International Journal of Learning, Teaching and Educational Research
Vol. 24, No. 4, pp. 568-591, April 2025
https://doi.org/10.26803/ijlter.24.4.26
Received Feb 22, 2025; Revised Apr 14, 2025; Accepted Apr 21, 2025

Direction of Gamification in Science Education: Literature Review and Indexed Bibliography

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Abstract. Gamification in science education has gained significant attention as an innovative approach to enhance student engagement, motivation, and comprehension of complex scientific concepts. This study conducts a systematic literature review and bibliographic analysis to explore the research trends in gamification within science education from 2015 to 2024. The study addresses existing gaps in applying and evaluating gamification in science learning, particularly focusing on its role in enhancing student engagement, motivation, and comprehension of complex scientific concepts. Data was collected from the Scopus database using search terms like "gamification," "science," and "education," yielding a total of 865 relevant publications, including articles, conference papers, and book chapters, published in English. The analysis identifies key contributors in the field, including influential authors such as Papadakis, Kalogiannakis, and Zourmpakis, and highlights prominent journals like Lecture Notes in Computer Science and Education Sciences. Various bibliometric techniques, including citation analysis and keyword co-occurrence mapping, were applied to uncover trends and key themes in gamification research. Findings reveal a sharp increase in publications, especially from 2023 to 2024, reflecting a growing global interest in gamifying science education. The study identifies several recurring themes, such as the integration of digital technologies like virtual reality, the impact of gamification on student motivation, and its diverse applications in science, technology, engineering, and mathematics education. Despite its potential, the research also points to significant challenges, including limited empirical evaluations, insufficient pedagogical frameworks, and the need for broader accessibility. The study concludes that while gamification offers considerable promise in science education, further research is essential to address these gaps, refine implementation strategies, and measure its long-term effects on learning outcomes.

Keywords: bibliometric; educational technology; gamification; science education

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1. Introduction

Gamification represents a fusion of game design principles and non-gaming environments, particularly educational settings, to foster motivation and enhance user engagement. Within the realm of science education, gamification has demonstrated its potential to transform conventional learning approaches by promoting curiosity and sustained participation (Castaneda et al., 2022; De Santo et al., 2022). The theoretical foundations of gamification are grounded in behavioral psychology, emphasizing intrinsic and extrinsic motivation, and leveraging game mechanics like rewards, challenges, and feedback systems. Gamification is not merely about incorporating game-like elements into educational contexts; it is a strategic approach that seeks to create an engaging and immersive learning experience. Educators can tap into the natural human desire for competition, achievement, and social interaction by applying game mechanics. This approach can increase motivation among students, as they are more likely to engage with the material when it is presented dynamically and interactively (Nurfadilah et al., 2023).

One of the key aspects of gamification is its ability to cater to different learning styles and preferences. For instance, visual learners may benefit from interactive simulations and visual feedback, while kinesthetic learners may thrive in hands-on activities that involve movement and collaboration (Johanna & Gutl, 2015). By providing various gamified experiences, educators can create a more inclusive learning environment that addresses the diverse needs of their students. Moreover, gamification encourages a growth mindset by allowing students to take risks and learn from their mistakes in a safe environment (Hovardas et al., 2022; Johanna & Gutl, 2015). The iterative nature of games, where players can retry challenges and receive immediate feedback, fosters resilience and perseverance. This is particularly important in science education, where students often encounter complex concepts that require critical thinking and problem-solving skills (Handayani & Nurfadilah, 2021; Rufaida & Nurfadilah, 2021).

Incorporating gamification into the subject of science education has attracted growing interest from teachers, researchers, and policymakers alike, mainly because of its potential to increase student motivation, engagement, and understanding of abstract scientific principles (Costa, 2025). Notable examples include the "Aengime" project, which used board and digital games to teach grammar effectively, and studies that integrated Minecraft into programming lessons to engage future teachers in collaborative and creative problem-solving (Chuah et al., 2021; Cozar-Gutierrez & Saez-Lopez, 2016; Riabko et al., 2024). Gamification leverages game mechanics such as points, leaderboards, and challenges within educational frameworks, transforming traditional learning into more dynamic, interactive experiences. From 2015 to 2024, significant advancements have been made in applying gamification to science education, driven by technologies such as virtual reality platforms, interactive simulation tools, and mobile applications like Labster. These innovations have enhanced experiential learning, offering realistic environments and instant feedback that align with pedagogical trends emphasizing student-centered and inquiry-based approaches (Morales-Nava et al., 2024; Rege, 2015; Serrano & Manrique, 2020).

Over the past decade, the integration of gamification into science education has intensified. This trend can be attributed to advancements in educational technologies and an increased emphasis on student-centered learning paradigms. Specifically, gamification has been employed to address critical challenges in science education, such as low student interest in complex scientific concepts, a gap in engagement strategies, and the need for experiential learning environments (Clarke et al., 2019, 2022). The proliferation of digital platforms in education has facilitated the application of gamified approaches (Torres-Toukoumidis & Vallejo-Imbaquingo, 2024). Interactive platforms, simulations, and collaborative tools have expanded the scope of gamification, making it accessible to diverse learning contexts. However, the impact of gamification on learning outcomes continues to be a subject of scholarly inquiry, necessitating a structured analysis of its growth and application (Langlands & Morales-Trujillo, 2023; Papadakis et al., 2023; Zourmpakis et al., 2023). The findings of this study provide valuable insights for improving the quality of education by integrating appropriate educational technology tools. The bibliometric analysis reveals a significant increase in publications and growing global interest in gamifying science education. This study demonstrates how these technological advancements can foster more dynamic, interactive, and immersive learning environments by identifying influential authors, key journals, and recurring themes such as the integration of virtual reality and digital learning tools (Khatibi et al., 2021; Luo, 2021). For policymakers and curriculum designers, these results emphasize the importance of leveraging gamification strategies to engage students, particularly in science, technology, engineering, and mathematics (STEM) fields, by incorporating interactive technologies that can enhance educational experiences. Researchers can use these findings to focus future investigations on underexplored areas, such as the long-term effects of gamification and its implementation across different educational levels (Khatibi et al., 2021). The selection of both a comprehensive literature review and a bibliometric analysis as methodologies for this study is grounded in their ability to provide a holistic view of the current research landscape (Sirvermez & Baltaci, 2023). The literature review allows for an in-depth understanding of the qualitative insights surrounding the use of gamification, while the bibliometric analysis quantitatively assesses publication trends, citations, and key contributions. This mixed-methods approach offers both broad patterns and detailed contextual understanding, making it possible to identify gaps, challenges, and emerging trends in the field.

Although research on gamification in education has shown significant progress, several gaps have not been thoroughly explored. First, most studies focus on technology education, such as programming and cybersecurity, while the application of gamification specifically in science education remains limited (Margalit, 2016). Second, research on the design of gamification elements specifically tailored to support science learning has not been deeply developed. Third, only a few studies have explored the impact of gamification on diverse types of learners with different backgrounds, learning styles, and needs. Lastly, although the effectiveness of gamification is often discussed in the context of experiments or systematic reviews, evaluations of its impact in real-world scenarios are still rare (Alemany et al., 2020; Luarn et al., 2024). Therefore, further research is needed to address these gaps and provide a more comprehensive understanding of the potential of gamification in science education. This study aimed to examine the trajectory of gamification in science learning through a comprehensive literature review and bibliometric analysis of the period 2015-2024.

The study was guided by the following research questions:

1. How has the research output on gamification in science education grown between 2015 and 2024?
2. Which source titles have significantly contributed to the gamification literature?
3. Who are the most influential authors in this domain?
4. Which countries have produced the most publications on gamification?
5. What keywords dominate the research on gamification in science education?
6. What is the overall research landscape in gamification?

2. Method

2.1 Research Design

This study adopted a mixed-methods approach, integrating both quantitative and qualitative research techniques with bibliometric analyses (Creswell & Creswell, 2023). It uses statistical analysis through quantitative bibliometric methods to examine the evolution of literature on gamification in science education between 2015 and 2024 (Bancong, 2024; Bancong et al., 2021). By using bibliometric techniques, the study aimed to identify core research themes, emerging areas, and the overall impact of gamification on science education and to map the interconnections between related subfields. The literature review explores qualitative insights into the use and impact of gamification in science learning (Swacha, 2021). By integrating these approaches, the study offers both broad patterns and deep contextual understanding of the research domain. The research design followed a descriptive-exploratory framework to identify patterns, gaps, and emerging themes within the field (Kartal et al., 2024; Khatibi et al., 2021).

2.2 Data Collection

Documents were extracted from the Scopus database on January 9th, 2025, using the search query: TITLE-ABS-KEY (gamification AND science AND education), which resulted in 1,132 documents. Subsequently, the search was narrowed by applying filters for the publication period from 2015 to 2024, selecting only documents in English. Following the search parameters, this refinement process resulted in 865 publications, including articles, conference papers, and book chapters. The detailed data collection process is illustrated in Figure 1.

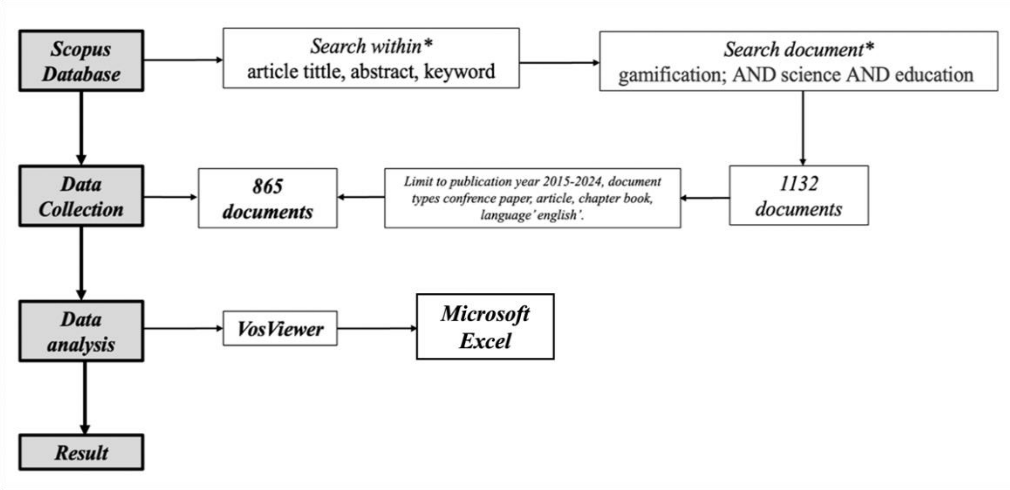

Figure 1: The Steps in Collecting and Analyzing the Data

The selection criteria and search terms were reviewed and validated through a pilot search in the Scopus database, ensuring their relevance and accuracy for identifying appropriate literature. The search terms were adapted from established keywords used in prior bibliometric analyses and systematic reviews related to gamification in education. To ensure the relevance and quality of the documents selected for review, the following inclusion and exclusion criteria were applied and are summarized in Table 1 below.

Table 1: Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Methodology	Quantitative and qualitative studies, bibliometric analyses	Opinion pieces, non-peer-reviewed articles
Population	Studies involving educational settings, K-12, university, and vocational education	Papers not focused on education or students as the subject
Language	English only	Non-English publications
Document Type	Peer-reviewed articles, conference papers, book chapters	Book reviews, editorials, short communications
Publication Year	Publications from 2015 to 2024	Publications outside the specified period (pre-2015 or post-2024)
Focus Area	Studies focusing on gamification in science education	Studies unrelated to education, technology, or gamification

2.3 Data Analysis

The data analysis techniques used in this research involve bibliometric analysis and literature review (Da Silva et al., 2019; Khatibi et al., 2021). The bibliometric analysis in this study examines key aspects of gamification research trends in science education. This includes publication trends over time, citation counts and influential journals, leading authors, countries, and institutions, keyword analysis and co-occurrence mapping, and literature review (Khatibi et al., 2021; Luo, 2021). The literature review complements the bibliometric analysis by delving deeper into selected articles related to the identification of themes, challenges, and their implications (Barbero et al., 2023; Da Silva et al., 2019). With Vosviewer, the analysis can be conducted through network visualization and overlay techniques, which enable the creation of comprehensive networks. These networks include various elements such as countries, institutions, journals, authors, references, and keywords. The connections within these networks are formed through various interactions, such as co-authorship, co-occurrence, citation, and co-citation links (Bancong, 2024). The visual representation relies on color, node size, and line thickness to convey information about numerical values, clusters, and the level of collaboration among these elements. Additionally, the analysis of annual publication trends was conducted through Microsoft Excel, focusing on quantitative changes.

3. Result

3.1 Statistics Analysis

Statistical analysis in this study was conducted to uncover trends, relationships, and patterns in the literature on gamification in science education from 2015 to 2024. This analysis integrates quantitative bibliometric methods and qualitative insights to provide a comprehensive view of the research landscape (Li & Wong, 2022; Yadav et al., 2023). As illustrated in Figure 2, the number of publications over the past decade (2015–2024) shows a significant increase in interest in this topic. This growth in publications reflects the academic community's growing attention to the potential of gamification in enhancing student engagement and learning outcomes in science education. This trend also indicates that gamification is increasingly regarded as an effective tool to address modern educational challenges, particularly in improving students' motivation, creativity, and active participation (Kalogiannakis et al., 2021; Panomrerngsak & Srisawasdi, 2018).

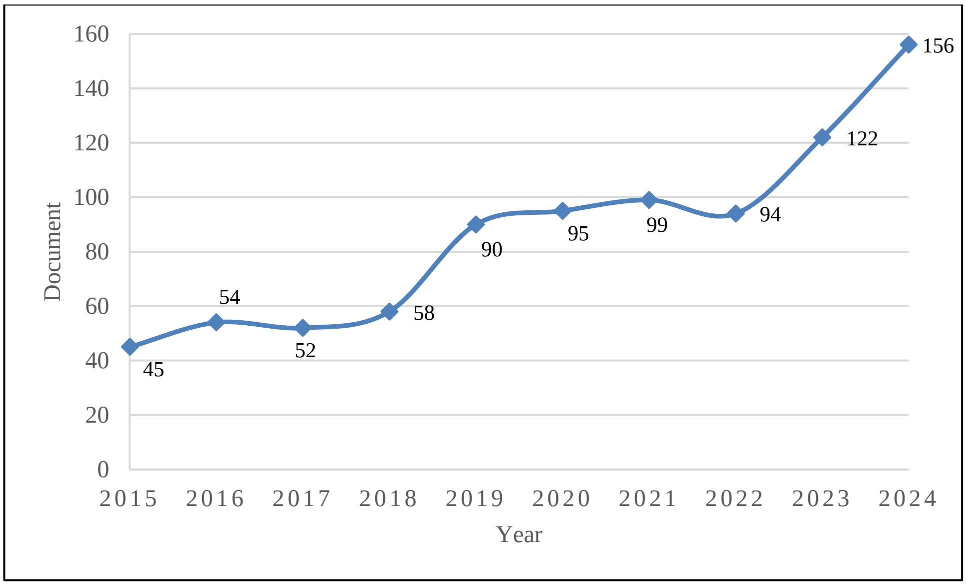

Figure 2: Number Of Articles Published Over the Last 10 Years (2015-2024)

As shown in Figure 2, there has been an increase in studies on gamification in science education. This growth began in 2015 and 2016, followed by fluctuations from 2017 to 2022. A significant increase resumed in 2023 and 2024, with 122 and 156 articles published, respectively. Research and publications on gamification in science education have gained significant global interest over the past 10 years. The number of articles in this area is expected to keep growing, showing a steady annual increase in writing and publishing, as shown in the Scopus database. Statistical analysis was used to find out which source titles had the biggest impact on gamification in science education over the past 10 years. A total of 865 documents were published, including 332 articles, 484 conference papers, and 49 book chapters.

Table 2: The Top 20 Source Titles

No.	Source Titles	Doc.	Quartile	Focus Area
1	Lecture Notes in Computer Science, Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	46	Q2 Q2	Computer science: general computer science Mathematics: theoretical computer science
2	Communications in Computer and Information Science	19	Q4	Computer science Mathematics
3	Education Sciences	19	Q2	Computer science applications; computer science (miscellaneous); development and educational psychology; education; physical therapy, sport therapy and rehabilitation; public administration
4	Lecture Notes in Networks and Systems	15	Q4	Computer networks and communications; control and systems engineering; signal processing
5	Advances in Intelligent Systems and Computing	11	Q4	Computer science; control and systems engineering
6	Education and Information Technologies	11	Q1	Education; e-learning; library and information sciences
7	International Journal of Emerging Technologies in Learning	8	Q2	Education; e-learning; engineering (miscellaneous)
8	Heliyon	6	Q1	Multidisciplinary
9	IEEE Access	6	Q1	Computer science (miscellaneous); engineering (miscellaneous); material science (miscellaneous)

No.	Source Titles	Doc.	Quartile	Focus Area
10	Journal of Physics Conference Series	6	Q4	Physics and astronomy (miscellaneous)
11	Lecture Notes in Educational Technology	6	Q2 Q3 Q2	Computer networks and communications; computer science applications; education
12	PLOS One	6	Q1	Multidisciplinary
13	Sustainability Switzerland	6	Q2 Q1 Q2 Q2	Computer science Social sciences Energy Environmental science
14	ACM Transactions on Computing Education	4	Q1	Computer science; computer science (miscellaneous); social sciences education
15	BMC Medical Education	4	Q1	Medicine (miscellaneous); social sciences, education
16	IEEE Transactions on Learning Technologies	4	Q1	Computer science, computer science applications; engineering, engineering (miscellaneous); social sciences, education, e-learning
17	Journal of Chemical Education	4	Q2	Chemistry; social science; education
18	British Journal of Educational Technology	3	Q1	Social science; education; e-learning
19	Computer Applications in Engineering Education	3	Q1; Q2; Q2	Computer science; engineering; social science; education
20	Computers and Education	3	Q1	Computer science; social science; education; e-learning

The main source of journal publications on gamification was Lecture Notes in Computer Science, which includes Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics, focusing on computer science and mathematics. Other notable sources were Communications in Computer and Information Science and Education Sciences, each with 19 publications. Lecture Notes in Networks and Systems, published 15. Additional sources included Advances in Intelligent Systems and Computing and Education and Information Technologies, both with 11 publications, and others contributing six to eight. Table 2 shows the 20 main source titles for scientific studies about using gamification in science education over the past 10 years. Research topics were not limited to computer science and mathematics; they also covered education, e-learning, engineering, material science, physics, and various multidisciplinary areas.

3.2 Bibliometric Analysis

3.2.1 Contributions of authors

Table 3: The Top 10 Most Productive Authors Over a Decade (2015–2024) Based on the Scopus Database

No	Author	Affiliation	Doc.	Citations	Total link strength
1	Papadakis, S.	University of Crete, Rethymnon, Greece	6	452	12
2	Kalogiannakis, M.	University of Thessaly, Volos, Greece	5	435	10
3	Zourmpakis, A.I.	University of Thessaly, Volos, Greece	5	435	10
4	Semerikov, S.O.	Kryvyi Rih State Pedagogical University, Kryvyi Rih, Ukraine	5	104	6
5	Striuk, A.M.	Academy of Cognitive and Natural Sciences, Kryvyi Rih, Ukraine	5	104	6
6	Paneva-Marinova, D.	Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria	5	5	4
7	Sanmugam, M.	Universiti Sains Malaysia, Minden, Malaysia	5	77	4
8	Abdullah, Z.	Universiti Teknologi Malaysia, Johor Bahru, Malaysia	4	76	4
9	Jeong, J.S.	Universidad de Extremadura, Badajoz, Spain	4	54	4
10	González-Gómez, D.	Universidad de Extremadura, Badajoz, Spain	4	54	4

Table 3 shows the contributions of the top 10 most productive authors over a decade (2015–2024) based on the Scopus database. As listed, Papadakis is the most significant author, with six articles and 452 citations. Following closely are Kalogiannakis and Zourmpakis, each with five articles and 435 citations. These three authors are from Greece. Next, Semerikov and Striuk from Ukraine each published five articles, accumulating 104 citations. Similarly, Paneva-Marinova contributed five articles and five citations. From Malaysia, Sanmugam and Abdullah made significant contributions by publishing five articles (77 citations) and five articles (76 citations), respectively. In addition, Paneva-Marinova published five articles. Lastly, Jeong and González-Gómez from Spain each published four articles, garnering 54 citations.

3.2.2 Contributions of countries

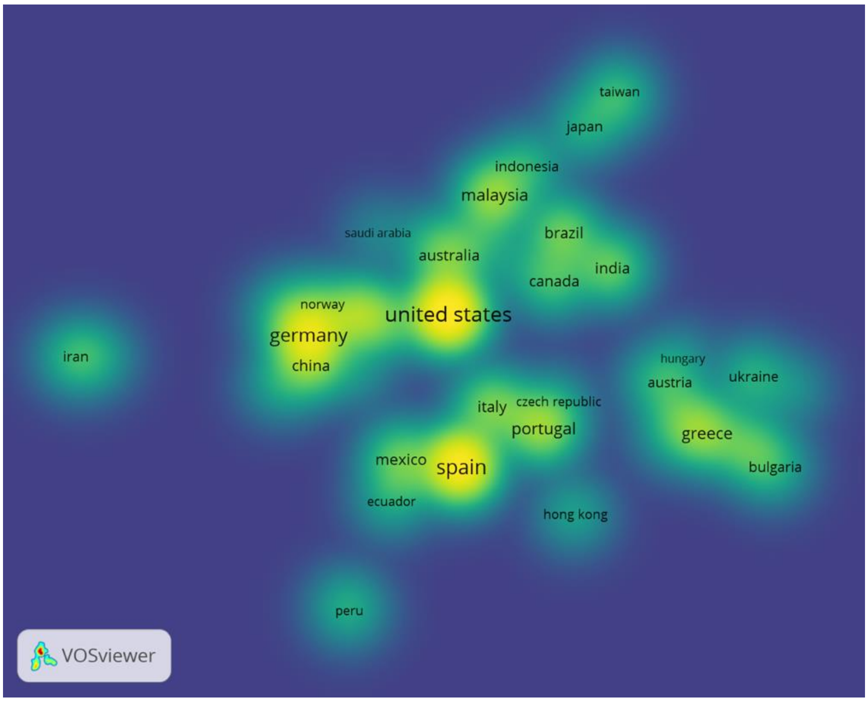

Figure 3: Visualization of Contributing Countries

Table 4 showcases the top 20 countries that have played a significant role in researching the topic of gamification over the past decade (2015–2024), as identified through the Scopus database. Ninety-three countries have contributed 865 documents to the Scopus database on gamification. The United States is the top contributor, with 111 publications, 1,558 citations, and 15 links. Spain comes next with 99 documents, getting 1,113 citations and 20 links, while Germany is third with 65 publications, 66 citations, and 18 links. Malaysia, the United Kingdom, and Portugal each have 41 publications. Malaysia has 405 citations and 20 links, the United Kingdom has 330 citations and 20 links, and Portugal has 568 citations and 19 links. Greece contributed 33 publications with 751 citations and 10 links. Italy has 31 documents with 122 citations and 12 links. Australia and Brazil each have 30 publications, with citations of 473 and 214, respectively. India contributed 29 publications with 136 citations and eight links, while China has 27 documents with 109 citations and five links, and Mexico has 26 documents with 186 citations and six links. Canada has 21 publications with 161 citations and 11 links. Iran, the Netherlands, and Turkey each have 18 publications. The Netherlands achieved 350 citations and 10 links, while Iran has 152 citations. The Russian Federation contributed 17 documents with 133 citations and nine links. The list ends with Indonesia and Ukraine, both with 15 publications; Indonesia received 153 citations and three links, and Ukraine received 227 citations and four links.

Table 4: The Top 20 Countries Contributing to the Topic of Gamification

No	Country	Doc.	Citations	Total link strength
1	United States	111	1558	15
2	Spain	99	1113	20
3	Germany	65	66	18
4	Malaysia	41	405	7
5	United Kingdom	41	330	20
6	Portugal	41	568	19
7	Greece	33	751	10
8	Italy	31	122	12
9	Australia	30	473	8
10	Brazil	30	214	9
11	India	29	136	8
12	China	27	109	5
13	Mexico	26	186	6
14	Canada	21	161	11
15	Iran	18	152	0
16	Netherlands	18	350	10
17	Turkey	18	133	4
18	Russian Federation	17	133	9
19	Indonesia	15	153	3
20	Ukraine	15	227	4

3.3.3 Keywords

This study applied a minimum threshold for two keywords across all research articles examined using VOSviewer. Figure 3 presents 421 author keywords detected over the past decade (2015–2024), categorized into seven distinct clusters. Cluster 1 is represented in red, cluster 2 in green, cluster 3 in blue, cluster 4 in yellow, cluster 5 in purple, cluster 6 in sky blue, and cluster 7 in orange. Each cluster consists of interrelated keywords and is visually represented by the same color. Notably, the size and shape of the nodes indicate the frequency of occurrence. In other words, there is a positive correlation between the node size and the frequency of keyword occurrence. This clustering is used to obtain comprehensive knowledge and understanding of bibliometric grouping, while the visualization mapping provides a holistic view of the bibliometric network.

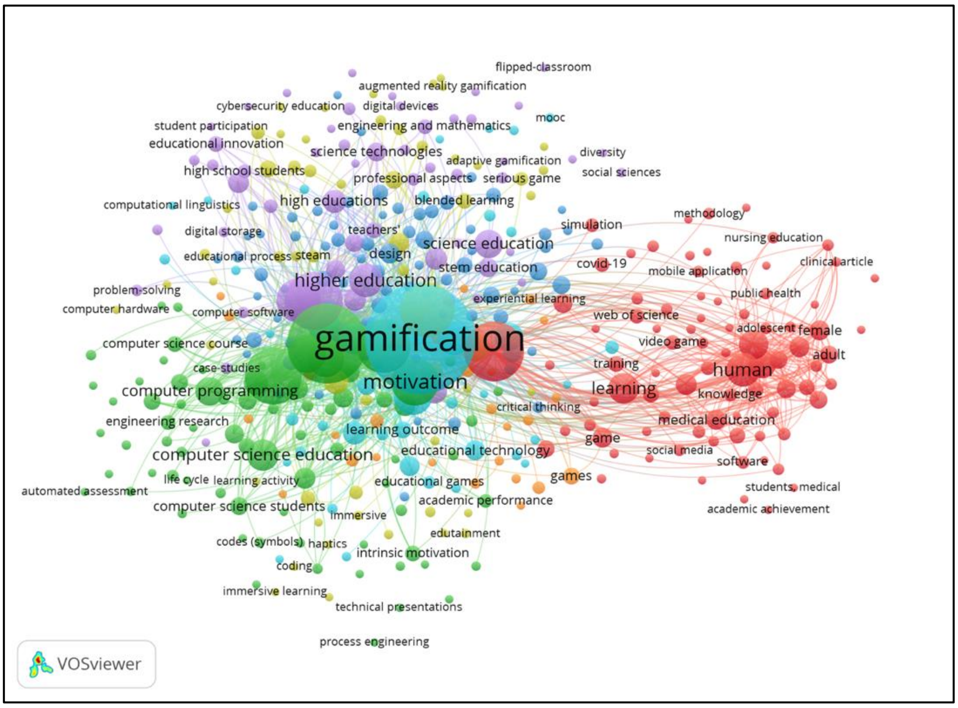

Figure 4: Visualization of Gamification Networks

Based on Figure 4, the clusters are as follows; Cluster 1 (red) **c**ontains 84 items, including keywords such as academic achievement, adult, child, collaborative learning, curriculum, education, game, health, human, internet, learning, knowledge, medical education, methodology, pandemic, science, social media, and software. Cluster 2 (green) comprises 76 items, including academic performance, accessibility, application programs, codes (symbols), computer science education, computing education, cooperative learning, game design, teacher, and websites. Cluster 3 (blue) includes keywords like behavioral research, computer technology, critical thinking, design science, digital platform, educational games, innovation, mobile applications, PBL (problem-based learning), problem-solving, data security, and technology. Cluster 4 (yellow) consists of augmented reality, coding, computation theory, e-learning, mobile learning, statistics, STEAM, STEM, and virtual reality. Cluster 5 (purple) includes 57 items such as active learning, adaptive gamification, educational technology, engineering, game-based learning, gamification in education, learning process, science education, teaching and learning, and virtual tools. Cluster 6 (sky blue) contains 46 items, including artificial intelligence, bibliometric analysis, computer, digital learning, game-based learning, gamification, learning strategy, and video games. Cluster 7 (orange) comprises 27 items, including constructivism, digital game-based learning, e-learning, experiential learning, gamified learning, inquiry-based learning, physics, science learning, and visualization.

The keywords in each cluster exhibit varying frequencies and link strengths. The number of occurrences and the total link strength demonstrate that research publications on gamification in science education over the past decade (2015–2024), indexed in Scopus, show strong and direct connections with these keywords. Table 5 illustrates the top 10 keywords with the highest occurrences and total link strength over the past 10 years on the topic of gamification.

Table 5: Occurrences and Total Link Strength of Keywords

No.	Keyword	Occurrences	Total Link Strength
1	Gamification	641	4261
2	Student	336	2939
3	Education	187	1557
4	Engineering education	178	1535
5	Education computing	170	1453
6	e-learning	158	1325
7	Teaching	150	1439
8	Motivation	120	1024
9	Learning system	105	967
10	Game-based learning	80	609

Based on the VOSviewer analysis, an overlay visualization of gamification over a decade (2015–2024) was obtained, as shown in Figure 5.

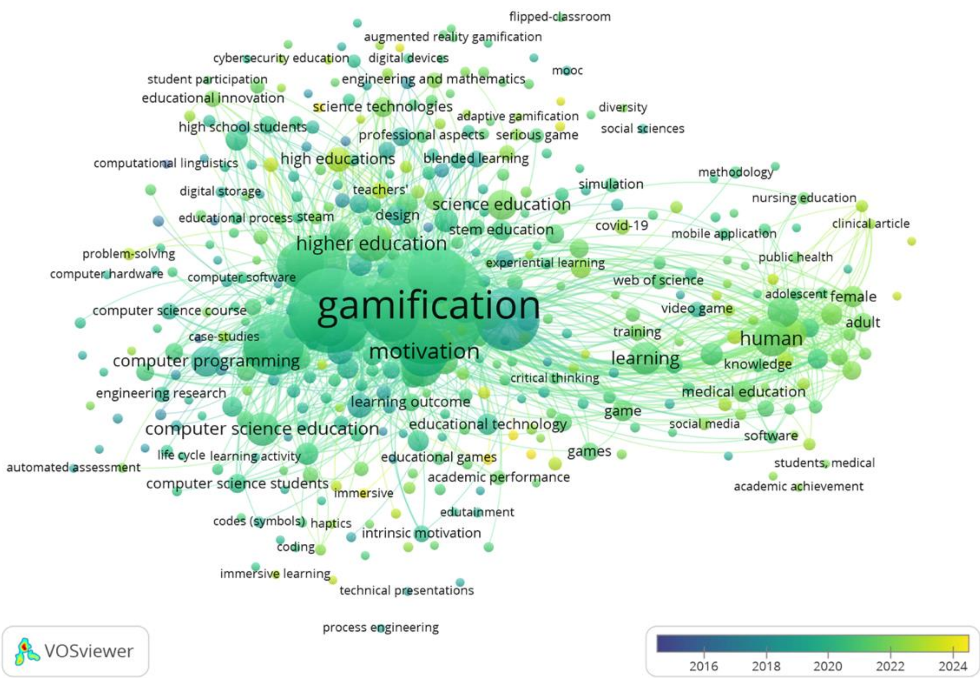

Figure 5: Overlay Visualization of Gamification over the Past Decade (2015-2024)

This figure illustrates the distribution of the number of articles containing keywords per year over the past 10 years. Each color represents the publication date of the related articles where these keywords appeared together. From 2015 to 2018, the keywords “computer” and “education” were still associated with the topic of gamification. Starting in 2020, the topic of gamification began to emerge as a primary keyword and became associated with keywords such as "motivation," "learning outcomes," "critical learning," "science technology," and "science education." Then, starting in 2023, gamification was linked to keywords such as "human," "training," "public health," and "nursing education." This indicates that the keyword has gained popularity in recent years. It can be concluded that some senior scholars have adopted gamification as a topic in their research (Ciuchita et al., 2023; O'Donnell et al., 2017; Rege, 2015).

3.3 Literature Review

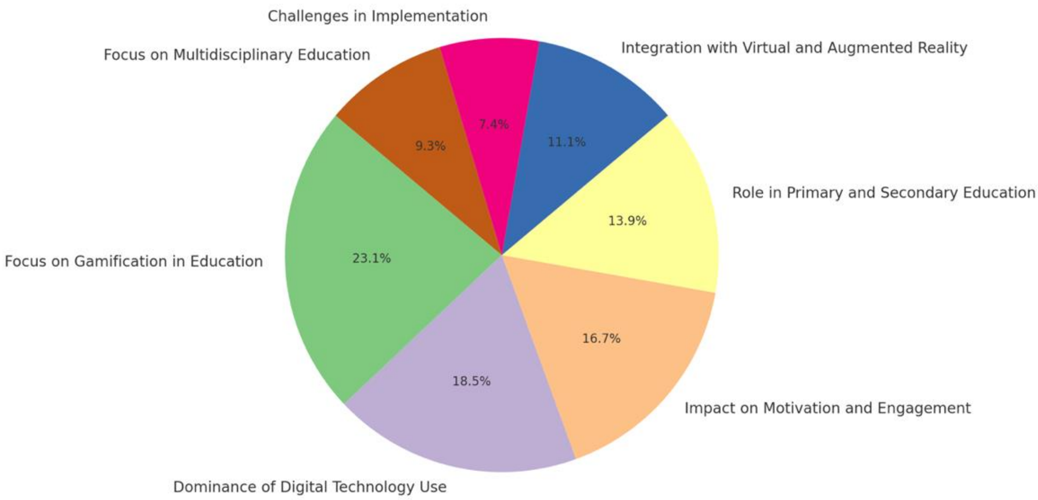

Figure 6: Distribution of Gamification Theme Trend

A thematic literature review based on research data on gamification in science education between 2015 and 2024 reveals key trends related to the theme of gamification, as shown in Figure 5. First, the trend of increasing focus on gamification in education (23.1%) indicates a rise in research in the educational gamification field, particularly in skill development, motivation, and student engagement. Many studies highlight the positive impact of gamification on learning outcomes, especially in STEM fields and social sciences. Second, is the dominance of digital technology usage (18.5%). Although analog gamification remains relevant, technology-based approaches, such as digital games and gamified learning platforms, dominate research and implementation. Examples include the use of Minecraft in education and adaptive gamified learning systems. The third theme, the impact on motivation and engagement (16.7%), shows that many studies find gamification elements, such as points, badges, and leaderboards, can enhance student motivation and engagement. However, some results indicate variability, particularly concerning student collaboration in gamified contexts. Regarding its role in primary and secondary education (13.9%), the implementation of gamification has become a primary focus, with positive impacts on argumentation skills and the development of collaborative skills. Integration with virtual and augmented reality (11.1%) highlights recent trends showing increased incorporation of gamification with technologies like virtual reality (VR) and augmented reality (AR). This provides a more immersive and interactive learning experience. The focus on multidisciplinary education (9.4%) shows that gamification is often applied across various disciplines, including engineering, healthcare, and language education. This reflects the flexibility of the gamification approach for diverse educational contexts. Lastly, challenges in implementation (7.4%) emerge as a theme to be addressed, with some studies highlighting difficulties in measuring the impact of gamification using validated instruments and more controlled studies. This underscores the need for further research to ensure the effectiveness and limitations of gamification in education. Table 6 outlines key challenges and the corresponding implications for gamification development in science learning, drawing insights from existing literature.

Table 6: Challenges and Implications in the Development of Gamification in Science Education

Aspect	Challenges	Implications
Pedagogical Design	• Integrating gamification elements with scientific concepts is challenging due to the complexity of topics. • Designing games that balance engagement with learning objectives.	• Encourages interdisciplinary collaboration between educators, game developers, and subject matter experts to create meaningful and pedagogically sound gamified experiences. • Suggests developing frameworks for integrating gamification within science curricula to ensure alignment with learning outcomes.
Technological Access	• Limited access to technology in under-resourced regions. • Issues related to device compatibility and maintaining updated gamified platforms.	• Promotes investment in cost-effective and accessible technologies for broader implementation. • Suggests the use of hybrid models (digital and analog gamification) to accommodate varying technological capacities in schools and institutions.
Student Engagement	• Sustaining student interest beyond the novelty effect of gamified learning. • Addressing diverse levels of motivation and prior knowledge in a single classroom.	• Highlights the need for dynamic and personalized gamification strategies, such as adaptive learning systems. • Suggests integrating continuous feedback mechanisms and progressive reward systems to maintain student motivation and engagement throughout the learning process.
Learning Outcomes	• Inconsistent evidence on the impact of gamification on critical thinking, collaboration, and scientific literacy. • Limited frameworks to measure learning outcomes effectively.	• Calls for standardized metrics to assess the effectiveness of gamification in improving science learning outcomes. • Encourages combining gamification with traditional teaching methods for a comprehensive learning approach. • Highlights the need for more empirical studies focusing on long-term impacts of gamification on knowledge retention and skill acquisition.

Aspect	Challenges	Implications
Cultural and Ethical Considerations	• Potential cultural bias in gamified content, especially in global implementations. • Ethical concerns related to data privacy and excessive reliance on extrinsic rewards.	• Encourages the creation of culturally inclusive gamified content tailored to diverse audiences. • Promotes the development of ethical guidelines for gamification, ensuring data security and balanced motivational strategies to avoid dependency on rewards. • Advocates for fostering intrinsic motivation alongside external gamified incentives.
Teacher Adaptation	• Resistance or lack of readiness among teachers to integrate gamification in science teaching. • Limited training resources for educators to use gamified tools effectively.	• Calls for professional development programs focusing on gamification tools and strategies tailored for science education. • Suggests the integration of gamification training in teacher education curricula. • Promotes collaborative platforms where educators can exchange best practices and resources for gamified science learning.
Research Gaps	• Lack of studies focusing on the integration of gamification in specific science disciplines. • Limited long-term studies to explore gamification's sustainability and adaptability.	• Encourages targeted research to explore gamification's effectiveness in underexplored domains like STEM and environmental sciences. • Advocates for longitudinal studies to evaluate the sustainability and adaptability of gamification methods. • Suggests including diverse geographical and socio-economic contexts to expand the generalizability of findings.

4. Discussion

This study used bibliometric mapping techniques to explore trends in research on gamification in science education over the last decade, specifically between 2015 and 2024. There has been a noteworthy increase in research related to gamification in science education, evident in both the rising number of publications and the variety of investigated themes (Swacha et al., 2020). Gamification in science learning has emerged as a revolutionary teaching strategy, incorporating game-like elements into educational environments to boost motivation, engagement, and learning effectiveness (Salehi et al., 2023). This research highlights the diverse applications and advancements of gamification across various educational areas, with a particular focus on science and technology learning contexts. The trend toward gamification in education signifies a considerable shift from traditional instructional methods, moving instead toward more interactive and student-centered approaches (Dolezal et al., 2018; Thongmak, 2019). By incorporating game mechanics such as points, leaderboards, badges, challenges, and narratives, gamification fosters an engaging and immersive learning experience. Key findings from the analyzed data underscore several important themes:

applications across different educational settings; the impact on learning outcomes; advancements in technology; and the challenges and prospects of gamification in education (Costa, 2025).

Publication trends in the analyzed data show that there has been a consistent increase in publications each year, especially after 2018. This surge is in line with the growing interest in technology-based learning and the gamification approach in education. The majority of research focuses on STEM learning, with themes such as physics, biology, and ecology often used as contexts for applying gamification (Hol, 2018; Morey et al., 2017). Although in the early period, research tended to explore gamification in simple forms, such as point-based quizzes, in recent years, there has been an integration of technologies such as AR, VR, and 3D simulations to create more immersive and interactive learning experiences (Bogusevschi & Muntean, 2020; El Mawas et al., 2020).

Key authors in this field include Papadakis, S., Kalogiannakis, M., and Zourmpakis, A.I., from Greece, whose works have been widely cited for their contributions to the theory and application of gamification. These authors have provided critical insights into designing gamification systems tailored to science education, addressing challenges such as cognitive overload and alignment of game mechanics with curriculum goals (Kalogiannakis et al., 2021; Papadakis et al., 2023; Zourmpakis et al., 2023). The results indicate a significant increase in interest and attention from researchers, academics, and professionals in exploring gamification. Although research in this field is still evolving, the findings suggest an annual growth in writing and publications on gamification recorded in the Scopus database. This growth indicates that research and publications on gamification are increasingly in demand and have garnered considerable global attention.

Although the research dominance is still in Europe and North America, contributions from Asian and Latin American countries are emerging. This indicates the globalization of the gamification approach in the context of science learning. Previous authors have researched how gamification, especially within science and education, has developed in various contexts, including English as a Foreign Language classrooms, programming education, and broader pedagogical applications. A key differentiation in this study lies in its holistic approach in using a literature review and indexed bibliography, contrasting previous research that often focused on specific implementations or case studies; for example, earlier studies (e.g., use of "Aengime" for EFL classrooms) focused narrowly on communicative methods and their direct impact on specific learning objectives like grammar proficiency. This research synthesized and evaluated a broad spectrum of gamification approaches across disciplines and educational levels, offering a macro view rather than isolated observations.

The exploration of gamification themes reveals important focus areas and emerging trends within the realm of science education (see Figure 5). These trends mirror both the priorities and challenges faced by researchers and practitioners as they work to create effective gamification strategies. This theme distribution emphasizes the complex and varied nature of gamification in science learning. While there is notable progress in areas such as motivation, engagement, and the use of technology, it remains essential to tackle implementation issues and ensure equitable access to resources to sustain this momentum. Successful implementation of gamification demands attention to several critical challenges, including access to technology, the readiness of educators, and the need for sustained student engagement. Educators and researchers can significantly enhance the role of gamification in science education by harnessing innovative technologies, promoting interdisciplinary collaboration, and developing inclusive and ethical gamification content. Moving forward, it is vital to expand empirical research, particularly in regions and disciplines that are currently underrepresented, to unlock the full transformative potential of gamification in education.

The integration of gamification in science learning presents significant opportunities but is accompanied by several challenges that need to be addressed in Table 5. One primary concern is the pedagogical design of gamification elements. The complexity of scientific concepts makes it difficult to design engaging and educationally sound gamified activities (Almanza-Arjona et al., 2020). This underscores the importance of interdisciplinary collaboration between educators, game designers, and subject matter experts to ensure that gamification aligns with learning objectives while maintaining student engagement (Shamim et al., 2022). Another critical challenge is the technological access and infrastructure required for implementing gamified learning systems. Many under-resourced regions face limited access to the necessary technological tools, exacerbated by compatibility and maintenance issues. To address this, hybrid models that combine digital and analog gamification methods can provide more inclusive solutions, ensuring that students in diverse educational settings benefit from gamified learning (Zourmpakis et al., 2023). Student engagement is a key factor in the success of gamification. However, sustaining motivation beyond the initial novelty effect remains a challenge. Furthermore, students exhibit varying levels of prior knowledge and motivation, complicating the design of one-size-fits-all solutions. Dynamic and adaptive gamification strategies, coupled with continuous feedback mechanisms, can help personalize the learning experience and maintain engagement throughout the learning process (Zourmpakis et al., 2022). When it comes to learning outcomes, the evidence on the effectiveness of gamification in science education remains mixed. While gamification has been linked to increased motivation and participation, its impact on critical thinking, collaboration, and scientific literacy is less clear (Delgado-Algarra, 2021; Monteagudo-Fernández et al., 2021). Developing standardized metrics to measure these outcomes is essential for validating the effectiveness of gamified approaches (Ripoll et al., 2024). In addition, combining gamification with traditional teaching methods can create a balanced and holistic learning environment.

Cultural and ethical considerations are also pivotal in the design and implementation of gamification. Cultural biases in gamified content can alienate certain student groups, while data privacy concerns and excessive reliance on extrinsic rewards may have unintended consequences. Developing culturally sensitive content and ethical guidelines for gamification, including data protection measures and a focus on fostering intrinsic motivation, are necessary steps forward (Ly et al., 2024; Usachova, 2023). Teachers play a central role in the successful adoption of gamified learning, but teacher adaptation remains a challenge. Many educators lack the training or readiness to effectively integrate gamification into their science teaching practices (Jiménez-Valverde et al., 2024; Prakasha et al., 2024). Providing professional development programs and incorporating gamification training into teacher education curricula are critical for equipping educators with the skills and confidence needed to implement gamified strategies.

The existing research gaps in gamification within science education present significant challenges to fully grasp its effectiveness and potential. So far, most studies have focused on short-term outcomes, such as enhanced student motivation, increased engagement in learning activities, and overall satisfaction. However, there is a clear lack of research exploring how gamification can contribute to more sustainable learning outcomes, including a deep understanding of complex scientific concepts, the cultivation of critical thinking skills, and the enhancement of collaborative abilities. By expanding the research to encompass a variety of academic disciplines, conducting longitudinal studies, and establishing standardized metrics, we can gain a deeper understanding of how gamification can effectively promote meaningful and lasting learning experiences.

5. Conclusions

Between 2015 and 2024, the research output on gamification in science education has experienced remarkable growth. At first, the publications increased gradually, but in 2023 and 2024, there was exponential growth, with 122 and 156 publications. There is increased global interest in using gamification to improve student engagement and learning in science education. Leading contributions to the gamification literature include “Lecture Notes in Computer Science,” which has been published 46 times. The other noteworthy sources are “Communications in Computer and Information Science” and “Education Sciences,” with 19 documents each. These sources identify the relationship between computer science, education, and gamification, showing the technical side of this approach.

Leading authors include Papadakis, S., with six papers and 452 citations. Closing in are Kalogiannakis, M., and Zourmpakis, A.I., with five papers and 435 citations each. Greek authors have contributed immensely to gamification in science education. The United States is at the forefront of research with 111 publications, followed by Spain with 99 and Germany with 65. Malaysia, Portugal, and the United Kingdom each contributed 41 documents, reflecting global interest in gamification. This illustrates that North America and Europe are at the forefront of research, but Asia and Latin America are catching up, highlighting a worldwide trend for education innovation.
Major gamification research keywords in science education indicate main trends. Terms like “gamification,” “student,” “education,” “engineering education,” and “e-learning” are predominant. “Game-based learning” focuses on incorporating

gaming into learning, emphasizing gamification's aptitude for interactivity and immersive experiences. The heightened number of publications by various authors and countries reflects greater awareness of gamification as a significant learning approach. However, issues occur in the effective application and measuring its impact on learning. Additional research is needed to overcome challenges and increase knowledge of gamification's potential in education.

The literature review of gamification in science learning indicates its revolutionary promise. By incorporating game design in learning, gamification enhances student motivation, interest, and understanding of abstract scientific concepts, with the potential to take science learning to a new level. Gamification enhances motivation, engagement, and collaboration, rendering learning more interactive and productive.

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