catalyses an evaluative shift away from product-based summative testing toward stealth assessment grounded in process data, which yields more authentic evidence of skill development (Dever et al., 2024; Udeozor et al., 2024). The integration of generative AI, large language models, and immersive technologies represents the next frontier of personalisation and adaptivity, subject to rigorous empirical validation before large-scale adoption.

Accordingly, curriculum developers and science faculty should ensure that every game mechanic corresponds explicitly to a target science process skill rather than deploying games as digital entertainment, provide pre-learning equalisation modules such as electronic books or two-tier diagnostic instruments to standardise prior knowledge in heterogeneous cohorts, and design scaffolding with a pre-planned fading schedule so that in-game assistance recedes as competence grows. Institutions are further encouraged to adopt stealth assessment as a primary evaluation component, to explore large language models as adaptive non-playable tutors capable of Socratic dialogue, to validate DGBL under limited-infrastructure conditions through offline and low-bandwidth design, and to commission multi-semester longitudinal studies with explicit controls for instructor effects, exposure duration, and implementation fidelity.

REFERENCES

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

Cai, Z., Mao, P., Wang, D., He, J., Chen, X., & Fan, X. (2022). Effects of scaffolding in digital game-based learning on student's achievement: A three-level meta-analysis. Educational Psychology Review, 34(2), 537–574. https://doi.org/10.1007/s10648-021-09655-0

Cai, Z., Zhang, X., Liu, C., & Zhan, J. (2025). Effects of digital game-based learning on student's problem-solving ability: A three-level meta-analysis. Journal of Computer Assisted Learning, 41(2). https://doi.org/10.1111/jcal.70002

Caparoso, J. K. V., & Orleans, A. V. (2024). DiGIBST: An inquiry-based digital game-based learning pedagogical model for science teaching. STEM Education, 4(3), 282–298. https://doi.org/10.3934/steme.2024017

Chen, C.-H., & Chen, C.-H. (2025). The timing of digital games in STEM instruction: Effects on learning outcomes, collaborative problem-solving, intrinsic motivation, cognitive load, and learning behavior. Research in Science and Technological Education. Advance online publication. https://doi.org/10.1080/02635143.2025.2561992

Chen, C.-H., Law, V., & Huang, K. (2023). Adaptive scaffolding and engagement in digital game-based learning. Educational Technology Research and

Development, 71(4), 1785–1798. https://doi.org/10.1007/s11423-023-10244-x

Chen, S. Y., & Hsiao, T.-C. (2024). The effects of incorporating an electronic book into digital game-based learning: A prior knowledge perspective. International Journal of Human-Computer Interaction, 40(19), 6015–6026. https://doi.org/10.1080/10447318.2023.2247595

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. Review of Educational Research, 86(1), 79–122. https://doi.org/10.3102/0034654315582065

Dever, D. A., Wiedbusch, M., Marano, C., Brosnihan, A., Smith, K., Patel, M., & Azevedo, R. (2024). From product to process data: Game mechanics for science learning. International Journal of Serious Games, 11(4), 127–153. https://doi.org/10.17083/ijsg.v11i4.790

Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. Computers & Education, 67, 156–167. https://doi.org/10.1016/j.compedu.2013.02.019

Gong, Y.-l., Wang, M.-k., Tu, Y.-F., Huang, C.-q., & Zhang, D. (2026). Beyond pre-scripted interactions: Mapping the integration of LLMs in digital game-based learning: A scoping review. Entertainment Computing, 56, 101082. https://doi.org/10.1016/j.entcom.2026.101082

Gui, Y., Cai, Z., Yang, Y., Kong, L., Fan, X., & Tai, R. H. (2023). Effectiveness of digital educational game and game design in STEM learning: A meta-analytic review. International Journal of STEM Education, 10(1). https://doi.org/10.1186/s40594-023-00424-9

Hong, Q. N., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., & Vedel, I. (2018). Mixed Methods Appraisal Tool (MMAT), version 2018. McGill University.

Hussein, M. H., Sulaiman, N. L., Noroozi, O., Elaish, M. M., & Alhasan, A. (2025). Value-added digital game-based learning in K-12 science education: A systematic literature review. Interactive Learning Environments, 33(5), 3282–3316. https://doi.org/10.1080/10494820.2025.2450652

Li, M.-C., & Tsai, C.-C. (2013). Game-based learning in science education: A review of relevant research. Journal of Science Education and Technology, 22(6), 877–898. https://doi.org/10.1007/s10956-013-9436-x

Lin, Y.-L., Wang, W.-T., & Lai, Z.-L. (2025). Exploring students' prior knowledge of and metacognitive skills for game-based learning in relation to cognitive strategy and learning effectiveness. Education and Information Technologies, 30(12), 17323–17360. https://doi.org/10.1007/s10639-025-13470-3

Mitsea, E., Drigas, A., & Skianis, C. (2025). A systematic review of serious games in the era of artificial intelligence, immersive technologies, the Metaverse, and neurotechnologies: Transformation through meta-skills training. Electronics, 14(4), 649. https://doi.org/10.3390/electronics14040649

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

Ramirez-Montoya, M. S., Patiño, A., & Hernandez, L. E. (2025). Formative assessment in DGBL: A qualitative analysis of players' perceptions of game-based feedback in complex scenarios. Lecture Notes in Educational Technology, Part F642, 53–63. https://doi.org/10.1007/978-981-96-5658-5_6

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Turiman, P., Omar, J., Daud, A. M., & Osman, K. (2012). Fostering the 21st century skills through scientific literacy and science process skills. Procedia - Social and Behavioral Sciences, 59, 110–116. https://doi.org/10.1016/j.sbspro.2012.09.253

Udeozor, C., Abegão, F. R., & Glassey, J. (2024). Measuring learning in digital games: Applying a game-based assessment framework. British Journal of Educational Technology, 55(3), 957–991. https://doi.org/10.1111/bjet.13407

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Wang, L.-H., Chen, B., Hwang, G.-J., Guan, J.-Q., & Wang, Y.-Q. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. International Journal of STEM Education, 9(1). https://doi.org/10.1186/s40594-022-00344-0

Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), Handbook of self-regulation (pp. 13–39). Academic Press. https://doi.org/10.1016/B978-012109890-2/50031-7