International Research Journal of Multidisciplinary Scope (IRJMS), 2026;7(3):1028-1046

Review Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2026.v07i03.010715

Game-based Learning in the Era of Generative Artificial Intelligence: A Systematic Review of Analytical Skill Development and Educational Innovation

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Abstract

This systematic literature review examines how generative artificial intelligence (GenAI)-enhanced game-based learning (GBL) influences analytical skill development and educational innovation. The review synthesizes 32 peer-reviewed studies published between 2024 and 2026 to identify emerging patterns in the use of GenAI within digital learning environments. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, the studies were analyzed across four thematic dimensions: design configurations of GenAI integration, empirical evidence of analytical and higher-order cognitive outcomes, mechanisms and moderators explaining observed effects and adoption, ethics and sustainability conditions. Among the included studies, 12 reported design-traceable AIGC–GBL configurations, of which 4 (33.3%) involved immersive or contextually immersive implementations. The findings show that GenAI most often functions as adaptive cognitive scaffolding embedded within iterative game mechanics rather than as a standalone content generator. Within the reviewed evidence, meta-analytic studies reported a moderately large positive effect on computational thinking ($g = 0.75$) and a large positive association with cognition-related outcomes ($r = 0.53$), while individual empirical studies generally indicated improvements in analytical or higher-order cognitive performance. The synthesis further identifies iterative feedback, calibrated cognitive load, dialogic scaffolding and sustained engagement as key mechanisms supporting analytical transfer. However, long-term sustainability is influenced by governance conditions, including academic integrity safeguards, algorithmic transparency, equity of access and institutional policy alignment. Overall, the review suggests that GenAI-enhanced GBL can foster transferable analytical competence when AI is used as a reflective scaffold within coherent pedagogical designs supported by metacognitive prompting and clear governance frameworks

Keywords: Adaptive Scaffolding, Analytical Skills, Educational Innovation, Game-Based Learning, Generative Artificial Intelligence.

Introduction

The mainstream diffusion of generative artificial intelligence (GenAI) and AI-generated content (AIGC) since 2023 has reconfigured digital pedagogy by enabling rapid content production, scalable personalization and on-demand feedback within formal learning. In parallel, Game-Based Learning (GBL) has increasingly developed into interactive and immersive instructional ecosystems that can operationalize iterative decision-making, evidence appraisal, reflective problem solving and learner–environment interaction through gameplay cycles (1, 2). Their convergence signals a pedagogical shift with direct implications for how analytical competence is cultivated and how it may be compromised, under AI-mediated learning conditions. AIGC can function as adaptive scaffolding that tailors prompts, feedback and task variants to learners' progress and task complexity. Evidence from AI-supported flipped classroom and engineering education suggests that AI-supported guidance can improve learning experience, AI literacy, competence development and higher-order learning processes when aligned with learner trajectories and cognitive demand (3–5). Conversational agents can also operate as dialogic feedback partners, accelerating iteration during complex tasks (6, 7). At the design level, AIGC can support the development of varied instructional materials, task prompts and scenario-based learning resources that may increase flexibility in adaptive environments (3, 6). However, increased engagement and efficiency do not necessarily translate into deeper analytical reasoning. AIGC

(Received 19th February 2026; Accepted 09th June 2026; Published 21st July 2026)

also introduces epistemic and ethical tensions that complicate claims of cognitive benefit. Scholarship increasingly emphasizes that generative tools should scaffold reasoning rather than substitute it (7, 8). Cognitive offloading, defined here as delegating evaluative and justificatory work to AI, may weaken metacognitive regulation and independent judgment (8, 9). Reduced cognitive friction can broaden access, yet it may also reduce persistence under complexity and encourage superficial integration of ideas (10, 11). These concerns are particularly salient in assessment contexts, where AI outputs blur authorship boundaries and intensify academic integrity challenges (12, 13).

Game-Based Learning (GBL) offers a particularly suitable pedagogical architecture for integrating Artificial Intelligence-Generated Content (AIGC) because its instructional logic is organized around iterative cycles of challenge, decision-making, feedback, consequence evaluation and strategic revision. Unlike many traditional digital learning systems that primarily deliver linear content, static exercises, or isolated adaptive recommendations, GBL environments create rule-governed experiential spaces in which learners must interpret information, test hypotheses, weigh alternatives and revise actions in response to evolving task conditions (1, 2). These features align closely with the generative and adaptive affordances of AIGC. AI-generated scenarios can diversify problem contexts, adaptive hints can respond to learner decisions in real time, dialogic agents can prompt justification and counterargument and difficulty calibration can preserve productive struggle across gameplay cycles. Accordingly, AIGC is pedagogically more consequential in GBL when it becomes embedded within the game's reasoning loop rather than functioning merely as an external content-production tool. This structural fit explains why AIGC-enhanced GBL may be especially relevant for analytical skill development: the technology can support repeated interpretation, evaluation, reflection and decision revision within authentic or simulated problem contexts. Recent GenAI-supported GBL designs further indicate that AI is more instructionally meaningful when game mechanics are explicitly mapped to learning objectives and supported by structured feedback, reflection, interaction and scaffolding (2, 6, 14, 15). Immersive and scenario-based implement-tations extend this architecture by enabling experimentation with consequences in controlled yet contextually rich settings, strengthening conditions for transfer (16–19).

Analytical skills, including analysis, evaluation, reasoning and complex thinking, remain central to academic achievement and professional readiness (20), particularly in information-dense environments shaped by algorithmic mediation (21). However, earlier research on analytical skill development remains methodologically uneven and conceptually fragmented. Studies operationalize analytical competence through partially overlapping but non-equivalent constructs, including critical thinking, computational thinking, problem-solving and complex thinking, while employing heterogeneous indicators such as standardized tests, rubric-based artifact evaluation, self-report dispositions and performance proxies (22–24). This variability limits cross-study comparability and complicates efforts to determine whether reported gains reflect durable analytical development or short-term task-specific performance. These concerns become more pronounced in AI-supported environments, where scaffolds may simultaneously enhance task completion and obscure the extent of independent reasoning, thereby raising validity concerns when interpreting reported analytical gains (25).

Despite accelerating interest, research on AIGC-enhanced GBL remains fragmented across intelligent tutoring, learning analytics, serious games and digital pedagogy and it often conflates short-term performance acceleration with durable analytical competence while under-examining dependency risks and governance conditions (11, 25). Earlier reviews were largely conducted prior to the rapid mainstream adoption of generative AI, limiting their relevance to the current landscape. Accordingly, this systematic literature review synthesizes peer-reviewed studies published between 2024 and 2026 through review procedures aligned with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to

(a) map AIGC integration configurations in GBL,
(b) evaluate empirical evidence on analytical and higher-order outcomes,
(c) identify mechanisms and moderators shaping observed effects and

(d) examine adoption, ethics and sustainability requirements for responsible educational innovation.

Methodology

This study employed a PRISMA-aligned systematic literature review (SLR) design to synthesize evidence on AIGC-enhanced Game-Based Learning (GBL), analytical skill development and educational innovation. The procedures followed the PRISMA 2020 statement to support methodological transparency and comparability (26). An a priori review plan guided the search strategy, eligibility criteria, data extraction, quality appraisal and synthesis procedures; however, the review was not preregistered in PROSPERO, the Open Science Framework, or another public registry.

Study identification was conducted using Scopus as the sole bibliographic database because it provides multidisciplinary coverage of peer-reviewed literature in education, social sciences, science and technology. This scope was appropriate because AIGC-enhanced GBL research is distributed across educational technology, artificial intelligence, digital pedagogy and discipline-specific learning contexts. Using one database also enabled consistent application of the predefined Boolean string, filters, language restrictions and screening logic. Nevertheless, reliance on Scopus may have excluded studies indexed only in other databases, as acknowledged in the Conclusion. The Boolean search strategy used in Scopus is presented below.

Scopus Boolean Search Strategy

("game-based learning" OR "digital game-based learning" OR "serious games")
AND
("artificial intelligence-generated content" OR "AIGC" OR "generative artificial intelligence" OR "AI-generated content")
AND
("educational innovation" OR "innovative teaching methodology" OR "curriculum design")

Synonym expansion, logical grouping and terminological variation were applied to improve the sensitivity and transparency of the systematic search strategy in line with PRISMA-aligned review procedures (26). The search was limited to English peer-reviewed journal articles published between 2024 and 2026. Although 2023 studies documented the earliest educational responses to public generative AI tools, this review focused on 2024–2026 because this period better captures explicit instructional designs, empirical learning outcomes and more stable terminology, implementation models and governance discussions. Thus, excluding pre-2024 studies represent a methodological delimitation rather than an assessment of scholarly relevance.

The search yielded 125 records. As shown in Figure 1, four pre-2024 records were excluded, no duplicates were identified and 121 reports proceeded to eligibility assessment after title and abstract screening. Applying document-type and language criteria produced 46 full-text articles, of which 14 were excluded for being out of scope or lacking analytically relevant outcomes; therefore, 32 studies were included in the final synthesis. A search log recording the database, search date, Boolean string, filters and record counts was maintained to support replicability (27, 28).

Eligibility criteria followed the review objectives. Studies were included if they examined Game-Based Learning or structured game-like educational environments, explicitly integrated generative AI or AI-generated content into instructional design and reported empirical outcomes related to analytical skills, including analysis, evaluation, reasoning, critical thinking, or computational thinking. Studies were excluded if they addressed AI or gaming outside education, were purely conceptual or opinion-based, used AI only for administrative purposes, or lacked accessible full text and adequate methodological reporting.

Data extraction used a standardized framework covering bibliographic information, educational level and discipline, learning modality, GBL format, AIGC function, integration workflow, analytical skill constructs and instruments, reported outcomes, moderators and ethical or governance considerations. Structured extraction templates were used to support consistency and reduce interpretive bias in SLR coding (14, 29).

To strengthen extraction and thematic coding credibility, the authors conducted reviewer calibration before full verification of the coding framework. They jointly reviewed extraction fields, thematic categories and decision rules to establish shared interpretations. The first author completed the initial extraction and categorization, while the co-authors reviewed the classifications across GBL format, AIGC function, integration workflow, analytical outcomes, mechanisms, moderators and governance considerations. Differences were resolved through consensus to enhance consistency and trustworthiness.

Given the methodological diversity of the included studies, quality appraisal used design-sensitive instruments rather than a single checklist. Experimental studies were considered using Cochrane principles (29), broader empirical designs using JBI tools (30), mixed-methods studies using MMAT (31), qualitative components using CASP-style criteria (32), observational studies using Newcastle–Ottawa-aligned criteria (33) and quantitative rigor using benchmarks on sampling adequacy and instrument reliability (34). Because intervention designs, participants, contexts and instruments varied substantially, synthesis followed a structured narrative thematic approach rather than meta-analysis. Findings were organized around AIGC integration patterns, analytical skill outcomes, explanatory mechanisms and moderators and governance and sustainability considerations, with effect direction and magnitude descriptors reported where appropriate (13, 27, 28).

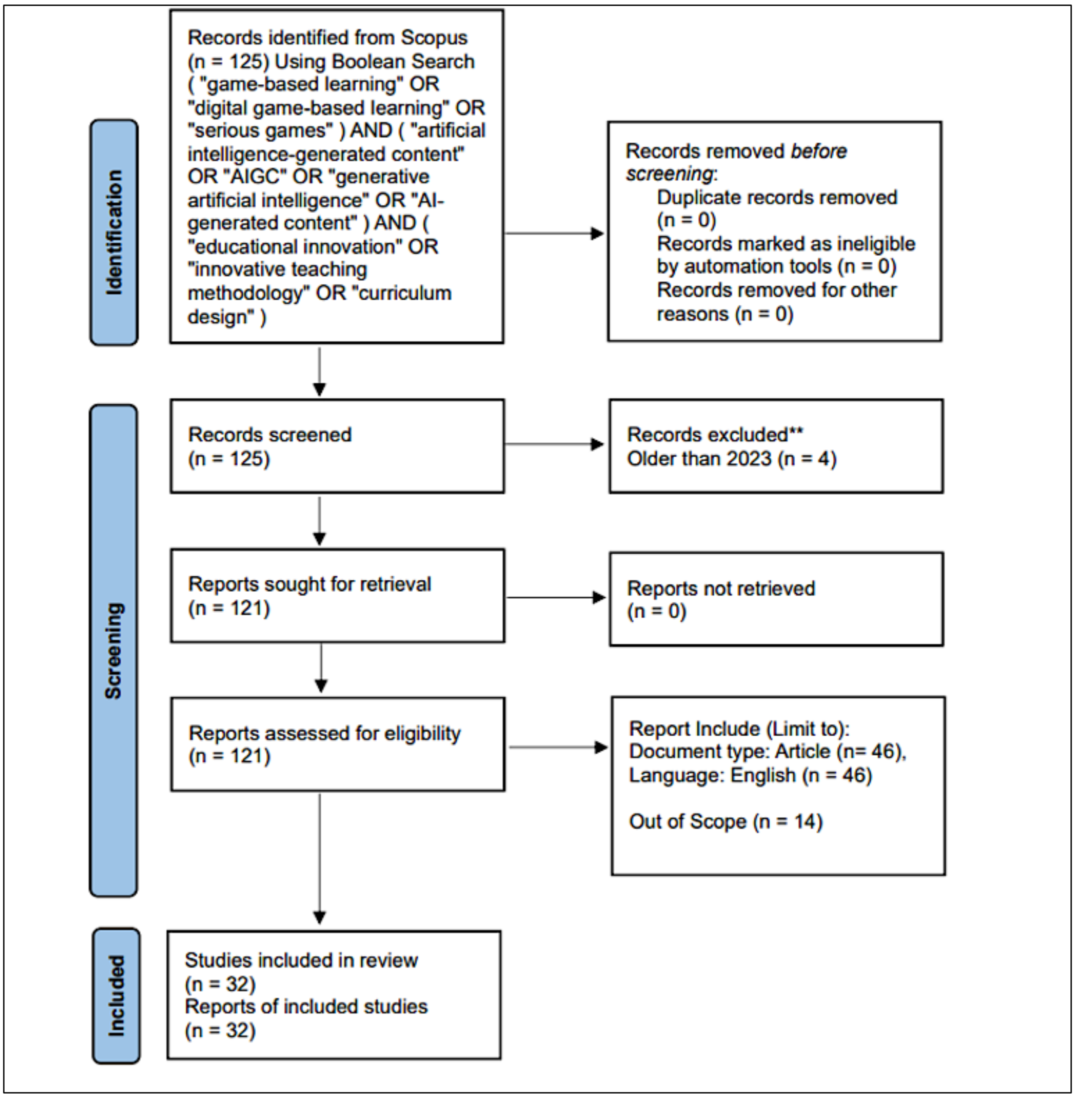

Figure 1: PRISMA Flow Diagram Detailing the Identification, Screening, Eligibility Assessment, and Inclusion Process of the Literature

Results

The first pattern identified in the synthesis concerns the design configurations of AIGC-enhanced game-based learning. Table 1 summarizes 12 empirical and synthesis studies that reported design-traceable AIGC integration in structured or semi-structured GBL environments. Studies were included in Table 1 only when they specified the GBL format/mechanics, the functional role of AIGC (e.g., adaptive feedback, dialogic agent, scenario generation) and the integration workflow (pre-game, in-game, or post-task). Studies that addressed AIGC or GBL without sufficient design detail informed the broader thematic synthesis but were not eligible for inclusion in the configuration table. Across the 12 studies, AIGC is not implemented as a generic add-on; instead, design choices converge into recurring architectures that shape challenge exposure, support delivery and iterative reasoning processes, consistent with constructivist, experiential and scaffolding perspectives (6, 7, 35).

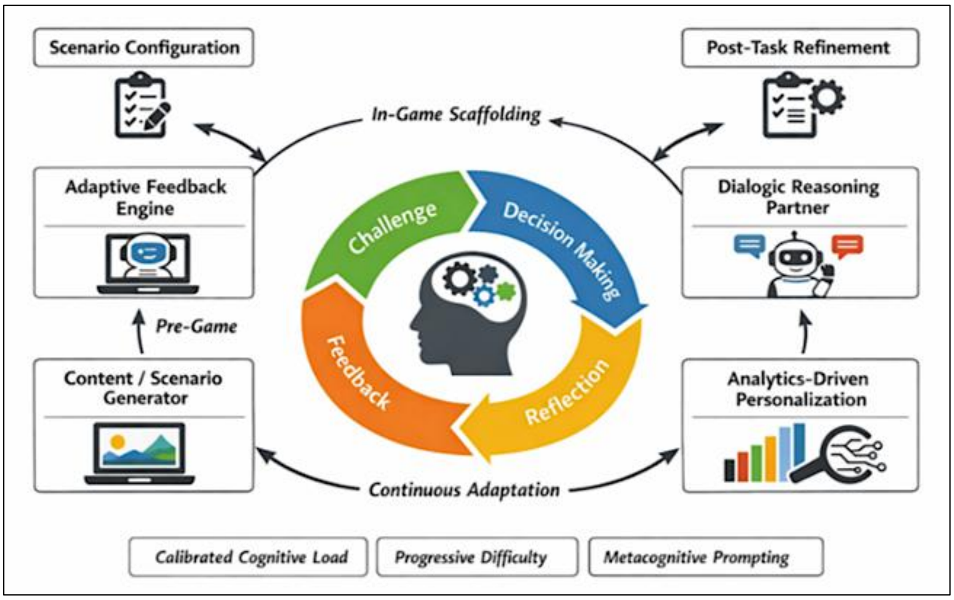

Figure 2: Configuration Architecture of AIGC-enhanced Game-based Learning: Functional Roles, Integration Workflows and Design Constraints

Figure 2 summarizes the dominant configuration logic identified in Table 1 by linking the experiential loop of challenge, decision-making, feedback and reflection with four recurring AIGC roles: content/scenario generation, adaptive feedback, dialogic reasoning support and analytics-driven personalization. It also shows that most implementations prioritize in-game scaffolding, while difficulty calibration, cognitive-load regulation and metacognitive prompting function as design controls to preserve productive struggle and reduce cognitive offloading risks.

Implementation is concentrated in higher education, likely reflecting comparatively stronger infrastructure, greater curricular flexibility and higher baseline AI literacy (3, 5, 36, 37). A smaller subset extends to secondary or cross-level contexts, indicating emerging diffusion beyond higher education but limited evidence on K–12 scalability and feasibility (38–40).

Across the reviewed studies, several game mechanics recur because they create repeated opportunities for analytical engagement. Escape-room designs rely on clue interpretation, puzzle resolution, sequential problem progression, time-bounded decision-making and narrative coherence, allowing learners to evaluate evidence and revise strategies under constraint (16–18). Project-cycle, AI-supported flipped-classroom and GenAI educational game designs employ iterative problem-solving, learner preparation, simulated interaction, feedback loops and post-task refinement, thereby linking instructional progression with planning, action, reflection and revision (3, 5, 15). Collaborative inquiry and AI-literacy role-play formats use role enactment, guided interaction, shared decision-making and reflective discussion to encourage learners to interrogate AI outputs and justify their reasoning (38, 41). Language learning and interpretive task designs emphasize conversational challenge, interpretation tasks and dialogic prompting, positioning AIGC as a reasoning partner that supports explanation, comparison and evaluative judgment (7, 36). Immersive Extended Reality (XR) and virtual-patient scenario designs further introduce contextual simulation, consequence-oriented choices and scenario adaptation, increasing the authenticity of analytical decision-making within the learning environment (16, 19). These mechanics suggest that the pedagogical value of AIGC-enhanced GBL is not tied to "gamification" in a general sense, but to specific mechanics that structure challenge, feedback, interpretation and iterative reasoning.

A closer inspection of the design corpus indicates that immersive or contextually immersive implementations constitute 4 of the 12 configuration studies summarized in Table 1 (33.3%). These include XR-based tasks, digital escape-room environments, AI-augmented escape -room analytics and virtual-patient scenario adaptation (16–19). Pedagogically, these implementations differ from non-immersive designs by embedding AIGC within scenario-rich, consequence-oriented environments that require learners to navigate contextual cues, make time-sensitive decisions and interpret feedback within a simulated experiential frame. By contrast, the remaining 8 studies (66.7%) rely primarily on non-immersive architectures such as intelligent tutoring, dialogic reading support, adaptive flipped classrooms, mobile gamified systems and AI-driven platform scaffolding, where AIGC functions mainly through feedback personalization, prompting, or learning analytics rather than environmental immersion.

Functionally, AIGC is most often positioned as cognitive infrastructure rather than as content production alone. Four roles recur across designs: scenario/content generation, adaptive feedback, dialogic tutoring or virtual agency and analytics-driven personalization. Many implementations foreground process-oriented feedback and scaffolding during gameplay, supporting coaching and metacognitive prompting rather than answer provision (3, 15, 40). Workflow patterns show that real-time in-game scaffolding commonly appears through hints, coaching prompts, dialogic guidance, simulated interaction, or virtual facilitation (3, 36, 37, 42). Hybrid architectures combine pre-game generation with in-game analytics (16–18), while longer trajectories support continuous personalization and difficulty calibration (19, 42). Reported design principles converge on preserving productive struggle through calibrated difficulty, narrative coherence and metacognitive prompting (3, 15–18, 40). Overall, AIGC is framed as a mediator of analytic engagement within structured game mechanics rather than as a substitute for gameplay.

Table 1: AIGC–GBL Design Configurations

Educational Level / Domain	GBL Format and Mechanics	AIGC Function	Integration Workflow	Key Design Principles/ Constraints	References
Higher Education/ ESP	XR immersive tasks	Adaptive content and bilingual scaffolding	In-game content adaptation	Immersion; inclusivity; affective support	(19)
K–12 and Higher Education / STEM	AI literacy games and role-play	AI as learning object and agent	In-game interaction and reflection	Age-appropriate and interdisciplinary design	(38)
Higher Education/ Language Learning	Intelligent tutoring tasks	NLP feedback and adaptive correction	In-game and post-task feedback	Communicative alignment; personalization; accuracy	(36)
Higher Education/ Online Master's	Digital escape rooms	AI-assisted puzzle design and hints	In-game hint generation	Challenge balance; narrative coherence; teacher orchestration	(17)
Adult Learning/ Ethics Training	Mobile role-playing game	ChatGPT-based non-player character scaffolding	In-game dialogic scaffolding	Situated learning; decision-making; reflective feedback	(6)
Medical Education	Digital escape room with	LLM-generated cases and tasks	In-game scenario adaptation	Bloom alignment; iterative refinement	(16)

Educational Level / Domain	GBL Format and Mechanics	AIGC Function	Integration Workflow	Key Design Principles/ Constraints	References
	virtual patients				
Higher Education/ Engineering	CDIO-based project game cycles	Project guidance and iterative feedback	In-game scaffolding and post-task refinement	Experiential alignment; cognitive-load monitoring	(3)
Higher Education/ Workplace Competency Training	Role-playing educational game with simulated workplace scenarios and NPC interaction	GenAI-based non-player character scaffolding and instant feedback	In-game simulated dialogue and post-task reflection	High-fidelity scenarios; metacognitive scaffolding; flow; germane cognitive load; short experimental duration	(15)
Higher Education/ Mobile Learning	Mobile gamified learning	Personalized content and gamification	Continuous personalization	Engagement analytics; security; real-time feedback	(41)
Secondary Education/Inquiry	Collaborative inquiry with virtual teachers	AI-powered virtual teacher	In-game facilitation and scripts	Structure–autonomy balance; motivation	(43)
Higher Education/ AI Platforms	AI-supported complex-thinking platform	AI scaffolds and usability adaptation	Pre-game design and in-game support	Usability; inclusivity; accessibility	(37)
Higher Education/ Accounting	Generative AI role-play games	Scenario and role-play support	In-game role-play interaction	Authentic decisions; learner agency; domain alignment	(44)

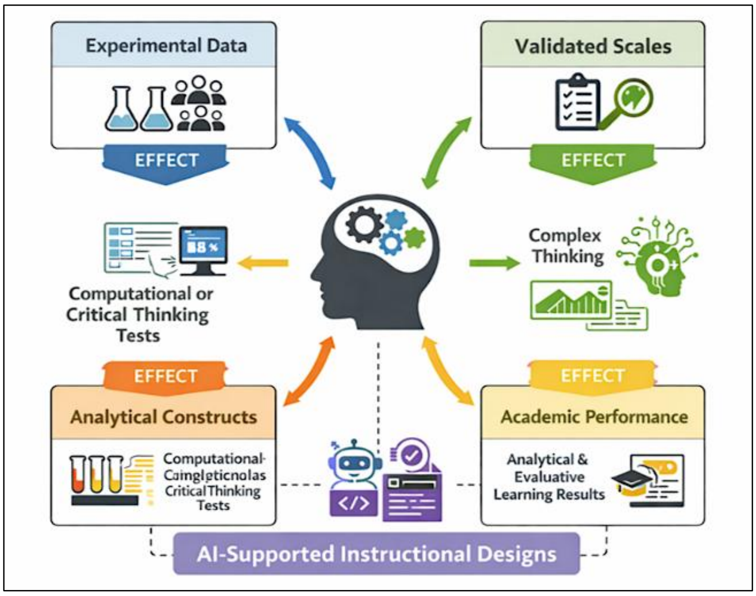

Figure 3: Empirical Evidence Pathways Linking AIGC-enhanced Game-based Learning to Analytical and Higher-order Cognitive Outcomes

A second major result concerns the impact of AIGC-enhanced GBL on analytical skills and higher-order cognition. Table 2 synthesizes 12 studies showing positive but methodologically heterogeneous effects across direct analytical constructs, validated complex-thinking measures and analytically aligned performance indicators.

Figure 3 summarizes the evidence pathways linking AIGC-enhanced GBL with analytical and higher-order cognitive outcomes. It positions computational, critical and complex thinking as focal outcomes and shows that positive effects are reported across experimental, quasi-experimental, validation and synthesis-based evidence, although durability and transfer remain dependent on duration, integration depth and reflective scaffolding.

Across the corpus, comparative designs are prominent, with multiple experimental and quasi-experimental studies evaluating AIGC-supported interventions against controls, complemented by systematic reviews and meta-analyses that provide higher-level synthesis across diverse contexts (3, 4, 8, 11, 42, 43, 45, 46). A three-level meta-analysis focusing on computational thinking further strengthens the evidentiary base by aggregating effects across studies and designs (47).

Computational thinking and structured analytic problem-solving show comparatively robust evidence. Moderately large pooled effects have been reported for AI-supported interventions on computational thinking, suggesting measurable gains when analytic decomposition and evaluation are embedded in structured tasks and assessed using standardized effect estimates (47). Convergent findings also appear in semester-based implementations in engineering and programming-related settings, including improvements in algorithmic reasoning and critical-thinking-aligned indicators, as well as mediated gains in broader analytical ability through changes in learning behaviors (3, 4). Together, these patterns are consistent with the interpretation that analytic gains are more likely when AI support is embedded within iterative project or game-like cycles and linked to sustained engagement rather than isolated assistance.

Critical thinking and evaluative reasoning outcomes are similarly positive but more sensitive to design conditions. Higher critical thinking scores have been reported in AI-supported reading and dialogic learning environments, alongside improved learning outcomes and creativity in AI-supported programming contexts (42, 45). Evidence from AI-supported flipped-classroom and inquiry-oriented environments also suggests positive effects on motivation, personalized learning experience, collaboration and reported critical thinking or problem-solving development, while large-scale implementations report grade improvements in structured, time-bounded problem-solving contexts such as educational escape rooms (5, 17, 40). These findings suggest that analytic gains are plausible across multiple domains, but they often depend on sustained exposure and coherent alignment between support, task demands and learning objectives.

Durability and transfer, however, are not uniform. Controlled evidence indicates that short-term task performance can improve under AI-supported conditions without producing statistically detectable knowledge transfer, reinforcing the distinction between supported performance and durable conceptual change (8). This divergence is consistent with theoretical concerns that efficiency gains can outpace deeper internalization when reflective checkpoints and scaffold fading are limited (9, 48).

Higher-level syntheses contextualize these results within broader AI-in-education trends. Large-scale meta-analytic evidence indicates strong positive associations between AI integration and cognition-related outcomes across studies, while domain-focused reviews suggest that many implementations remain at an augmentation level rather than representing full pedagogical redefinition, with uneven translation into durable learning change (11, 46). Measurement-oriented studies further support the evidence base by validating complex-thinking instruments within AI-supported platforms and documenting feasibility across diverse learning ecologies, including sustainability and equity considerations in hybrid digital settings (32, 37).

Overall, Table 2 indicates positive associations between AIGC-enhanced GBL and analytical performance across computational, critical and complex thinking outcomes. However, these gains remain sensitive to time-on-task, intervention duration and instructional design. Sustained or course-based implementations more consistently report combined cognitive, motivational and engagement-related improvements than single-session studies, suggesting that analytical consolidation requires iterative exposure, reflective scaffolding and integration depth rather than short-lived AI assistance (3–5, 8).

Table 2: Learning Outcomes and Analytical Skill Evidence

Study Design and Sample	Context (Level / Subject / Modality)	Analytical Skill Construct and Instrument	Effect Direction / Magnitude Descriptor	Duration	References
Three-level meta-analysis; 32 studies, 44 effect sizes	K–12 and Higher Education / Computational Thinking / AI tools	Computational thinking; Hedges' g	Significant moderately large effect; g = 0.75	Varied	(47)
Systematic review and meta-analysis; 228 studies, 464 effect sizes	Multi-level / Cross-disciplinary / AI applications	Cognition, knowledge utilization, metacognition	Large cognition effect; r = 0.53; moderate knowledge utilization	Varied	(46)
Quasi-experimental; n = 76, 3 groups	Higher Education / Engineering Data Mining / AIGC-CDIO	Computational thinking: algorithmic, critical thinking, problem-solving	Experimental group significantly outperformed controls	One semester	(3)
Quasi-experimental; n = 102	Undergraduate Engineering / AI-assisted instruction	Analytical ability and data processing ability	Significant indirect improvement through learning behaviors	One semester	(4)
Randomized experiment; n = 117	Higher Education / Writing task / ChatGPT support	Self-regulated learning processes and essay performance	Short-term performance gain; no significant knowledge transfer	Single task	(8)
Quasi-experimental; n = 64	Undergraduate / Foreign language reading / ChatGPT platform	Critical thinking and academic reading achievement	Experimental group showed higher critical-thinking scores	Intervention-based	(41)
Quantitative study; n = 3,175	Online Master's / Educational escape rooms	Academic performance as analytical engagement proxy	Significant grade improvement	Course-based	(17)
Experimental study; n = 62	Secondary Education / Collaborative inquiry with virtual teachers	Academic performance and inquiry reasoning	Photo-realistic virtual teacher improved performance	Activity-based	(43)
Systematic review; 139 articles	Higher Education / GAI classroom applications	Higher-order instructional strategies	Mostly augmentation-level integration; positive but limited redefinition	2014–2024 studies	(11)
Quasi-experimental; n = 46 + 46	Vocational Higher Education / Programming / GAI-supported learning	Learning outcomes, creativity and 5C competencies	Experimental group showed higher outcomes and creativity	Course-based	(45)
Explanatory sequential mixed-methods; one-group pretest-posttest design; n = 33, with interviews involving 17 students	Higher Education / Web Design and Coding / AI-supported flipped classroom	AI literacy, flipped learning perception, learning experience and reported critical thinking/problem-solving development	Significant improvement in AI literacy; positive perceptions; reported gains in motivation, personalized learning, collaboration, critical thinking and problem-solving	14 weeks	(5)

Study Design and Sample	Context (Level / Subject / Modality)	Analytical Skill Construct and Instrument	Effect Direction / Magnitude Descriptor	Duration	References
Pilot validation; n = 218 users	Higher Education / AI-driven educational platform	Complex Thinking scale and usability-linked cognitive support	Positive validation of AI-supported complex thinking development	Cross-sectional pilot	(37)

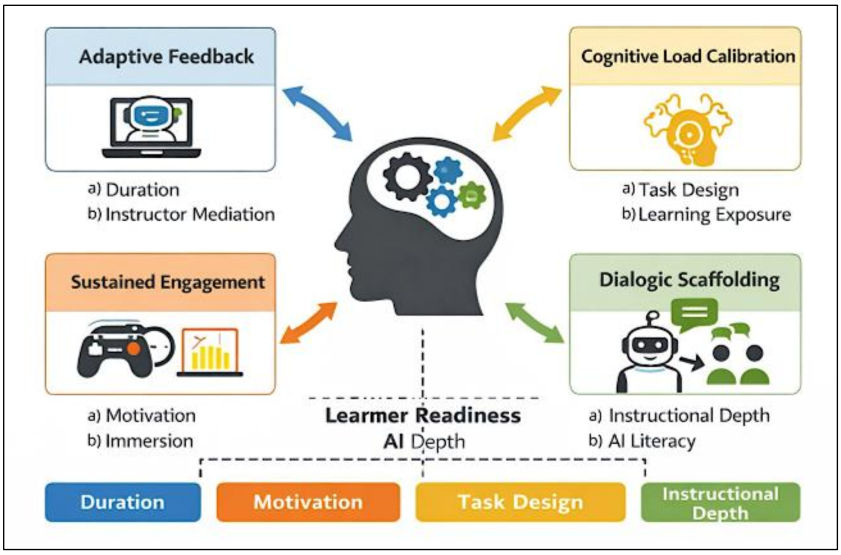

Figure 4: Mechanism–moderator Framework Explaining Analytical Skill Development in AIGC-enhanced Game-based Learning

A third result concerns the mechanisms and moderators explaining analytical skill development in AIGC-enhanced GBL. As summarized in Table 3, analytical gains are not produced by AI availability alone, but emerge through adaptive feedback cycles, cognitive-load calibration, sustained engagement and dialogic scaffolding, moderated by intervention duration, learner readiness, instructional alignment and integration depth.

Figure 4 integrates the mechanism–moderator patterns identified in Table 3. It shows that analytical competence emerges when adaptive feedback, calibrated cognitive demand, sustained engagement and dialogic scaffolding operate together within iterative game cycles, while duration, learner readiness, task design and instructional depth moderate the strength and durability of these effects.

Adaptive feedback embedded in iterative cycles is the most prominent mechanism. Real-time, process-oriented feedback is repeatedly associated with revision, strategy comparison and justification, particularly in engineering, GenAI educational game, AI-supported flipped-classroom and language learning contexts where learners are required to interact with prompts, feedback, or dialogic scaffolds (3, 5, 36, 41). Similar patterns appear in platform-level implementations where dynamically adjusted scaffolds are linked to complex thinking development (37). Across these contexts, feedback is most productive when it triggers reflective iteration rather than supplying final answers.

Cognitive-load calibration provides a second explanatory pathway. Structured AI guidance can reduce extraneous processing by organizing tasks and directing attention, thereby reallocating capacity toward higher-order reasoning (4). However, evidence also suggests that excessive friction reduction can yield short-term performance gains without durable transfer, implying that productive struggle can be unintentionally displaced when automation becomes too directive (8, 9, 48). Cognitive-load regulation therefore operates as a dual pathway, enabling analysis when calibrated and undermining internalization when over-optimized. A third mechanism concerns engagement as a mediator of repeated analytic practice. Immersive or time-bounded game formats and AI-personalized gamified systems are frequently associated with increased time-on-task and sustained motivation, which are necessary conditions for consolidating higher-order skills (17, 41). Motivation also interacts with performance under facilitated inquiry conditions, including settings using anthropomorphic virtual teachers (43). In AI-supported flipped-classroom contexts, students also report increased motivation, personalized learning experience, collaboration and more active learning engagement, although time management remains an implementation challenge (5).

Dialogic scaffolding constitutes a fourth mechanism and is most visible when learners are required to externalize reasoning, interrogate outputs and negotiate meaning. Designs that position AI as a reasoning partner in reading and inquiry, implement AI literacy gameplay that foregrounds critique of AI outputs, or use escape-room collaboration under constraints illustrate how analytic reasoning can be strengthened through discourse and counterargument exposure (16, 18, 38). These patterns support the view that analytical development is amplified when interaction structures force justification and evaluation rather than passive acceptance.

Moderator patterns clarify why effects vary. Duration is particularly consequential: multi-week, semester-long, or course-based implementations more consistently report broader cognitive or motivational gains than single-session tasks, which more often show limited transfer (4, 5, 8). Learner readiness and educational level also appear relevant, given the predominance of higher education contexts where baseline AI literacy and infrastructure may support deeper integration (40). Integration depth further differentiates outcomes. Reviews indicate that many classroom implementations remain at an augmentation level, whereas designs embedding AI within core reasoning tasks through immersive contextualization, structured modelling, or scenario variation tend to show stronger analytic engagement (11, 16, 18, 19).

Overall, Table 3 supports a systems interpretation: analytical transfer is conditional and design-dependent, emerging when adaptive feedback, calibrated cognitive demand, engagement persistence and dialogic scaffolding align within sustained instructional contexts (8, 11, 37).

Table 3: Mechanisms and Moderators in AIGC–GBL Analytical Outcomes

Mechanism Category	Specific Process	Empirical Evidence Context	Moderator Variables Identified	Outcome Pattern	References
Adaptive Feedback	Real-time feedback in CDIO cycles	Higher Education Engineering; quasi-experimental	Semester duration; instructor mediation	Improved computational thinking	(3)
AI-Supported Flipped Learning	Personalized preparation, instant AI feedback, interactive learning and collaborative in-class activities	Higher Education / Web Design and Coding; explanatory sequential mixed-methods	AI literacy; time management; learner readiness; student-centered interaction	Improved AI literacy and positive learning experiences; reported development of collaboration, critical thinking and problem-solving	(5)
Dialogic Scaffolding	ChatGPT as reasoning partner	Undergraduate Foreign Language; quasi-experimental	Supervision; task complexity	Higher critical-thinking scores	(36)
Cognitive Load Calibration	AI-supported learning behaviors	Undergraduate Engineering; quasi-experimental	Behavioral engagement; semester exposure	Indirect analytical ability gain	(4)
Short-Term Performance	AI writing support	Higher Education; randomized	Single task; self-regulation	Short-term gain; no transfer	(8)
Engagement Mediation	Escape-room immersion	Online Master’s; quantitative, n = 3,175	Time pressure; narrative coherence	Significant grade improvement	(17)
Collaborative Inquiry	Virtual teacher facilitation	Secondary Education; experimental	Anthropomorphism; motivation	Improved academic performance	(43)
Platform Scaffolding	AI complex-thinking scaffolds	Higher Education; pilot validation	Usability; accessibility	Validated complex-thinking support	(37)

Mechanism Category	Specific Process	Empirical Evidence Context	Moderator Variables Identified	Outcome Pattern	References
Immersive Contextualization	XR-based adaptive content	Higher Education ESP	Inclusivity; immersive realism	Enhanced contextual engagement	(19)
System-Level Integration	Augmentation–redefinition spectrum	Higher Education; systematic review	Pedagogical depth; policy environment	Positive but limited transformation	(11)
Content Expansion and Analytics	AI escape-room content modelling	Interdisciplinary education	Scalability; topic modelling	Cross-disciplinary engagement	(18)
Scenario Adaptation	LLM-generated case variation	Medical Education	Bloom alignment; iterative refinement	Enhanced applied reasoning	(16)

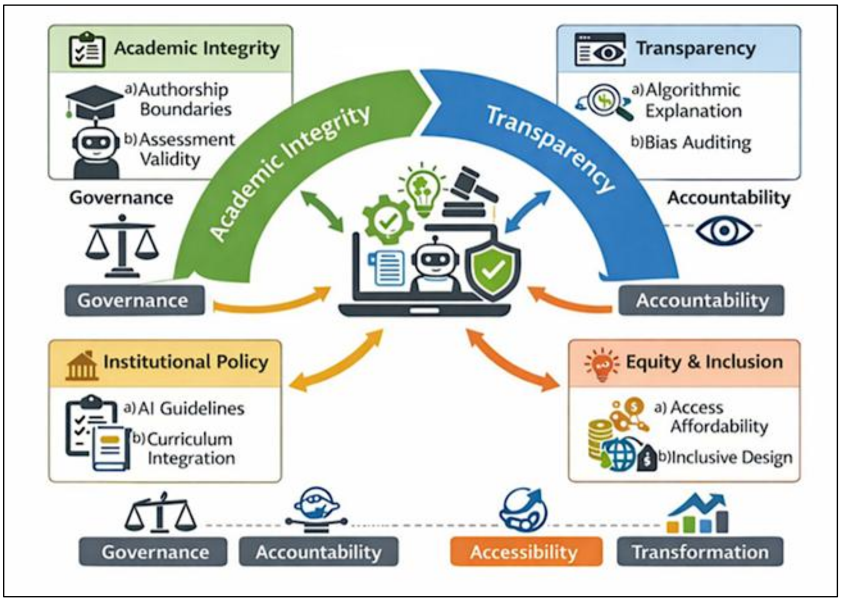

Figure 5: Governance and Sustainability Framework for AIGC-Enhanced Game-Based Learning (Integrity, Transparency, Equity and Institutional Alignment)

A fourth result concerns adoption, ethics and sustainability in AIGC-enhanced GBL. As summarized in Table 4, sustainable implement-tation depends on governance capacity, ethical safeguards, equity conditions and institutional readiness. Stronger and more durable analytical gains tend to appear when AI use is embedded within guided instructional routines and policy-aware assessment structures.

Figure 5 presents the governance and sustainability framework derived from Table 4. It organizes AIGC-enhanced GBL around four interdependent pillars: academic integrity, transparency and accountability, equity and inclusion and institutional policy alignment. These pillars indicate that sustainable implementation depends on coordinated governance rather than isolated technical safeguards.

A central adoption constraint concerns academic integrity and assessment governance. AI-generated outputs blur boundaries between legitimate scaffolding and authorship substitution, especially when AI shapes assessed work (49, 50). Accessibility-oriented support also raises validity concerns when real-time assistance becomes an unregulated performance advantage (51). In GBL settings, embedded scaffolds may shift from prompting reasoning to supplying solutions if assessment redesign and explicit AI-use policies are absent (9, 12).

Transparency and trust form a second boundary. AI feedback and recommendations may operate opaquely, raising concerns about credibility, bias and uncritical reliance (52, 53). These risks require instructor verification, disclosure protocols, explanation prompts, provenance awareness and structured critique so that learners treat AI outputs as contestable rather than authoritative (3).

Equity and inclusion represent a third sustainability condition. Infrastructure gaps, socioeconomic disparities and uneven digital literacy may stratify access to AI-enabled scaffolding (54, 55). Overreliance may also be greater among learners with weaker self-regulation, reinforcing dependency and performance disparities (44, 56). Thus, equitable impact requires access-oriented implementation and inclusive design (19, 37).

Institutional policy alignment remains decisive. Many AI classroom applications remain at an augmentation level because integration into curriculum and assessment is uneven (11). Policy ambiguity can limit adoption depth, especially in secondary contexts (43). Multi-level governance should therefore integrate curriculum planning, assessment reform, technology standards and reporting norms to support responsible scaling and reproducibility (27, 28, 57, 58).

Cross-theme comparison across the evidence on learning outcomes and the identified mechanism–moderator patterns indicates that sustained analytical gains are more consistently associated with structured scaffolding, instructor mediation and policy clarity, whereas minimal supervision and short-term integration may accelerate performance without supporting durable transfer (3, 5, 8, 15). This pattern implies that governance and design depth jointly moderate long-term value. Ethical safeguards therefore function best as built-in components of pedagogical architecture rather than post hoc compliance measures.

Overall, adoption sustainability should be treated as a systems-level requirement in which assessment integrity, transparency, inclusive access and institutional governance jointly ensure that generative AI augments rather than replaces analytical reasoning (11, 28).

Table 4: Adoption, Ethics and Sustainability Factors in AIGC–GBL

Adoption Dimension	Specific Issue	Context of Evidence	Risk / Governance Implication	Sustainability Consideration	References
Academic Integrity	AI-generated submissions	Higher Education	Blurred authorship boundaries	Clear AI-use policies	(50)
Academic Integrity	Detection and attribution	Higher Education	Faculty uncertainty in AI-authored work	Assessment redesign; AI literacy	(49)
Accessibility and Integrity	AI support vs. assessment validity	Higher Education	Misuse under accessibility framing	Accommodation guidelines	(51)
Transparency	Algorithmic opacity	Cross-disciplinary	Unclear credibility and bias	Disclosure; model explanation	(53)
Transparency	Dataset bias	Multicultural education	Reinforced inequities	Bias auditing; contextual adaptation	(52)
Transparency and Feedback	AI feedback reliability	AI-supported learning	Overreliance without verification	Instructor validation loops	(3)
Equity	Digital divide	Global education	Unequal analytic-skill opportunity	Infrastructure investment	(54)
Equity	Socioeconomic moderation	Latin American education	Amplified performance gaps	Inclusive digital policy	(55)
Autonomy and Dependency	Reduced independence	Higher Education	Cognitive offloading	Metacognitive prompts	(56)
Autonomy and Dependency	AI overreliance	Secondary and Higher Education	Weak self-regulation	Guided inquiry scaffolds	(44)
Institutional Policy	AI governance needs	Secondary education systems	Policy ambiguity	Institutional AI guidelines	(43)
Institutional Policy	Curriculum integration	Higher Education	Fragmented AI deployment	Integrated curriculum–assessment policy	(57)
Policy and Reporting	Reporting transparency	Review contexts	Inconsistent standards	PRISMA-aligned documentation	(27)
Policy and Reporting	Responsible AI integration	Cross-institutional reviews	Ethical oversight gaps	Institutional monitoring	(28)

Adoption Dimension	Specific Issue	Context of Evidence	Risk / Governance Implication	Sustainability Consideration	References
System-Level Adoption	Augmentation vs. transformation	Higher Education; 139 studies	Limited pedagogical redefinition	Strategic AI planning	(11)

Discussion

This review examined when AIGC-enhanced Game-Based Learning (GBL) supports durable analytical skill transfer rather than short-term performance acceleration. Synthesizing evidence across design configurations, outcome patterns, mechanism–moderator dynamics and governance conditions yields five integrated implications for AI-supported analytical development.

First, durable transfer is most plausible when learning objectives, game mechanics and AI scaffolding are structurally aligned. Sustained gains are more consistently observed when adaptive feedback and prompting are embedded within the core reasoning loop of gameplay or within structured AI-supported learning routines, rather than positioned as auxiliary assistance (3, 5, 15, 43). In contrast, narrow or single-task AI support can improve immediate performance without reliably supporting internalization or transfer (8). This pattern indicates that the critical variable is not AI presence but the coherence of the pedagogical architecture connecting mechanics, evidence use and justificatory practice (41, 59).

A key pedagogical distinction should be made between adaptive scaffolding and static AI-generated feedback. Adaptive scaffolding responds dynamically to learners' decisions, misconceptions, progress, or reasoning patterns through context-sensitive hints, calibrated prompts, dialogic questions, difficulty adjustment and revision-oriented feedback. It is pedagogically significant because it intervenes within the game's reasoning loop while preserving productive struggle. By contrast, static AI-generated feedback is fixed or minimally responsive, often delivered after task completion or at predefined stages. Although it may improve clarity or correction, it is less likely to support analytical transfer unless embedded in reflective and decision-responsive instructional design.

Second, contextual immersion appears to strengthen transfer by situating analytical routines within authentic constraints. Escape-room and XR-based designs repeatedly leverage time pressure, narrative coherence and simulated realism to anchor reasoning in consequential decision-making rather than abstract exercises (16, 17). Such contextual framing can stabilize transfer by linking conceptual abstraction to experiential meaning and by requiring repeated navigation of trade-offs and consequences (27, 60).

The descriptive evidence clarifies differences between immersive and non-immersive implementations. Immersive designs account for one-third of the design-traceable studies in Table 1 and are characterized by scenario embodiment, narrative coherence, consequence tracking and contextual decision-making. The strongest large-sample immersive evidence comes from an online escape-room study involving 3,175 learners that reported significant grade improvement (17). By comparison, non-immersive interventions in Table 2 use smaller experimental or quasi-experimental samples, including n = 76, n = 102, n = 117 and n = 64 and report improvements in computational thinking, analytical ability, short-term task performance, or critical-thinking outcomes (3, 4, 8, 41). Because these studies differ in domain, duration, instruments and outcome constructs, these patterns should not be interpreted as a direct statistical comparison of efficacy.

Third, reflective and metacognitive scaffolding moderates the depth of learning. Designs that require justification, comparison and evaluation through dialogic prompting and structured self-regulation are more consistent with analytical consolidation than designs that primarily optimize efficiency (37). Where reflection is weak or absent, performance gains may mask superficial processing, aligning with prior concerns that speed can outpace depth under AI-mediated learning (9, 61). Reflection therefore functions as a bridge between supported task success and durable analytical competence.

Fourth, duration and iterative exposure appear central to consolidation. Multi-week, semester-long and course-based implementations more consistently report stable analytical, motivational, or literacy-related outcomes than brief interventions, plausibly because extended timelines allow repeated feedback cycles, difficulty calibration, collaborative interaction and scaffold fading across progressively complex tasks (4, 5). This trajectory aligns with experiential learning and cognitive apprenticeship accounts in which competence accumulates through cyclical practice and guided refinement rather than isolated performance episodes (62, 63).

Fifth, sustainability depends on governance alignment and mitigation of dependency risks. Academic integrity concerns, authorship ambiguity and policy uncertainty remain decisive adoption constraints, particularly where assessment validity is vulnerable to AI-generated outputs (11, 49, 50). Evidence indicates that safeguards are most effective when designed as pedagogical features, such as metacognitive prompting, guided inquiry routines and transparent AI-use protocols, rather than post hoc compliance measures (52, 56, 64). Institutional mechanisms that coordinate curriculum integration, assessment reform and reporting standards further condition responsible scaling of AIGC-enhanced learning environments (57, 65–68).

These findings generate practical recommendations for educational technology practitioners, curriculum developers, instructional designers and institutional policymakers. Practitioners should use AIGC as supervised scaffolding rather than autonomous instruction by requiring learners to justify, compare and revise their reasoning. Curriculum developers should align AIGC-enhanced GBL with explicit analytical outcomes, including evaluation, argumentation, computational thinking and evidence-based decision-making. Instructional designers should connect quests, puzzles, simulations, role-play, feedback loops and reflection tasks to specific analytical operations. Institutional policymakers should establish guidance on acceptable AI use, assessment integrity, data protection, transparency, accessibility and instructor oversight so that AI-supported gameplay strengthens rather than replaces human reasoning.

Overall, the synthesis suggests that AIGC-enhanced GBL supports durable analytical transfer when AI functions as a reflective scaffold embedded within coherent game mechanics, reinforced through longitudinal cycles and bounded by transparent governance. When these conditions are weak, performance acceleration can outpace conceptual depth. Sustainable innovation therefore requires systemic alignment among instructional design, AI scaffolding and institutional policy so that generative systems augment, rather than substitute for, human reasoning.

Conclusion

This review synthesizes evidence on Artificial Intelligence-Generated Content (AIGC)-enhanced game-based learning (GBL) and analytical skill development across design configurations, empirical outcomes, explanatory mechanisms and governance conditions. Three conclusions emerge. First, analytical gains are most plausible when AIGC functions as adaptive scaffolding embedded within core game mechanics through feedback, dialogic prompting and iterative revision, rather than as peripheral content generation. Second, durable transfer appears to depend on contextual immersion, sustained engagement and reflective supports aligned with explicit learning objectives; short-term performance gains may occur, but consolidation requires repeated exposure and metacognitive regulation. Third, effectiveness and sustainability are inseparable from governance: integrity safeguards, transparency, equitable access and instructor oversight condition whether AIGC augments reasoning or fosters dependency.

Several limitations should be considered when interpreting these findings. The review relied exclusively on Scopus and was not preregistered in a public registry, although it was guided by an a priori plan. The temporal scope was intentionally limited to 2024–2026 to examine the post-initial adoption phase of generative AI, but this may have omitted foundational 2023 studies and limited assessment of longitudinal trajectories, delayed learning effects and long-term sustainability. The included studies also varied substantially in learning domain, intervention duration, game mechanics, outcome constructs and measurement instruments, limiting direct cross-study comparability and precluding statistical aggregation or causal comparison between immersive and non-immersive implementations. Evidence from primary education, low-resource contexts and long-term follow-up designs also remains limited.

Future research should also integrate foundational studies from the early public adoption period of generative AI and conduct longitudinal syntheses or follow-up investigations capable of distinguishing short-term performance acceleration from durable analytical competence.

Abbreviations

AIGC: Artificial Intelligence-Generated Content, CDIO: Conceive–Design–Implement–Operate, CT: Complex Thinking, ESP: English for Specific Purposes, GBL: Game-based Learning, GenAI: Generative Artificial Intelligence, LLM: Large Language Model, NLP: Natural Language Processing, SLR: Systematic Literature Review; XR: Extended Reality.

Acknowledgement

This research was supported by the Doctoral Scholarship Program for Indonesian Lecturers (Grant No. 202508111685), administered by the Center for Higher Education Funding and Assessment, Ministry of Higher Education, Science and Technology of the Republic of Indonesia.

Author Contributions

Bayu Adi Laksono: Conceptualization, Methodology, Data Curation, Formal Analysis, Writing—Original Draft Preparation, Bachtiar Sjaiful Bachri: Supervision, Validation, Writing—Review and Editing andi Mariono: Supervision, Validation, Writing—Review and Editing.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The data supporting this review are derived from the included studies and the extraction matrix developed by the authors. The extraction template and coded dataset are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

The authors declare that generative AI tools were used only to assist in language editing (ChatGPT and Grammarly). All conceptualization, analysis and interpretation were conducted by the authors.

Ethics Approval

This study is a review based exclusively on published literature and does not involve human participants, personal data, or identifiable individual-level information. Therefore, ethical approval and informed consent were not required.

Funding

This research was supported by the Doctoral Scholarship Program for Indonesian Lecturers (Grant No. 202508111685), administered by the Center for Higher Education Funding and Assessment, Ministry of Higher Education, Science and Technology of the Republic of Indonesia.

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How to Cite: Laksono BA, Bachri BS, Mariono A. Game-based Learning in the Era of Generative Artificial Intelligence: A Systematic Review of Analytical Skill Development and Educational Innovation. Int Res J Multidiscip Scope. 2026;7(3):1028-1046. DOI: 10.47857/irjms.2026.v07i03.010715