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Literature Review

Gamification and Improvement of Mathematical Creative Thinking: Systematic Literature Review

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Abstract: Mathematics education in the digital era faces fundamental challenges in developing students' mathematical creative thinking skills. The 2022 PISA data shows Indonesia's mathematics literacy score was 366, below the average of 472, indicating a significant gap in higher-order thinking skills. Gamification offers an innovative solution through reward mechanisms, challenges, and feedback that enhance intrinsic motivation. This systematic literature review conducted using PRISMA guidelines, analyzed 336 Scopus articles from 2018 to 2024 with *VOSviewer*, identifying 4 relevant articles. Results demonstrate gamification effectively increases computational thinking skills from 4% to 46%, academic achievement by 12%, and engagement to 94.1%. Furthermore, Gamification develops decomposition, abstraction, pattern recognition, and algorithmic problem-solving with optimal effectiveness through systematic student-centered design. Recommendations include developing mathematical creativity assessment instruments and conducting longitudinal studies on their sustained impact.

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INTRODUCTION

Mathematics education in the digital era faces fundamental challenges in developing students' mathematical creative thinking as an essential 21st-century competency. Conventional approaches that emphasize algorithmic procedures and formula memorization are less effective in facilitating the development of creative thinking, which involves fluency, flexibility, and originality abilities in generating diverse solutions (Istikomah et al., 2024; Rahmayanti et al., 2025). The 2022 PISA data shows that Indonesian students' mathematics literacy skills are below the OECD average with a score of 366 from an average of 472. This indicates a significant gap in mastering higher-order thinking skills (OECD, 2023). Low motivation and engagement among students who perceive mathematics as difficult and boring exacerbate this problem (Nusantara et al., 2024)

Gamification as the application of game design elements in non-game contexts offers an innovative solution through reward, challenge, and feedback mechanisms that enhance intrinsic motivation based on self-determination theory, fulfilling the needs for autonomy, competence, and relatedness (Deci & Ryan, 2000; Deterding et al., 2011). Furthermore, gamification facilitates active learning and experiential learning that enables exploration of mathematical concepts through trial-and-error in a safe learning environment conducive to creative thinking (Dichev & Dicheva, 2017). The urgency of this research is driven by digital transformation in education following the *Covid-19* pandemic (Pokhrel & Chhetri, 2021), global workforce needs for creative thinking skills (NCTM, 2020), and the gap between the theoretical potential of gamification and its systematic empirical implementation which requires comprehensive study (Sailer & Homner, 2020).

Research on gamification in education has developed rapidly, with meta-analyses showing medium to large effect sizes ($d = 0.49$) on learning outcomes (Zainuddin et al., 2020). Empirical studies prove that game-based learning increases mathematical achievement by 15-20% (Huang et al., 2019), serious games achieve 94.1% engagement rate (Cruz & Guayara, 2021), gamification platforms increase mathematics achievement by 12% (Shana et al., 2024), and game programming activities increase computational thinking from 4% to 46% among high-achieving students (Soboleva et al., 2021). However, research specifically targeting gamification's impact on mathematical creative thinking remains limited. Gaps persist regarding the specific game element mechanisms that facilitate creative thinking processes, the frequent use of general creativity measures rather than mathematical creativity instruments (Arifandi et al., 2022), and minimal longitudinal studies on sustained impact (Hanus & Fox, 2015).

This research conducts a systematic literature review using PRISMA guidelines to identify, analyze, and synthesize evidence-based findings on gamification implementation in mathematics learning and its impact on creative thinking. Bibliometric analysis using *VOSviewer* maps research trends, key concepts, and knowledge gaps, while thematic synthesis reveals effective mechanisms, optimal design principles, and contextual factors. The novelty of this research lies in the development of a conceptual framework that integrates Game-Based Learning Theory (Prensky, 2003), Creative Thinking Framework in Mathematics (Leikin & Pitta-Pantazi, 2013), and Technology Acceptance Model (Davis, 1989). This framework explains how gamification facilitates mathematical creative thinking through mediation of intrinsic motivation, cognitive engagement, and affective states. It operates on the proposition that effectiveness depends on aligning game mechanics, dynamics, and aesthetics with mathematical creative processes. Consequently, this research addresses six objectives: (1) identify publication trends and collaborations; (2) map key concepts through bibliometric network analysis; (3) analyze the effectiveness of gamification approaches on mathematical creative thinking dimensions; (4) identify design principles and best practices; (5) reveal moderating factors; and (6) formulate a research agenda and practical recommendations.

METHOD

The method used in this research is a Systematic Literature Review (SLR). The SLR method is a systematic approach involving processes of identification, evaluation, and interpretation of all research findings related to a specific topic, aiming to provide answers to formulated research questions (Kitchenham & Charters, 2007). The SLR generally consists of three main stages: planning, conducting, and reporting (Figure 1.). The Literature review aims to obtain the theoretical foundations supporting research problem-solving.

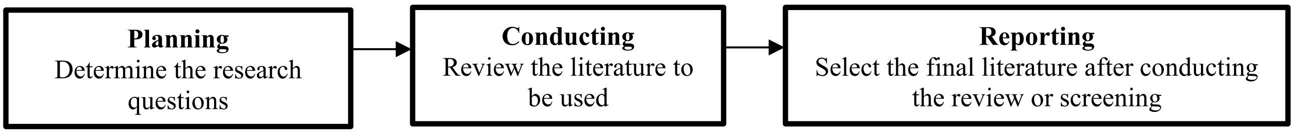

Figure 1. SLR Process Flow

Planning the review

This research uses the Systematic Literature Review (SLR) method to analyze and synthesize literature related to gamification and the enhancement of mathematical creative thinking abilities. An SLR was chosen because it can provide comprehensive, systematic, and objective review of published research within specific periods. This method follows PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and replicability of the research process.

The SLR approach in this research includes five main stages: (1) research question formulation, (2) systematic literature search, (3) article selection and screening, (4) data extraction, and (5) findings analysis and synthesis. Additionally, Bibliometric analysis using *VOSviewer* is integrated to map research trends, identify main theme clusters, and visualize collaboration networks among researchers and interconnections among key concepts.

Conducting the review

The review begins with several steps: literature search, inclusion screening, data extraction, data analysis and synthesis, and review reporting. Research data consists of bibliographic metadata and Scopus-indexed journal articles retrieved with the keywords "gamification" and "creative thinking". The search process yielded 336 articles published between 2018 and 2024. All metadata were exported in RIS format, including article titles, authors, affiliations, publication years, citation counts, abstracts, and keywords. Data cleaning procedures were then performed based on inclusion and exclusion criteria to ensure the significance and quality of the selected literature. Table 1. presents the criteria and exclusions used in this investigation.

Initial screening was conducted using title words, keywords, and relevant databases, leading to identification of 336 articles from Scopus, as presented in Table 2. The researchers then assessed obtained articles and filtered out duplicate articles, resulting in 207 remaining articles. Subsequently, researchers analyzed the titles and abstracts using inclusion and exclusion criteria.

Table 1. Search Keywords, Database, Exclusion, and Inclusion Criteria

Database	Scopus (primary database)
Title Words	“Gamification”
Keywords	“Gamification” and “creative thinking” “Gamification” and “mathematics learning”
Exclusion Criteria	- Any of the selected keywords not appearing title, abstract, keywords, full text - Not in English - Publisher is unclear - Beyond the scope of mathematics
Inclusion Criteria	- Any of the selected keywords appeared in the title, abstract, keywords, full text - Be published in any of the selected databases - Be a journal article or Thesis - Be in the English languange

Table 2. Literature Search Results Based on Database, Title Words, and Keywords

Title Words	Keywords	Scopus
Gamification	"Gamification" and "creative thinking"	278
	"Gamification" and "mathematics learning"	58
	Total documents	336

Through a rigorous literature screening process, we successfully identified 22 documents meeting established inclusion criteria, while other articles did not meet requirements. Subsequently, from the 22 eligible documents, 18 documents were accessible in full-text. These were further selected by narrowing research objectives to measure creative thinking specifically, yielding 4 articles relevant to this research. These 4 articles from Scopus were ultimately selected for synthesis as they were deemed to have substantial relevance potential to answer the posed research questions. A visual representation of this document selection process flow can be seen in the PRISMA diagram (Figure 2.).

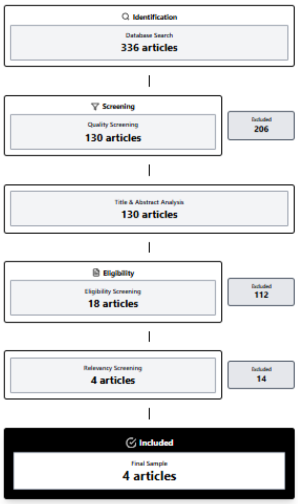

Figure 2. Systematic Article Selection Process Following PRISMA Guidelines

Reporting the review

The obtained bibliometric findings were interpreted through qualitative analysis. This interpretation aims to reveal dominant themes, conceptual relationships among topics, emerging research subjects, as well as identify areas still minimally explored in the related study field. This objective interpretation process enables research to clearly identify existing research gaps and formulate potential future study directions. Subsequently, the interpretation of the results is integrated into a comprehensive research recommendation formulation in the discussion section to strengthen drawn conclusions and support the findings.

RESULTS

This research utilizes Scopus as its primary database due to its high credibility and rigorous peer-review standarts for scientific publications. Bibliometric data were analyzed using *VOSviewer* to visualize citation networks, inter-article relations, and bibliometric mapping. Keyword searches for "gamification", "creative thinking", and "mathematics learning" for period 2018-2024 yielded 336 metadata articles in RIS format. *VOSviewer* analysis was used to map inter-article relations, keyword distribution, and research trends. Visualization of article numbers per year is presented in Figure 3.

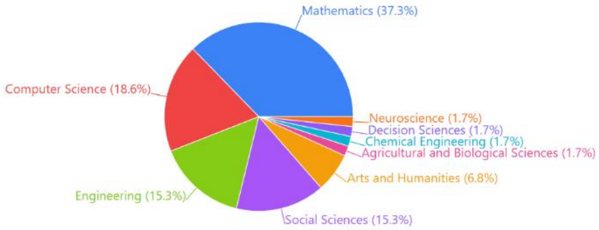

Figure 3. Distribution of Publications by Field of Study in 2018-2024

Based on the filtered dataset represent in Figure 3., from 59 identified documents, research is distributed across nine subject areas with disproportionate distribution. Mathematics dominates with 22 documents (37.3%), showing that gamifiying creative thinking is most heavily researched within mathematics learning due to needs for innovative approaches in complex problem-solving. Computer Science ranks second with 11 documents (18.6%), which is logical considering gamification development relies on technology and programming. Engineering and Social Sciences each contribute 9 documents (15.3%), reflecting application of engineering principles and studies on motivational aspects and psychological impacts of gamification.

Arts and Humanities contribute 4 documents (6.8%), providing critical insights into aesthetic design and narratives. Four other fields (Agricultural and Biological Sciences, Chemical Engineering, Decision Sciences, and Neuroscience) each contribute only 1 document (1.7%), yet show gamification versatility across disciplines.

This distribution reveals two important patterns: first, STEM field dominance covering over 70% of literature shows research intensity on creative thinking through gamification in STEM contexts; second, significant Social Sciences presence indicates holistic approaches considering technological, psychological, social, and pedagogical aspects. Besides subject area distribution, temporal publication patterns show research interest development on this topic. The following presents visualization of document distribution per year in Figure 4.

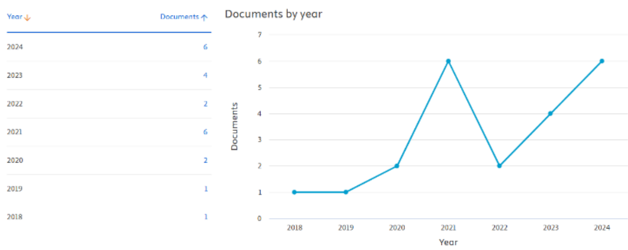

Figure 4. Distribution of Publications in Learning Pathways in 2018-2024

As illustrated in Figure 4., the annual distribution of Scopus-indexed publications addressing gamified learning media for creative thinking reveals a fluctuating yet significant growth research trends during 2018-2024. Research on gamification-based learning media to enhance creative thinking shows dynamic development during 2018-2024 period. Starting from emerging phase with only 1 document per year in 2018-2019, research experienced significant surge to 6 documents in 2021, driven by *Covid-19* pandemic accelerating digital learning technology adoption. Although experiencing decline to 2 documents in 2022, trend increased again with 4 documents in 2023 and reached highest peak of 6 documents in 2024.

Overall, from 23 documents in seven-year span, positive growth trend is visible showing this topic as new yet rapidly developing research area. Fluctuating pattern indicates research is dynamic and responsive to global education contexts. The Peak output in 2024 strongly suggest that gamification for developing creative thinking will continue as important research focus, aligned with 21st-century skills needs and education digital transformation. This temporal dynamics also reflects diverse geographical contributions in this research field development, based on Figure 5.

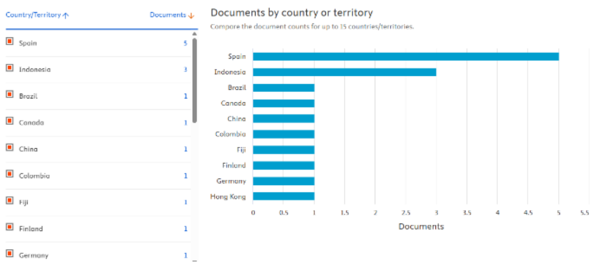

Figure 5. Distribution of Publications by Country in 2018-2024

Based on Figure 5., research distribution on gamification-based learning media development to enhance creative thinking shows global spread with varied contributions. Spain dominates with 5 documents, indicating strong research ecosystem and progressive education policies. Indonesia ranks second with 3 documents, showing significant developing country contributions and awareness of creative thinking importance in national education.

Other countries contribute 1 document each, including: Brazil and Canada (Americas), China, Fiji, and Hong Kong (Asia), and Colombia, Finland, and Germany (Europe). This diversity reflects global research topic relevance across economic and cultural contexts. This geographical distribution reveals three important patterns: first, Spain and Indonesia cumulatively contribute over one-third of total publications; second, participation from developed and developing countries shows universal topic relevance; third, geographical diversity opens opportunities for international collaboration and comparative studies to identify best practices in various global education contexts. Spain shows European leadership, while Indonesia indicates research dynamism in Southeast Asia. Publication distribution on learning pathways, categorized by journal, is presented in Figure 6.

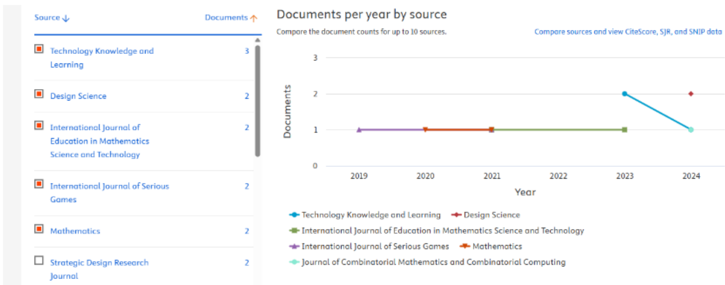

Figure 6. Distribution of Learning Pathway Publications by Journal in 2018-2024

According to Figure 6., Technology Knowledge and Learning dominates this subfield with 3 documents (published across 2019, 2023, and 2024, establishing it as a primary avenue for tech-integrated gamification research. Five journals contribute 2 documents each: Design Science, International Journal of Education in Mathematics Science and Technology, International Journal of Serious Games, Mathematics, and Strategic Design Research Journal, This spread emphasizes the shared importance of instruction design, rigorous STEM learning, and serious gaming theories.specialized venues like Computational Intelligence and Journal of Combinatorial Mathematics and Combinatorial Computing, contribute 1 document each, targeting advanced computational algorithms and advanced mathematics.

Temporal patterns show early exploration phase (2019-2021) with stable publications, activity peak in 2023, and consolidation in established journals in 2024. Quality journal diversity with different focuses enriches academic discussions, while consistent publication patterns indicate this is sustainable research area continuing to develop with contributions from various specialization academic communities. Exploration and diversity characteristics are also reflected in individual researcher contribution patterns, presented in Figure 7.

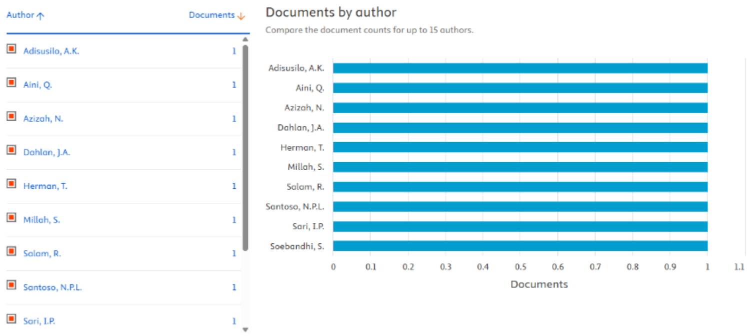

Figure 7. Distribution of Learning Pathway Publications by Author in 2018-2024

As presented in Figure 7., Adisusilo contributed one document. The remaining top authors likewise each contributed a single document, reflecting a balanced distribution of publications with no dominant individual author. This pattern indicates research is still exploratory with diverse researcher involvement yet not showing intensive specialization. Absence of authors with multiple publications shows this area is still in development stage without dominantly established experts or thought leaders.

This even distribution reflects lack of intensive collaboration or research continuity, where most researchers conduct single studies without follow-up. However, ethnic and geographical background diversity of authors strengthens global and multidisciplinary characteristics of this topic, aligned with research spread findings in various countries.

Overall, research on gamification-based learning media development to enhance creative thinking is still in emerging phase with broad yet not deep participation. This pattern opens great opportunities for focused expertise development, research group formation, and long-term collaboration that can produce more comprehensive and impactful research in the future. Research activity can also be identified through author institutional affiliations, providing overview of most productive institutions in this topic development, as seen in Figure 8.

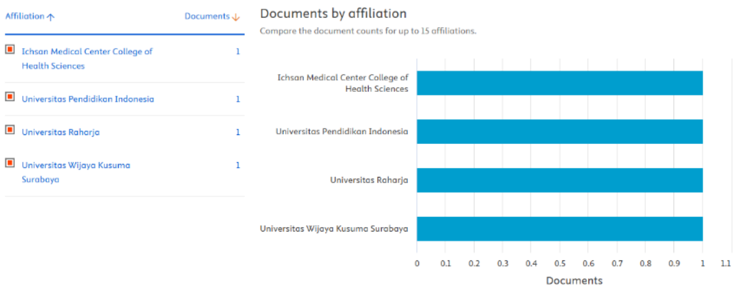

Figure 8. Distribution of Learning Pathway Publications by Affiliation in 2018-2024

In Figure 8., scientific publication distribution shows that Ichsan Medical Center College of Health Sciences, Universitas Pendidikan Indonesia, Universitas Roharjo, and Universitas Wijaya Kusuma Surabaya from Indonesia confirm Indonesia's position as second largest contributor after Spain. The dominance of Indonesian institution reflects the strong activity and commitment of higher education institutions in exploring gamification for creative thinking. Furthermore, the diversity of Institution types, ranging from medical center college and pedagogical universities to general universities, indicates a broad interest that is not limited solely to technology-focus institutions.

The presence of Universitas Pendidikan Indonesia is highly relevant given its pedagogical focus, while Ichsan Medical Center College of Health Sciences shows gamification exploration in health education for clinical reasoning. The Geographical distribution is also noteworthy with Universitas Wijaya Kusuma Surabaya in East Java, indicating that research is spread across major cities.

However, the even distribution pattern (1 article each) indicates that this research has not become a main focus or ongoing program at these institutions. This opens opportunities for specialized research center development, inter-institutional collaboration, and establishment of centers of excellence in learning gamification in Indonesia. Overall, this visualization captures an early development phase of research with significant potential for systematic growth in the future.

The importance of student-centered approach is reinforced by the systematic literature review network visualization showing "students" concept as most dominant central point in research on gamification-based learning media development to enhance creative thinking. This dominance is visible through its large node size and bright yellow color intensity, indicating that students are main focus in all analyzed literature studies. This also affirms that gamification effectiveness in mathematics learning depends on the extent to which learning media design places students as active subjects in learning process, as shown in Figure 9.

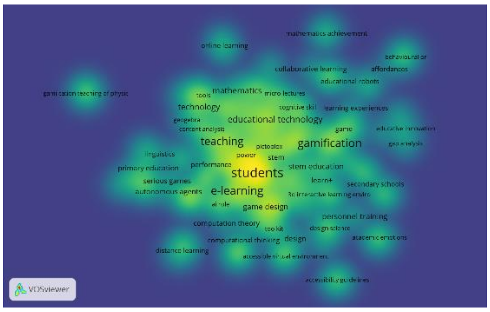

Figure 9. Density Visualization

The visualization reveals two main clusters: first, gamification and game-based learning with "gamification" node as dominant concept connected with game design, serious games, and game-based learning. Second, educational technology and e-learning encompassing online learning and digital technology as enablers of gamified and interactive learning experiences.

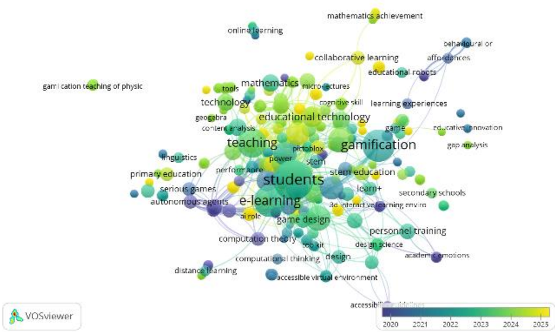

Figure 10. Overlay Visualization

VOSviewer bibliometric visualization highlights several primary focuses in mathematics learning pathway research. Regarding the learning process, large "teaching" and "learning" nodes connected with collaborative learning, distance learning, and autonomous agents, indicating focus on optimizing learning experiences through gamification. "STEM education" and "mathematics" node presence indicates STEM becomes fertile area for gamification implementation in developing creative thinking. In term of Computational-cognitive aspects, concepts such as computational thinking, cognitive skill, and design thinking connected with problem-solving and critical thinking, showing creative thinking integration with other higher-order thinking abilities. Pedagogically, performance, assessment, and motivation become concerns for measuring gamified learning media effectiveness across education levels from primary to secondary education. Lastly, personalized learning and student emotions shows an increased attention toward individual student needs and affective aspects, rather than just cognitive ones. Advanced technology utilization is visible through emerging virtual environments and AI role, while accessibility guidelines indicate awareness of inclusivity in developing learning media that is accessible to all students.

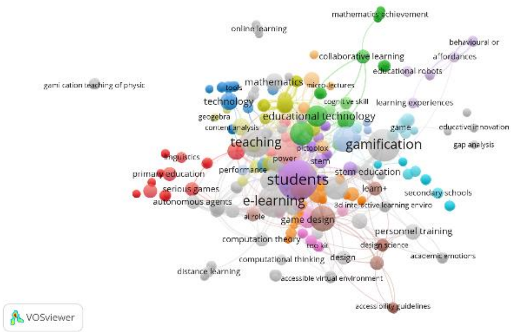

Figure 11. Network Visualization

In Figure 11., connectivity patterns in this network show relationship complexity among various concepts. Areas with highest density center on students, gamification, teaching, and learning concepts, while supporting concepts are evenly distributed in peripheral areas forming comprehensive research ecosystem. Yellow-green-blue color gradation indicates concept significance levels in literature, with yellow marking most dominant concepts.

This visualization implies several principles for developing gamification-based learning media. First, the design must be student-centered with mature e-learning technology integration. Second, gamification approach needs systematic implementation with deep pedagogical considerations, rather than merely adding superficial element. Third, cognitive aspects like computational thinking, problem-solving, and critical thinking must be integrated in design, not treated as secondary components.

The prominent STEM context can be implementation starting point, though it does not limiting application to other fields. Social-emotional dimensions through collaborative learning and student emotions need consideration to create holistic learning experiences. Personalization and accessibility must be fundamental principles to accommodate student diversity. By considering these elements, gamification-based learning media can be developed effectively, inclusively, and meaningfully in enhancing students' creative thinking, as outlined in Table 3.

Table 3. Keywords, Cluster, Occurrence, and Link Strength

Cluster	Keywords	Occurrence	Total Link Strength
Green	educational technology	45	180
	collaborative learning	20	85
	Education	18	75
	Mathematical achievement	12	48
Orange	e-learning	40	160
	Game design	15	58
	Autonomous agents	7	24
	Power	3	8
Purple	Gamification	35	140
	Students	30	120
	Educational robots	11	42
	Pictablox	5	14
	Behavioral affordances	7	25
Red	Serious Games	16	65
	primary education	8	30
	gamification teaching of physics	4	10
	Robotics	4	10
Pink	Learning	30	115

Cluster	Keywords	Occurrence	Total Link Strength
	Game	22	90
	Performance	14	52
Blue	Mathematics	25	100
	Technology	20	80
	Content Analysis	5	15
	geographical games	3	8
Light Blue	STEM Education	18	70
	Secondary Schools	10	38
	3D Interactive Learning Environment	6	20
	educational innovation	5	18
	gap analysis	5	15
Gray	online learning	15	60
	Cognitive Skills	12	45
	micro lectures	10	40
	computational thinking	10	35
	design	9	35
	personnel training	9	32
	distance learning	8	28
	accessible virtual environment	6	22
	accessibility guidelines	4	12

In Table 3., overall cluster distribution indicates that gamification for mathematics learning is implemented using a student-centered approach, integrated with digital technology, applied across education levels, and designed considering cognitive aspects, performance, and inclusivity to create effective, holistic, and accessible learning ecosystems for all students.

DISCUSSION

Content analysis/qualitative analysis

The digital transformation in education has shifted conventional learning paradigms toward more interactive approaches through gamification implementation using game elements to enhance motivation and learner participation. Four comparative studies conducted in Greece, United Arab Emirates, Russia, and Colombia offer multidimensional perspectives on gamification implementation across various education levels, from early childhood to senior high school, with learning focuses including children's rights understanding, mathematics and ICT academic achievement, computational thinking formation, and English language competency development.

This systematic literature review analyzes four main studies exploring relationships between gamification and enhancement of mathematical creative thinking accross various geographical and methodological contexts:

1. First study, conducted by Sakka and Gouscos (2023) in Athens, Greece, investigated children's rights education through game-based intervention activities at kindergarten level involving 12 participants (6 males and 6 females) aged 4.5-5.5 years. Using qualitative research methods with interview instruments, questionnaires, projects, and comments, this study measured children's understanding and perceptions of learning processes. Although not directly focused on mathematics, this study revealed that critical thinking development through role-playing can train students to analyze situations from various perspectives-essential skills in mathematical creative thinking.Furthermore, the empathy developed through games can transfer to mathematics contexts as ability to understand problems from different viewpoints, encouraging creative solutions. This

interactive game method shows gamification effectively develops thinking flexibility, a key component of mathematical creativity.

2. Second study by Shana et al. (2024) in United Arab Emirates used quasi-experimental design with 29 elementary school students (15 control group, 14 experimental group) to evaluate web-based learning platform Purple Mash impact on academic performance. With pre-test, post-test, questionnaire, classroom observation, and interview instruments, this study found significant 12% academic achievement increase in experimental group, showing interactive learning enhances concept understanding. High student satisfaction levels indicate increased intrinsic motivation, a strong predictor of mathematical creativity. Interactive platforms enable students to experiment with various approaches, training originality in mathematical problem-solving. Additionally, enjoyable learning also reduces math anxiety, opening mental space for creative thinking.
3. Third study by Soboleva et al. (2021) in Russia has strongest connection to mathematical creative thinking. Using theoretical analysis and empirical methods (surveys, pedagogical observations, measurements, and case studies) with elementary school students, this research explores computational thinking skills formation using computer games in teaching mathematics through special tests and surveys. The results showed a dramatic increase, with students achieving high-level computational thinking jumping from only 4% to 46%. This study identified four key components that directly contribute to mathematical creativity: (1) Decomposition trains students to break complex problems into simple parts, developing fluency aspect (generating many solution ideas); (2) Abstraction develops ability to identify patterns and core concepts, training flexibility (thinking from various mathematical viewpoints); (3) Pattern Recognition becomes foundation for generating creative generalizations and discovering new concept relationships; (4) Algorithmic Problem-Solving encourages elaboration (developing ideas in detail and structured manner). This significant increase shows programming gamification very effectively develops higher-order thinking essential for mathematical creativity.
4. Fourth study by Cruz & Guayara (2021) in Colombia uses qualitative case study method with 17 tenth-grade students to evaluate serious game Bethe1Challenge in English language learning through interview instruments, pre-test, and post-test. Although focused on English, this findings provide important insights into the motivational aspects of gamification that highly relevant to mathematical creativity. The motivation level reaches 94.1%, showing gamification creates learning environments conducive to creative exploration. Scavenger Hunt activity as student favorite indicates preference for discovery-based challenges, parallel to creative mathematical discovery processes. Significant post-test improvement ($p < 0.05$) shows gamification effective for knowledge transfer, ability needed in creative application of mathematical concepts. Positive perception of 76% creates self-efficacy encouraging risk-taking in creative mathematical exploration.

A synthesis of four studies reveals that gamification supports four dimensions of mathematical creative thinking based on Torrance framework: fluency developed through trial-and-error environments without fear of failure and problem decomposition, proven from 42% increase in high-level students in Soboleva et al. (2021) study; flexibility trained through role-playing, abstraction, and pattern recognition as shown in Sakka and Gouscos (2023) and Soboleva et al. (2021) studies; originality facilitated through free experimentation and interactive exploration on Purple Mash platform; and elaboration developed through systematic algorithms and programming activities. Additionally, three additional supporting factors identified: very high intrinsic motivation (94.1% engagement), positive self-efficacy (76% positive perception), and math anxiety reduction through enjoyable learning environments. These studies collectively show gamification not only increases academic achievement but also develops mathematical creative thinking capacity through cognitive mechanisms (computational thinking), affective (motivation and self-efficacy), and behavioral (exploration and risk-taking).

Specific content of ratio and proportion

Analysis of four studies shows gamification in mathematics learning develops creative thinking through specific pedagogical elements. Soboleva et al. (2021) implemented mathematics game programming increasing high computational thinking from 4% to 46% (t empirical = 8.2 > t critical = 2.06, $\alpha = 0.05$), developing decomposition, abstraction, pattern recognition, and algorithm problem-solving. Shana et al. (2024) confirms Purple Mash platform effectiveness with 12% academic achievement increase (experimental: 89.9 vs control: 77.2), Cruz & Guayara (2021) shows 94.1% students motivated as prerequisite for alternative solution exploration, while Sakka and Gouscos (2023) identifies role-playing develops critical thinking through experiential learning. All four studies confirm consistent pedagogical mechanisms: active problem-solving, immediate feedback with trial-and-error, and competitive-collaborative elements in student-centered design. However, crucial gap exists that creative thinking as specific outcome encompassing fluency, flexibility, originality, and elaboration has not been deeply explored, with majority focus on computational thinking, academic achievement, or motivation, indicating significant research opportunity to measure gamification contribution to creative mathematical thinking in innovative problem-solving contexts.

Competency

All four studies show focus on higher-order thinking competency development through gamification. Soboleva et al. (2021) research identifies four key computational thinking components developed through gamification: decomposition (ability to break complex problems), abstraction (ability to identify patterns and general principles), pattern recognition (ability to recognize regularities), and algorithmic problem-solving (ability to design systematic solution steps). Their Results show drastic increase in the proportion of students achieving high-level computational thinking, jumping from 4% to 46%. The statistical significance of this growth is proven by empirical t- value (8.2) exceeding t critical (2.06) at $\alpha = 0.05$. Shana et al. (2024) research shows academic achievement increase with 12% score difference between experimental (89.9) and control (77.2) groups. Sakka and Gouscos (2023) research identifies critical thinking and empathy development through role-playing approach. However, analysis identifies limitation that creative thinking as specific outcome, including fluency, flexibility, originality, and elaboration dimensions, has not been deeply explored in mathematical problem-solving contexts.

Subject/context

The analyzed research was conducted accross diverse geographical contexts and education levels. Soboleva et al. (2021) research conducted in Russia with elementary school student subjects, Shana et al. (2024) in UAE with 29 students divided into control (15 students) and experimental (14 students) groups, Sakka and Gouscos (2023) in Athens, Greece with 12 early childhood participants (4.5-5.5 years), and Cruz & Guayara (2021) in Colombia with 17 tenth-grade students. This context diversity provides multidimensional perspectives on gamification implementation in various education settings, from early childhood to senior high school.

Modelling tools

Gamification platforms and tools utilized varied according to the pedagogical objectives of each study. Soboleva et al. (2021) research uses mathematics game programming activities involving students in game creation process, not merely playing games. Shana et al. (2024) implements Purple Mash gamification platform proven effective in increasing mathematics and ICT academic achievement with high student satisfaction toward interactive learning experiences. Sakka and Gouscos (2023) uses The Unstoppables game rated "brilliant" by all 12 students, while Cruz & Guayara (2021) uses Bethel Challenge with Scavenger Hunt favorite game achieving 94.1% motivation level.

Activity

Existing research (Cruz & Guayara, 2021; Sakka & Gouscos, 2023; Shana et al., 2024) (Soboleva et al., 2021)consistently demonstrates that gamification is effective in mathematics learning when designed with clear pedagogical objectives and actively involves students in problem-solving. This effectiveness is supported by significant improvements in academic achievement (a score increase of approximately 12% in Shana et al. (2024), enhanced motivation (94.1% in Cruz & Guayara, 2021), and the development of Computational Thinking (decomposition, abstraction, pattern recognition, and algorithmic problem-solving) through activities such as programming and role-playing. While gamification shows great potential for developing mathematical creativity by enhancing problem-solving skills and motivation, there is a limitation where explicit research measuring specific dimensions of creative thinking (such as fluency, flexibility, originality, and elaboration) in the gamification context remains limited. Overall, gamification proves effective when implemented through a student-centered approach that provides opportunities for trial-and-error, direct feedback, and both competitive and collaborative elements.

Research gaps and suggestions for future research

Analysis of four studies identifies several critical research gaps that require further development within gamification and the enhancement of mathematical creative thinking:

1. Sakka and Gouscos (2023) study identifies four main gaps: need for deep analysis of emotional responses and student interest in specific rights content to optimize game design based on Children's Rights Education; understanding gap about correlation between child preferences with specific game mechanisms and dynamics; need for multiple perspectives including parents in exploring child perceptions; and limitations in serious games availability specifically for child rights for preschool demographics and methodological limitations in data collection, particularly inability to conduct post-game interviews. Researchers suggest future research explore child and parent views on child rights and digital game use, investigate long-term child adherence to attitude changes, develop serious games specifically for preschool children, and conduct comprehensive analysis of game mechanisms contributing to positive player experiences.
2. The study by Shana et al. (2024) reveals five key gaps: existing studies overlook the unique characteristics of specific platforms like Purple Mash, hindering evidence-based decisions; the ambiguity regarding the comparative effectiveness of educational websites creates confusion in resource selection; inconsistencies in empirical findings demand investigation into mediating variables and contextual conditions; limited access to professional development restricts the capacity for optimal technology utilization; and the implications of technology integration within the UAE context, potentially relevant to other Arab nations, remain systematically unexplored. Future research is suggested to investigate the specific characteristics of educational websites that enhance academic achievement, explore their influence across different subject areas and grade levels, understand the conditions for a significant impact on academic outcomes, and address discrepancies in the literature regarding the effectiveness of platforms like Purple Mash.
3. The study by Soboleva et al. (2021) identifies five crucial gaps in the development of computational thinking: the absence of a systematic methodological basis for training graduates to meet the demands of computational thinking in the modern economy; ambiguity regarding the optimal integration mechanism of gamification into students' research activities; lack of clarity on the specific conditions and contextual variables that facilitate the formation of computational thinking; limited exploration of the challenges and limitations of using computer games in mathematics education; and the need to investigate the optimization of digital learning resources for students' independent mastery of new technologies. Researchers suggest exploring the implementation of computer games with mathematical content to enhance students' cognitive activity and support their professional self-determination, developing innovative methods and tools for teaching computational thinking emphasizing the integration of digital gamification resources, investigating the effectiveness of gamification principles in mathematics to improve

teaching quality, and conducting further studies on the conditions affecting the formation of computational thinking, including outcome analysis and practical applications.

4. Cruz & Guayara (2021) found five limitations: limited studies on gamification implementation in Colombian public schools, which restricts the understanding of contextual effectiveness; students' reluctance to use Mobile-Assisted Language Learning due to unresolved concerns about infrastructure failure; the complexity of the Serious Game Bethel Challenge registration process, hindering the user experience; the unexplored potential of collaborative missions to enrich student learning and teamwork; and the limited capacity of educators to create or access games aligned with specific learning outcomes. Future research should explore the integration of cultural and intercultural collaborative missions in serious games to enhance depth and engagement, investigate the impact of adding team modes in gamification to facilitate general learning goals, and continue evaluating new strategies given the novelty factor of gamification activities in enhancing learning outcomes in online teaching.

The analysis of gaps from the four studies indicates three priority areas for future research: first, the development of systematic methodology for integrating gamification into mathematics learning specifically to enhance computational thinking and mathematical creativity; second, in-depth investigation into specific game mechanics (points, levels, challenges, feedback) and contextual conditions that facilitate the increase of mathematical creative thinking dimensions (fluency, flexibility, originality, elaboration); third, comprehensive exploration of motivational factors, self-efficacy, and collaboration within gamification that support knowledge transfer and the creative application of mathematical concepts. These gaps affirm the necessity for longitudinal research, comparative studies across geographical contexts and educational levels, and the development of a theoretical framework that coherently integrates computational thinking, gamification, and mathematical creativity.

CONCLUSION

This systematic literature review of 336 Scopus articles from the 2018–2024 period, following rigorous screening, identified 22 documents meeting the inclusion criteria, with 18 full-page accessible documents and 4 final articles substantively relevant to answering the research question on gamification in enhancing students' mathematical creative thinking. The research demonstrates a positive growth trend, peaking in 2024, with global distribution dominated by Spain (5 documents) and Indonesia (3 documents), and Mathematics as the dominant subject area (37.3%). Bibliometric analysis identified nine clusters with the central concepts of "students," "gamification," "teaching," and "learning," affirming the student-centered approach as a fundamental principle.

Empirical findings indicate the effectiveness of gamification through: a significant increase in computational thinking from 4% to 46% (Soboleva et al., 2021), a 12% increase in academic achievement in mathematics (Shana et al., 2024), an engagement rate of 94.1% (Cruz & Guayara, 2021), and the development of critical thinking through role-playing (Sakka & Gouscos, 2023). Gamification is proven effective in developing decomposition, abstraction, pattern recognition, and algorithmic problem-solving, with the highest effectiveness achieved through structural gamification that is systematically designed with clear pedagogical goals.

Research gaps identified include: the minimal explicit measurement of mathematical creative thinking dimensions, limited longitudinal studies, and unexplored specific mechanisms of game elements in facilitating creative thinking processes. The theoretical contribution of this research is a conceptual framework integrating Game-Based Learning Theory, the Creative Thinking Framework in Mathematics, and the Technology Acceptance Model. Practical recommendations encompass: implementing structural gamification with a narrative-driven design, adopting a student-centered approach with personalized learning, integrating collaborative elements, utilizing immersive technologies, addressing accessibility, and systematically integrating cognitive aspects. The future research agenda should focus on developing mathematical creativity assessment instruments, longitudinal studies, comparative studies across contexts, exploration of emerging technologies, and investigation of moderating factors. Gamification is an effective innovative approach for the transformation of 21st-century mathematics learning through the implementation of holistic, inclusive, and meaningful evidence-based design principles.

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