

Hierarchical Cognitive Structuring and Game Mechanics Alignment in Educational Game Systems: A Systematic Literature Review

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Abstract. Educational games are increasingly used to support meaningful learning, yet the ways in which cognitive progression is translated into game mechanics and system-level design remain insufficiently explicit in the literature. This study followed the PRISMA 2020 guidelines to review empirical studies published between 2015 and 2025 and indexed in Scopus and IEEE Xplore. After screening and eligibility assessment, 68 studies were included. Constructivist approaches were predominant, while only 15 studies (22.1%) explicitly represented a hierarchical cognitive structure to organize gameplay progression; the remaining 53 studies (77.9%) represented cognitive progression implicitly. Recurring operational patterns included level-based progression, sequenced task organization, and adaptive scaffolding through feedback. The findings indicate that explicit cognitive-mechanics alignment is underreported in the reviewed corpus rather than absent from educational game design. For design practice, the results highlight the need for traceable frameworks that connect cognitive objectives with missions, rules, feedback, progression, and assessment tasks. Because the search was limited to Scopus and IEEE Xplore, the findings should not be interpreted as exhaustive coverage of all educational game research.

Keywords: Educational Games, Game System Design, Cognitive Integration, Systematic Literature Review, PRISMA

1. INTRODUCTION

Educational games are educational information systems in which cognitive learning objectives are translated into rules, missions, game mechanics, progression, feedback, and assessment [1], [2], [3], [4]. In this review, hierarchical cognitive structuring denotes the deliberate organization of objectives from lower- to higher-order cognitive processes; game mechanics alignment denotes their translation into playable actions and rules; and architectural alignment denotes their implementation through coordinated system components, including missions, feedback, progression logic, and assessment structures. Although educational games often incorporate pedagogical and adaptive features, studies do not always report how specific cognitive levels are mapped to game mechanics and system architecture. The central problem is therefore not the absence of pedagogical intent, but limited transparency and traceability of cognitive-level mapping. Without explicit documentation, it is difficult to distinguish cognitive progression from increasing game difficulty or to reproduce design knowledge across contexts [2], [5], [6].

Educational games have been applied across language learning, safety education, information literacy, human-computer interaction, programming, artificial intelligence, ethics, mathematics, science, music, and culturally contextualized learning [7] - [29]. This breadth makes it important to examine how cognitive objectives are operationalized within game mechanics and architecture, not only whether games support learning. Educational game design draws on constructivist, cognitive, motivational, and behaviorist perspectives [2], [3], [14], [15], [16], [30], [31], [32], [33]. Bloom's Revised Taxonomy provides an established hierarchy from lower- to higher-order thinking [34], [35], [36], but adopting a pedagogical theory does not itself ensure explicit cognitive-to-gameplay mapping. Empirical evaluations commonly emphasize learning outcomes, motivation, or user experience [17], [22], [37], [38], [39]. Fewer studies provide a traceable account of how cognitive objectives are converted into learning mechanics, game mechanics, mission sequencing, feedback, progression, and assessment [40], [41], [42], [43].

Based on this background, the present study conducts a systematic literature review of empirical educational game research to synthesize empirical evidence on how hierarchical cognitive structures are represented and operationalized within educational game systems. Specifically, this study addresses the following research questions:

- 1) RQ1. What pedagogical approaches and theories are employed in empirical educational games, and how are they distributed within the literature?
- 2) RQ2. How are cognitive levels integrated and operationalized into game mechanics in empirical educational games?
- 3) RQ3. What structural design patterns characterize the representation of cognitive levels in empirical educational games?

By synthesizing empirical evidence, this systematic literature review provides a structured understanding of how pedagogical approaches underpin educational game design, how cognitive levels are integrated and operationalized through game mechanics, and what structural design patterns characterize their representation. The following section describes the systematic review methodology adopted to identify, screen, and synthesize the relevant empirical studies.

2. METHODS

This study employed a Systematic Literature Review (SLR) following PRISMA 2020 to support a transparent and reproducible process [44]. The review comprised literature searching, study selection, methodological quality assessment, data extraction, coding, and synthesis to address the three research questions

2.1. Search Strategy

A systematic search was conducted on 1 December 2025 in Scopus and IEEE Xplore for empirical studies published from 2015 to 2025. Scopus provided broad multidisciplinary coverage across education, computer science, information systems, and engineering, while IEEE Xplore complemented it with technology-focused literature on educational game systems, adaptive systems, and game mechanics [45], [46]. Scopus and IEEE Xplore were selected for complementary pedagogical and technological coverage. Web of Science was not added because of substantial overlap with Scopus, while Google Scholar was excluded because of limitations in reproducible searching and standardized metadata [47], [48]. The database scope is therefore treated as a limitation rather than exhaustive coverage of educational game research.

The search strategy used concept-based keyword groups combined with Boolean operators (AND, OR) [47], [49]. Broad pedagogical, instructional, motivational, and game-design terms were intentionally used to maximize sensitivity because cognitive progression may be expressed through learning objectives, scaffolding, task sequencing, feedback, or mechanics without explicit terms such as "Bloom's taxonomy," "higher-order thinking," or "cognitive complexity".

The database-specific search strings retained the same conceptual groups and publication filters. The complete Scopus query and its IEEE Xplore adaptation are provided in Supplementary Table S1 to support reproducibility. For IEEE Xplore, the Scopus field syntax was adapted to IEEE metadata fields while preserving the conceptual groups, Boolean relationships, publication years, document types, and language restrictions. Because cognitive-specific terms were not included in the main query, studies indexed primarily through such terminology may have been missed. Hierarchical cognitive structuring was therefore identified during full-text screening and coding. The findings should be interpreted within the predefined databases, search strategy, eligibility criteria, and search date.

2.2. Study Selection Process (PRISMA)

Following the identification stage, the retrieved records were screened using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework to ensure a transparent and reproducible study selection process [44]. The study selection comprised duplicate removal, title and abstract screening, full-text eligibility assessment, and final study inclusion. Figure 1 presents the PRISMA flow diagram adopted in this review.

Screening was managed in Rayyan to organize records, identify duplicates, and document title–abstract decisions. The first author conducted title–abstract screening, full-text eligibility assessment, extraction, and coding using predefined criteria, with decisions recorded in Rayyan and Microsoft Excel. A repeat review verified full-text exclusions and explicit/implicit cognitive-structuring classifications; ambiguous cases were re-examined against the coding criteria. Because no independent second reviewer assessed the

complete corpus, inter-rater reliability was not calculated and potential reviewer subjectivity is acknowledged as a limitation.

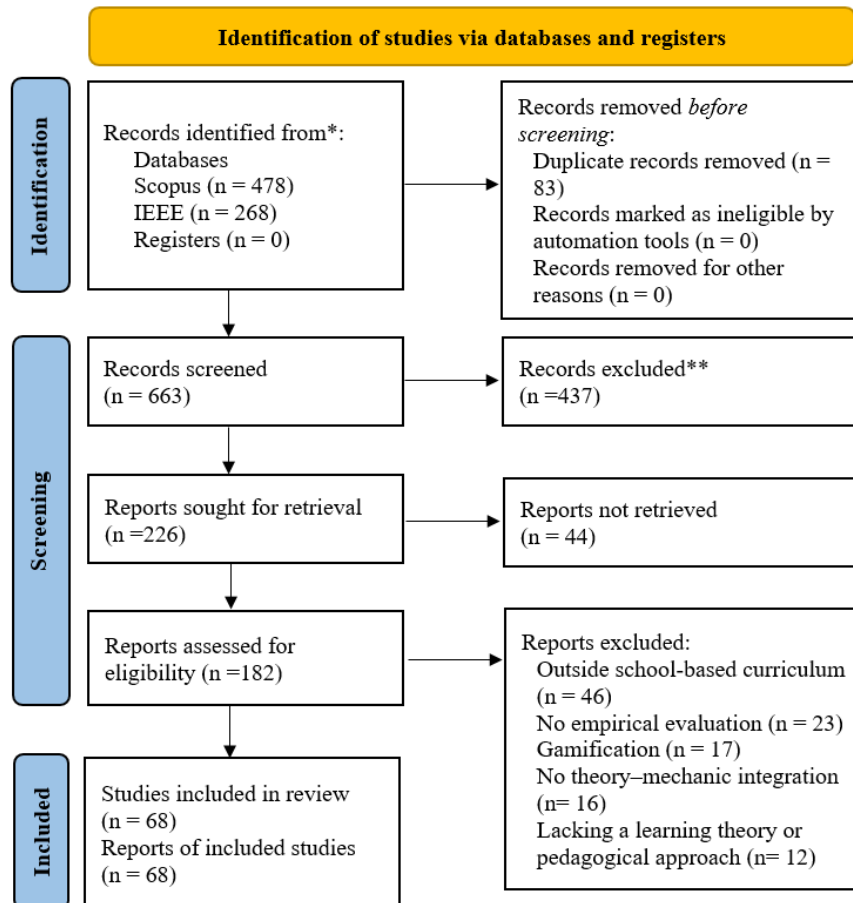


Figure 1. Prisma Flow Diagram

To ensure consistency throughout the screening process, predefined inclusion and exclusion criteria were established before study selection. These criteria were developed to identify empirical studies directly relevant to the objectives of this review while excluding studies outside the intended scope. The complete eligibility criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Empirical studies involving educational or serious games in formal learning contexts	Studies outside the predefined formal-education scope or without a clearly identifiable learner group

Inclusion Criteria	Exclusion Criteria
Studies published between 2015 and 2025	Studies without empirical evaluation
Articles written in English	Gamification-based studies
Peer-reviewed journal or conference articles	Studies without theory–mechanical integration
Studies applying a learning theory or pedagogical approach	Studies without a pedagogical framework

The database search identified 746 records, comprising 478 studies retrieved from Scopus and 268 from IEEE Xplore. After removing 83 duplicate records, 663 unique studies remained for title and abstract screening. Based on the predefined eligibility criteria, 437 records were excluded, leaving 226 studies for full-text assessment. Of these, 44 studies could not be retrieved, resulting in 182 articles assessed for eligibility. A further 114 studies were excluded because they did not satisfy the inclusion criteria, resulting in a final dataset of 68 empirical studies included in the qualitative synthesis. During the eligibility assessment, studies were excluded because they addressed educational contexts outside the scope of this review ($n = 46$), lacked empirical evaluation ($n = 23$), focused exclusively on gamification rather than educational games ($n = 17$), did not report the integration of pedagogical concepts with game mechanics ($n = 16$), or did not explicitly describe a pedagogical framework ($n = 12$).

2.3. Methodological Quality Assessment

A methodological quality assessment was conducted for all 68 included studies using an eight-item checklist adapted from established SLR quality-assessment principles in software engineering and computer science [50], [51]. The criteria were tailored to this review and rated as 1 (fully satisfied), 0.5 (partially satisfied or incompletely reported), or 0 (not satisfied or not reported). The criteria are shown in Table 2.

Table 2. The quality assessment criteria.

No.	Quality criterion	Score
QA1	Research aim or question is clearly stated.	0 / 0.5 / 1
QA2	Educational context, participants, and learning domain described.	0 / 0.5 / 1

No.	Quality criterion	Score
QA3	Game intervention or system design is sufficiently described.	0 / 0.5 / 1
QA4	Pedagogical theory or instructional rationale is identified and related to design.	0 / 0.5 / 1
QA5	Cognitive objectives or cognitive demands, processes or levels are described.	0 / 0.5 / 1
QA6	Game mechanics, progression, feedback, or scaffolding described and connected to learning.	0 / 0.5 / 1
QA7	Empirical data collection and analysis appropriate and transparent.	0 / 0.5 / 1
QA8	Findings support and limitations acknowledge.	0 / 0.5 / 1

Total scores could range from 0 to 8. For descriptive interpretation, scores of 6.0–8.0 were categorized as high, 4.0 to <6.0 as moderate, and <4.0 as low. These thresholds were not used as exclusion criteria; the scores characterized reporting transparency and supported cautious interpretation of the synthesis. No study was excluded solely on the basis of its quality score because the review aimed to synthesize recurring pedagogical, cognitive, and structural design patterns across the eligible literature. The first author conducted the assessment using predefined scoring definitions and re-examined ambiguous ratings against the rubric. Because no independent assessor evaluated the complete corpus, inter-rater reliability was not calculated. The full scoring rubric in Supplementary Table S2 and study-level scores are provided in Supplementary Table S3.

2.4 Data Extraction and Analysis Procedure

Following the study selection process, data were extracted from the 68 included studies using a structured Microsoft Excel extraction form developed for this review. The extracted information included publication characteristics, educational domain, pedagogical foundations, cognitive structures, learning mechanics, game mechanics, architectural design elements, and evaluation methods. Standardized data extraction ensured consistency and reproducibility while providing a structured basis for the qualitative synthesis [52], [53].

Extracted fields included bibliographic information, educational context, system design/architecture, pedagogical approach, cognitive structuring, hierarchical cognitive

model, key game mechanics, cognitive–mechanics alignment, empirical evaluation, primary pedagogical orientation, and explicit/implicit classification. Complete study-level extraction and coding are provided in Supplementary Table S4. Data were analyzed deductively by research question. RQ1 coded primary pedagogical orientation; RQ2 examined how cognitive objectives or demands were translated into mechanics, progression, feedback, scaffolding, and missions; and RQ3 identified recurring structural patterns representing cognitive progression.

A study was coded as explicit when it identified a hierarchical cognitive framework or ordered cognitive levels and used them to organize objectives, gameplay, mechanics, or progression. It was coded as implicit when increasing cognitive demand was evident through tasks, levels, adaptive challenges, feedback, or scaffolding but no formal hierarchy was explicitly identified or mapped to gameplay. Thus, implicit coding denotes limited explicit reporting, not absence of cognitive alignment. Coding was based on information explicitly reported in the primary studies. When evidence was insufficient for an explicit classification, the study was coded conservatively as implicit. Frequencies and percentages were combined with qualitative comparison of recurring pedagogical, cognitive, mechanical, and structural relationships.

3. RESULTS AND DISCUSSION

3.1. General Characteristics of the Studies

A total of 68 empirical studies met the inclusion criteria. Figure 2 shows their annual distribution from 2015 to 2025, with publication activity increasing markedly in recent years. The studies covered primary, secondary, vocational, and higher education and domains including language learning, information literacy, human computer interaction, programming, artificial intelligence, ethics, engineering, science, road safety, and special education. Evaluation designs included experimental and quasi-experimental studies, classroom implementations, user evaluations, and qualitative investigations; several recent studies also used adaptive systems that adjusted gameplay difficulty to learner performance. Overall, the corpus reflects growing and methodologically diverse research on pedagogically grounded educational games across formal education.

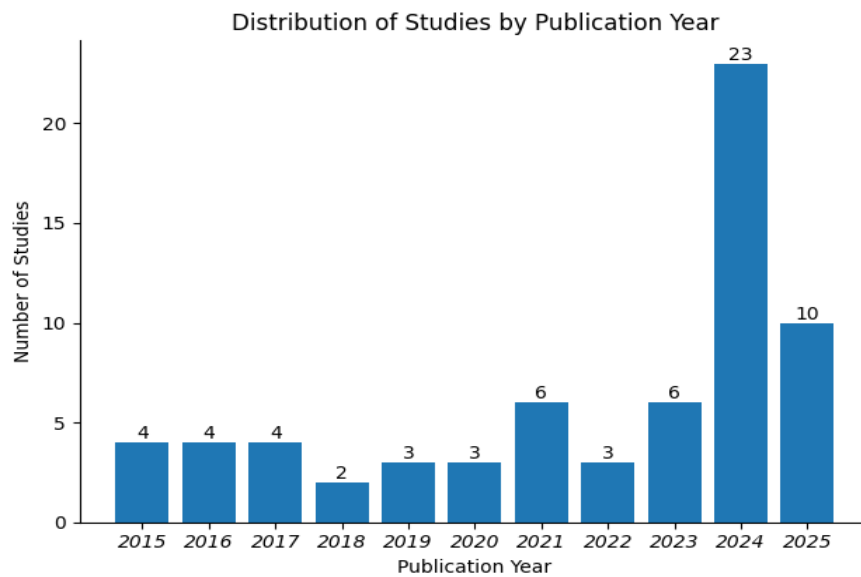


Figure 2. Distribution of Study by Publication Year

Methodological quality was predominantly moderate to high: 24 studies (35.3%) were categorized as high quality and 44 (64.7%) as moderate, with none below the predefined low-quality threshold (Table 3). Detailed study-level scores are provided in Supplementary Table S3.

Table 3. Distribution of Methodological Quality Scores

Quality category	Score range	Studies (n)	Percentage
High	6.0–8.0	24	35.3%
Moderate	4.0–<6.0	44	64.7%
Low	<4.0	0	0.0%
Total		68	100%

3.2. Pedagogical Approaches in Educational Game Design

RQ1 identified four pedagogical orientations (Table 4). Constructivist approaches predominated (41/68; 60.3%), followed by cognitive-oriented (17; 25.0%), motivational-oriented (9; 13.2%), and behaviorist approaches (1; 1.5%). Constructivism was commonly operationalized through exploration, collaboration, simulation, and contextual problem solving [18], [26], [27], [54]. However, constructivism explains how learners construct knowledge rather than prescribing an ordered hierarchy of cognitive complexity; a constructivist game may therefore leave cognitive progression implicit. Rather than

functioning primarily as instructional delivery tools, educational games were designed to promote experiential learning and active learner participation, reflecting the broader adoption of student-centered pedagogical practices within digital learning environments [4], [55].

Table 4. Distribution of Pedagogical Orientations

Pedagogical orientation	Studies (n)	Percentage
Constructivist	41	60.3%
Cognitive-oriented	17	25.0%
Motivational-oriented	9	13.2%
Behaviorist-oriented	1	1.5%

Cognitive-oriented studies emphasized reasoning, conceptual understanding, structured problem solving, feedback, and adaptive challenge [56], whereas motivational approaches such as ARCS and Self-Determination Theory emphasized attention, engagement, confidence, persistence, rewards, and challenge [57]. The single behaviorist-oriented study relied mainly on reinforcement principles [6].

Across orientations, similar pedagogical foundations produced different gameplay implementations. Constructivist principles appeared in collaborative missions, simulations, inquiry, role-playing, and adaptive problem solving [10], [26], [58]; cognitive-oriented studies more often used structured feedback and progressive task sequencing [30], [59], [60]; and motivational approaches used rewards, adaptive challenges, and progression [57], [61], [62]. This variation shows that pedagogical theory alone does not determine a standardized gameplay architecture.

3.3. Integrating Cognitive Levels into Game Mechanics

RQ2 distinguished explicit from implicit cognitive structuring. Fifteen studies (22.1%) explicitly connected a hierarchical cognitive structure to gameplay, whereas 53 (77.9%) represented progression implicitly (Table 5). This classification reflects reporting explicitness and does not imply that the remaining games lacked cognitive alignment.

The distinction is between incorporating increasing cognitive demand and systematically organizing gameplay through an articulated hierarchy. Many studies increased task

complexity, but relatively few explicitly identified the cognitive structure governing that progression.

Table 5. Distribution of Cognitive-Structuring Categories

Cognitive-structuring category	Studies (n)	Percentage
Explicit/hierarchical	15	22.1%
Implicit/non-structured reporting	53	77.9%

Explicit studies used cognitive hierarchies to coordinate objectives, gameplay progression, mechanics, and learner advancement. Examples include progressive levels with scaffolding [13], [58], [63], Bloom-based sequencing from lower- to higher-order thinking [34], [36], [38], [64], and successive gameplay stages aligned with hierarchical objectives [64], [65]. Typical mechanics included unlocked levels, staged missions, adaptive challenges, and performance-based progression.

Implicit studies embedded progression through sequential tasks, adaptive feedback, contextual scenarios, dialogue, or narrative without explicitly mapping these features to a cognitive hierarchy. Examples include cognitive-style-based gameplay [9], ARCS-based learning activities [28], conversational scaffolding [27], [58], adaptive competency development [66], [67], [68], [69] and Activity-Theory-based task progression [70]. Across both categories, mechanics often increased task complexity, but only a minority explicitly traced that progression to hierarchical cognitive objectives. The reviewed literature therefore suggests underreporting of cognitive–mechanics alignment rather than a universal absence of alignment.

3.4. Structural Design Patterns in the Representation of Cognitive Levels

RQ3 identified three recurring structural patterns: level-based progression, sequenced task organization, and adaptive scaffolding through feedback. These patterns appeared across pedagogical approaches and domains and provided system-level mechanisms for representing increasing learning demands. Level-based progression organized gameplay into increasingly challenging levels, modules, missions, or difficulty tiers [8], [13], [15], [36], [38]. Sequenced task organization used ordered activities, scenarios, dialogue stages, or authentic tasks with increasing conceptual or procedural complexity [59], [63], [70], [71], [72]. Adaptive scaffolding regulated progression through feedback, hints, conversational support, contextual guidance, or performance-based assistance [13], [27], [28], [66], [68].

These patterns operationalize progression, but explicit mapping to formal cognitive hierarchies remains relatively uncommon.

Table 6. Cognitive Levels and Representative Gameplay Mechanisms

Cognitive demand	Typical learning activity	Mechanics/architectural elements	Alignment interpretation
Remember	Recall, recognition, identification	Quizzes, matching, immediate feedback, introductory missions	Retrieval and familiarization.
Understand	Explain, classify, interpret	Dialogue choices, sorting, contextual scenarios, explanatory feedback	Meaning-making beyond recall.
Apply	Execute procedures or use concepts	Simulation, tool use, rule-based missions, worked-task progression	Knowledge translated into action.
Analyze	Compare, diagnose, identify relationships	Branching problems, evidence inspection, multi-step missions, adaptive challenge	Decomposition and relational reasoning.
Evaluate	Judge alternatives using criteria	Decision scenarios, feedback, score justification, consequence systems	Judgment linked to criteria and outcomes.
Create	Design, construct, produce solutions	Open-ended missions, sandbox construction, project tasks, iterative feedback	Synthesis and original production.

3.5. Discussion

This review shows that pedagogical grounding is well established in educational game design, but the formal representation of cognitive progression remains inconsistently reported. In response to RQ1, constructivism was the most prevalent pedagogical orientation, accounting for 60.3% of the reviewed studies. This predominance reflects the widespread use of exploration, collaboration, simulation, contextual problem solving,

and active learner participation in educational games. However, constructivism primarily explains how learners construct knowledge through meaningful activity and interaction; it does not, by itself, prescribe a sequence of increasingly complex cognitive outcomes. Consequently, a game can be pedagogically constructivist while still leaving the intended progression from basic to higher-order thinking unspecified.

The findings for RQ2 reinforce this distinction. Only 15 studies (22.1%) explicitly linked a hierarchical cognitive structure to gameplay, whereas 53 studies (77.9%) reported cognitive progression implicitly. This result should not be interpreted as evidence that the latter games lacked cognitive alignment. Rather, it indicates that the relationship between cognitive objectives and gameplay elements was often not made visible in the reported design. Many studies incorporated increasing task difficulty, sequential activities, adaptive feedback, or contextual scenarios; however, these features were rarely mapped explicitly to a formal hierarchy of cognitive demand. Therefore, increasing game difficulty should not automatically be equated with increasing cognitive complexity. A more difficult task may require faster responses, greater persistence, or more game experience without necessarily requiring more advanced reasoning.

RQ3 identified three recurring structural patterns through which educational games can represent cognitive progression: level-based progression, sequenced task organization, and adaptive scaffolding. Level-based progression organizes learning through increasingly challenging levels, modules, missions, or difficulty tiers. Sequenced task organization structures activities, scenarios, dialogue stages, or authentic tasks in an ordered manner, enabling learners to build conceptual or procedural understanding progressively. Adaptive scaffolding supports this process through feedback, hints, conversational guidance, and performance-based assistance. These patterns provide practical architectural mechanisms for operationalizing progression across different pedagogical approaches and educational domains. Nevertheless, their educational contribution is clearer when designers explicitly state the cognitive purpose of each stage and its relationship to learner advancement.

The central finding is thus not the absence of cognitive–mechanics alignment, but its limited documentation in the reviewed corpus. Explicit alignment improves the transparency of how learning objectives are translated into game rules, missions,

feedback, progression conditions, and assessment activities. It also enables researchers and practitioners to distinguish between gameplay progression that is primarily motivational or performance-oriented and progression that deliberately supports increasingly complex cognitive engagement.

For educational game designers, each cognitive objective should be documented alongside the learner action that demonstrates achievement, the game mechanic that enables the action, the feedback or scaffolding that supports performance, and the progression rule that governs advancement. For example, remembering may be supported through quizzes and immediate feedback, whereas analysis may require evidence inspection, branching problems, and multi-step missions. Similarly, evaluation and creation require mechanics that allow learners to justify decisions, compare alternatives, construct solutions, or revise outputs iteratively. Such traceability can improve the auditability, reuse, and evaluation of educational game design decisions, while supporting more systematic alignment between pedagogical intent, cognitive demand, and gameplay architecture.

4. CONCLUSION

This systematic literature review synthesized evidence from 68 empirical studies indexed in Scopus and IEEE Xplore to examine pedagogical orientations, cognitive structuring, and architectural patterns in educational game design. Constructivism emerged as the predominant pedagogical orientation, represented in 41 studies (60.3%), confirming the central role of active, experiential, and learner-centered approaches in the field. However, only 15 studies (22.1%) explicitly mapped a hierarchical cognitive structure to gameplay, whereas 53 studies (77.9%) reported cognitive progression implicitly. Level-based progression, sequenced task organization, and adaptive scaffolding were identified as the main structural patterns used to support increasing learning demands. Overall, the findings indicate that cognitive-mechanics and architectural alignment is more frequently underreported than absent, as many studies incorporated progressive mechanics without explicitly linking them to cognitive objectives. This review is limited by its coverage of Scopus and IEEE Xplore, the predefined search strategy that did not include cognitive-specific search terms, and single-reviewer screening and coding, which may have restricted retrieval and introduced interpretive subjectivity. Future research

should develop and empirically validate a cognitive–mechanics alignment framework that explicitly connects cognitive objectives with learning mechanics, game mechanics, missions, feedback, scaffolding, progression rules, and assessment across diverse educational contexts.

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