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GAMIFICATION IN SCIENCE EDUCATION: AN OVERVIEW OF SCIENTIFIC PRODUCTION

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Abstract

Gamification in education uses game elements and principles in learning processes and is one of the most prominent active methodologies. In science teaching, gamification facilitates the construction of practical knowledge, stimulating student development and enriching the educational process. Given the limited literature on integrating gamification into science teaching, this study aimed to map scientific production and identify emerging trends and themes. To this end, a bibliometric analysis of 316 articles published between 2007 and 2023, extracted from the Scopus and Web of Science databases, was carried out. The results revealed the evolution of scientific production, with a significant increase in publications since 2018. Undergraduate and gamification were areas of growing interest. The USA and China lead scientific production and international collaboration. In addition, the most relevant journals were the Journal of Chemical Education, Education Sciences, and the Journal of Science Education and Technology. The study highlights the need for comprehensive applied research to deepen the integration of gamification and science teaching.

Keywords: Gamification; Science Education; Bibliometrics.

GAMIFICAÇÃO NO ENSINO DE CIÊNCIAS: UM OLHAR SOBRE A PRODUÇÃO CIENTÍFICA

Resumo

A gamificação na educação utiliza elementos e princípios de jogos em processos de aprendizagem e é uma das metodologias ativas de maior destaque. No ensino de Ciências, a gamificação facilita a construção de conhecimento prático, estimulando o desenvolvimento do aluno e enriquecendo o processo educacional. Considerando que a literatura sobre a integração da gamificação

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no ensino de Ciências ainda é bastante limitada, este estudo teve como objetivo mapear a produção científica, identificando tendências e temas emergentes. Para isso, realizou-se uma análise bibliométrica de 316 artigos publicados entre 2007 e 2023, extraídos das bases de dados Scopus e Web of Science. Os resultados revelaram a evolução da produção científica, com um aumento significativo nas publicações a partir de 2018. Tópicos como graduação e gamificação foram identificados como áreas de interesse crescente. Estados Unidos e a China lideram a produção científica e a colaboração internacional, enquanto os periódicos mais relevantes foram Journal of Chemical Education, Education Sciences e Journal of Science Education and Technology. O estudo ressalta a necessidade de pesquisas aplicadas abrangentes que aprofundem a integração entre a gamificação e o ensino de Ciências.

Palavras-chave: Gamificação; Ensino de Ciências; Bibliometria.

GAMIFICACIÓN EN LA ENSEÑANZA DE CIENCIAS: UNA MIRADA A LA PRODUCCIÓN CIENTÍFICA

Resumen

La gamificación en la educación incorpora elementos y principios de los juegos en los procesos de aprendizaje y se ha consolidado como una de las metodologías activas más destacadas. En la enseñanza de las ciencias, la gamificación favorece la construcción de conocimientos prácticos, estimula el desarrollo del estudiantado y enriquece el proceso formativo. Dado que la literatura sobre la integración de la gamificación en este campo aún es limitada, este estudio tuvo como objetivo mapear la producción científica e identificar tendencias y temas emergentes. Para ello, se realizó un análisis bibliométrico de 316 artículos publicados entre 2007 y 2023, recuperados de las bases de datos Scopus y Web of Science. Los resultados evidenciaron la evolución de la producción científica, con un aumento significativo de publicaciones a partir de 2018. Se identificaron temas como los estudios de pregrado y la gamificación como áreas de interés creciente. Estados Unidos y China lideran la producción científica y la colaboración internacional, mientras que las revistas más influyentes fueron Journal of Chemical Education, Education Sciences y Journal of Science Education and Technology. El estudio resalta la necesidad de investigaciones aplicadas más integrales que profundicen en la relación entre la gamificación y la enseñanza de las ciencias.

Palabras clave: Gamificación; Enseñanza de las Ciencias; Bibliometría.

1. Introduction

Science is a complex subject because it encompasses areas such as Biology, Chemistry, Physics, and Astronomy, and addresses multiple subjects simultaneously. This characteristic can make it difficult for students to assimilate their knowledge, thereby complicating the teaching and learning process. (Sant'anna *et al*., 2015). To make this process more accessible, active methodologies were integrated into the school environment, transforming traditional teaching into a dynamic, playful approach that encourages students' active participation (Parra-Gonzalez *et al*., 2020).

Active methodologies are essential to improving science teaching, as they facilitate the construction of practical knowledge, promote student development, and enrich the educational process by stimulating autonomy (Darling-Hammond *et al*., 2020). Integrating tools and technologies into these methodologies has also modernized teaching, encouraging the adoption of techniques better suited to students' needs (Andrade *et al*., 2019).

Active methodologies correspond to a variety of teaching strategies. Currently, some methods are well known: Problem-Based Learning, Project-Based Learning, Peer Instruction, Writing Across the Curriculum (WAC), gamification, and flipped classrooms (Hübner; Modesto, 2020).

These strategies offer alternatives for engaging, dynamic teaching and for exploring new ways to construct knowledge. Gamification is one of these strategies (Kalogiannakis, Papadakis, Zourmpakis, 2021) and has gained relevant space in the academic environment (Frazão, Nakamoto, 2020).

Gamification in education involves integrating elements of mechanics, aesthetics, and cognitive and behavioral aspects of games into non-playful educational content. This approach seeks to engage and motivate students in challenging situations and improve the learning experience (Zourmpakis, Kalogiannakis, Papadakis, 2023; Neto, Penteado, Carvalho,2023). Digital and manual games use graphic elements to stimulate engagement and maintain focus on the activity, impacting individual teaching and learning (Malagueta, Nazário, Cavalcante, 2023). The growing cultural presence of games has increased academic interest in game-inspired learning strategies, particularly gamification. (Zourmpakis; Kalogiannakis; Papadakis, 2023).

In science education, gamification stands out as an innovative approach that integrates game elements into the educational context to increase active student participation and improve learning effectiveness (Deterding *et al*., 2011).

Recently, interest and research on gamification as an educational strategy has grown significantly (Anderson; Dill, 2013). Despite this, there is still a need to expand knowledge of scientific production in the area, making quantitative analysis essential for a better understanding of the current panorama. This analysis can reveal trends, relevant topics, and research gaps. This study aims to analyze, quantitatively, the scientific production on gamification in science education. The research examines the number of published studies, the leading journals, the countries involved, and the directions of the investigations.

2. Gamification in Science Education

In recent years, researchers have become interested in gamification, particularly in science, which is often associated with negative emotions and complex knowledge. Learning strategies based on game elements can motivate students to learn science.

Promoting science education is essential for society's progress and individuals' development. Scientific literacy enables us to understand and appreciate the world's complexities and supports evidence-based decision-making. These benefits extend to individuals, regardless of their future involvement in science and technology (Zourmpakis; Kalogiannakis; Papadakis, 2023).

Gamification in science education has emerged as a promising approach to increase student engagement and improve learning outcomes. By integrating game elements into educational contexts, educators seek to increase motivation and promote a deeper understanding of scientific concepts (Kalogiannakis; Papadakis; Zourmpakis, 2021). One example is interactive digital learning platforms that offer game-like experiences in which students can engage with scientific topics, virtual laboratories, simulation games, and interactive quizzes (Khattib; Alt, 2024).

Gamification should incorporate a set of challenges into the proposed activities. This result indicates that the challenge in gamification involves defining an objective task whose difficulty increases progressively, testing the individual's skills, and encouraging motivation to complete the activity (Khattib; Alt, 2024).

This approach offers numerous benefits, such as increased motivation and engagement in learning, better educational outcomes, the development of positive attitudes towards studying, more attractive and accessible education, improvement of skills such as critical thinking and understanding of scientific concepts, and more active participation of students in activities (Alahmari *et al*., 2023). According to Khattib and Alt (2024), integrating digital games into science classes increases students' perceptions of achievement, challenge, playfulness, immersion, and motivation.

However, implementing gamification presents significant challenges, including short-term effects on effectiveness, difficulties accessing the internet and technological equipment, the need for students to have technological skills, and the lack of resources and training among teachers (Alahmari *et al*., 2023).

Gamification in science education offers a promising approach to increasing student engagement and learning outcomes. However, its successful implementation requires overcoming several challenges and further research to optimize its use in diverse educational settings. As educators continue to explore this innovative strategy, it has the potential to transform science education, making it more interactive and engaging for students (Rivera; Garden, 2021).

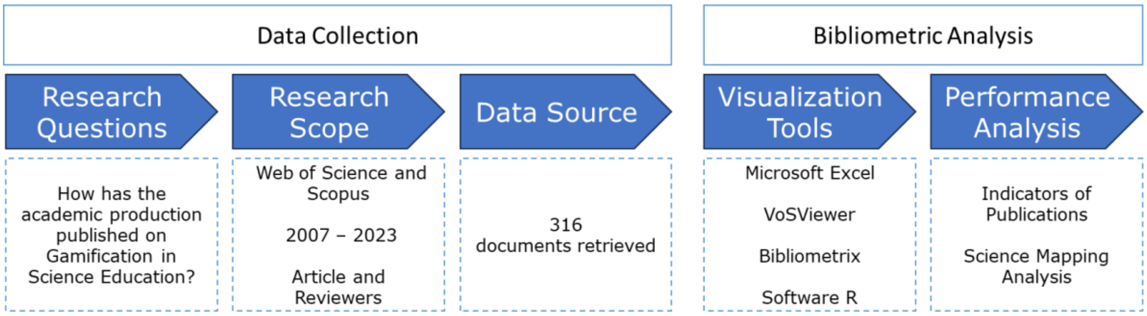
3. Methodology

This study is a quantitative, exploratory, and descriptive research. The methodological procedures employed aimed to evaluate the scientific production of learning through gamification in science teaching. The searches were conducted on March 25, 2024, in the Scopus and Web of Science databases, using the following Boolean expressions applied to the title, abstract, and keywords fields.

The defined time period was 2007-2023, when publications on gamification in education began to emerge and consolidate. It was decided not to apply a specific time frame to the search to encompass all scientific production available in the consulted databases and to obtain a comprehensive view of the evolution of publications on the subject.

The authors applied the search term to the title, abstract, and keyword fields. They then excluded documents such as conference papers, book chapters, abstracts, and editorials, keeping only "articles" and "review articles."

Figure 1 – Methodological workflow of the study.



Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

This first step yielded 181 documents in Web of Science and 274 in Scopus, with 136 duplicates across the databases. Three papers were identified in the databases; however, their metadata could not be retrieved, so they were excluded from the analysis.

We selected documents that (i) addressed gamification in science teaching (Biology, Chemistry, Physics, or Astronomy); (ii) took place in formal education at the primary, secondary, or higher levels; and (iii) presented empirical or theoretical research, such as experimental interventions, quasi-experiments, case studies, or conceptual articles.

After the search, the researchers selected the documents using the established filters, resulting in 316 results. Finally, they performed a bibliometric analysis to quantify the data with a statistical tool and refine the theme (Pimenta, 2017).

For transparency and reproducibility, the following data are presented:

- Search string: TS=("game-based learning" OR "gamification" OR "gamified education" OR "reality gamification") AND TS=("Chemistry Education" OR "Physics Education" OR "Biology Education" OR "scientific education" OR "science teaching" OR "teaching of science" OR "science education" OR "chemistry" OR "physics" OR "biology" OR "astronomy" OR "natural sciences") NOT PY=(2024 OR 2025 OR 2026) NOT DT=("Proceedings Paper" OR "Book Chapter" OR "Meeting Abstract" OR "Early Access" OR "Retracted Publication" OR "Editorial Material")
- TITLE-ABS-KEY("game-based learning" OR "gamification" OR "gamified education" OR "reality gamification") AND TITLE-ABS-KEY("Chemistry Education" OR "Physics Education" OR "Biology Education" OR "scientific education" OR "science teaching" OR "teaching of science" OR "science education" OR "chemistry" OR "physics" OR "biology" OR "astronomy" OR "natural sciences")) AND PUBYEAR > 2006 AND PUBYEAR < 2024 AND (DOCTYPE(ar) OR DOCTYPE(re))

- Applied Bibliometrix parameters.

To generate the co-occurrence networks, thematic map, and keyword analyses, we used the Bibliometrix package with the following parameters:

  - Minimum frequency: 2 occurrences for inclusion in the network
  - Stemming: enabled, using the Porter algorithm
  - Normalization method: Salton's cosine
  - k-core selection: 3, to ensure the retention of well-connected nodes
  - Edge weighting: association strength
  - Keyword field: Authors' Keywords (DE)
  - Counting method: complete counting for keyword occurrences

These parameters follow the recommended practices for constructing bibliometric networks with Bibliometrix.

- Script for the Bibliometrix package

```
WoS <- "savedrecs.bib"

Scopus <- "scopus.bib"

WoS_df <- convert2df( WoS, dbsource = "wos", format = "bibtex" )

Scopus_df <- convert2df( Scopus, dbsource = "scopus",  format = "bibtex" )

M <- mergeDbSources( WoS_df, Scopus_df, remove.duplicated = TRUE ) biblioshiny().
```

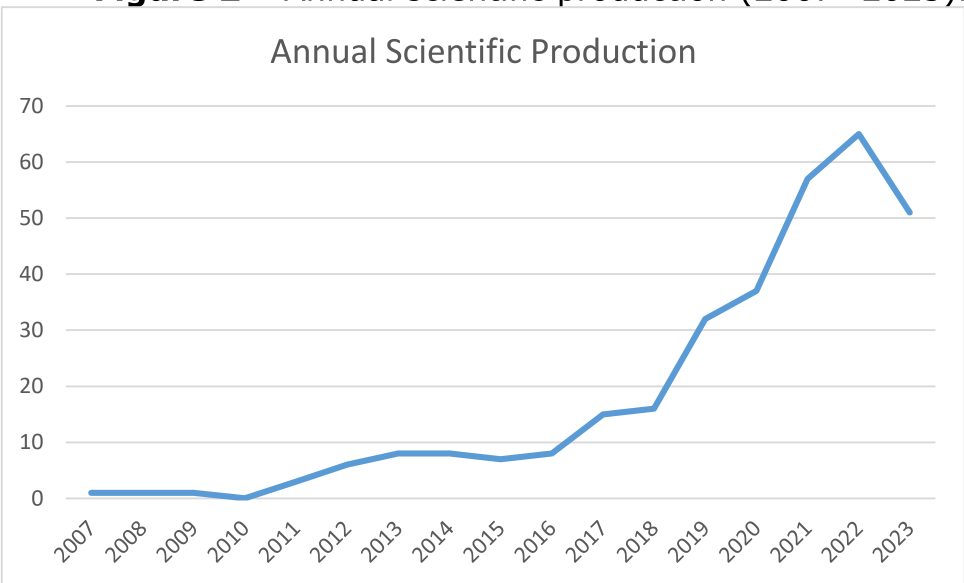
4. Results and Discussion

4.1. Evolution of Scientific Production

The researchers analyzed scientific literature on gamified learning in science teaching from 2007 to 2023. Figure 2 illustrates the evolution of this production in the Web of Science and Scopus databases. Between 2007 and 2010, growth was incipient. From 2011 onwards, the number of publications increased annually, except in 2015 and 2023, which saw slight reductions. In the period analyzed, the average growth rate of publications was 18.22%, calculated as the arithmetic mean of the year-to-year percentage changes in publication volume from 2007 to 2023.

It is essential to highlight that gamification, or the use of game design elements outside the context of the game, was first introduced by the British Nick Pelling in 2002. However, the concept only gained popularity in 2010 at the Design, Innovate, Communicate, Entertain Conference (Hebebci; Alan, 2021). Therefore, it is understandable that the topic was very little explored until 2010.

Figure 2 – Annual scientific production (2007- 2023).



Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

Figure 2 shows that 2022 had the highest number of publications, with 65 documents, representing 21% of the total analyzed. Between 2019 and 2022, there was a significant increase, with 191 publications corresponding to 60.4% of the dataset. This growth coincided with increasing exploration of alternative instructional approaches and new forms of interaction and engagement (Burlacu, Coman, Bularca, 2023). While this overlap suggests contextual influences from expanding technology-mediated teaching, causal relationships cannot be inferred.

Article citations reflect the prestige of publications and indicate the dissemination of scientific knowledge, functioning as a map of scientific communication (Vanz; Caregnato, 2003). Between 2007 and 2023, the annual average was 58.4 citations. This value was obtained by arithmetic averaging of the total citations. In 2007, 2009, and 2013, the highest numbers of citations were recorded, with 368, 168, and 166 documents cited, respectively.

4.2. Thematic Analysis

The study generated a word cloud of the 50 most recurrent terms (Figure 3) to highlight the central terms in the analyzed articles. The size of the words reflects their frequency in the selected documents. Terms such as *gamification, game-based learning, science education, and digital game-based learning* are strongly related to the topic and appear to be the most frequent. The figure demonstrates coherence with the topic studied by highlighting the terms used in the searches and those that summarize the object of study.

Figure 3 – Keyword clouds used in published articles.

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

The authors used a TreeMap to visualize the keywords in the document set, a fundamental tool for identifying the most relevant terms. This approach highlights the most explored topics and identifies areas that require further study. Figure 4 shows the TreeMap with the most frequent terms occupying a prominent position. The size of the box represents the frequency and relevance of the terms. Among the most relevant are gamification (16% of occurrences), game-based learning (14%), and science education (6%).

These terms can be organized into clusters of a co-occurrence network. Table 1 presents the identified groups: student engagement, gamification, interactive learning environments, second-year undergraduate, undergraduate, and exothermic and endothermic reactions.

This thematic analysis highlights key topics in academic publications, providing a comprehensive understanding of the study's scope and identifying trends and priority research areas.

Figure 4 – World TreeMap highlighting authors' Keywords.

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

Table 1 allows us to assess relevance (centrality) and level of development (density). Callon Centrality measures the level of interaction with other networks, while Callon Density provides the internal strength of a network, representing the sum of connections between keywords of a topic (Handoyo, 2024). The combination of this information allows us to categorize issues into basic, motor, emerging, and niche, each contributing to the research domain's structure, growth, and configuration (Catone, 2023).

Table 1 - Thematic Terms.

Cluster	Callon centrality	Callon density	Rank centrality	Rank density	Cluster frequency
student engagement	0.20547619	41.7989418	4	4	42
gamification	0.90410685	21.58786238	6	1	521
interactive learning environments	0.023809524	46.80952381	2	5	21
second-year undergraduate	0.888555294	38.51428982	5	3	81
undergraduate	0.09	31.0625	3	2	18

exothermic and endothermic reactions	0	75	1	6	4

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

Callon centrality: measures the degree of interaction of a network with other networks.

Callon density: a measure of the network's internal strength as a proxy for development.

Rank centrality: measures the importance of a node based on the number of incoming links from other nodes.

Rank density: measures the importance of a node based on the number of links it has with other nodes.

Motor themes have high centrality and density, connecting to other topics beyond the cluster, which amplifies their density and impact. Driving themes play a central role in the structure of a research field, identifying the most active and influential areas (Catone, 2023). Basic themes, in turn, are general, highly central, and low-density, representing fundamental areas of research (Shi *et al*., 2018). The density values are the main difference between driving and basic themes (Bansal *et al*., 2024). Emerging themes have low density and centrality (Zhou *et al*., 2019), indicating initial development and limited current relevance, but with potential for future impact (Bansal *et al*., 2024). These topics suggest possible directions for new research. Niche themes, on the other hand, have high density and low centrality, with well-developed internal ties but few external connections. They represent isolated and highly specialized areas with no possibility of generalization (Catone, 2023; Bansal *et al*., 2024). Together, these four quadrants provide a strategic view of the area, allowing for the identification of consolidated areas, emerging opportunities, and specialized lines of research (Cantorani; Oliveira, 2024).

The analysis of thematic clustering (Table 1) shows that second-year undergraduate (Callon centrality = 0.89; density = 38.51) functions as a motor theme, combining high centrality and high density. In addition, gamification (centrality = 0.90; density = 21.59) can be considered a basic/motor theme because it presents strong connections with other topics and has a structural role in the area. In contrast, student engagement (centrality = 0.21; density = 41.80) and interactive learning environments (centrality = 0.02; density = 46.81) have low centrality and high density and are considered niche themes. Furthermore, undergraduate (centrality = 0.09; density = 31.06) appears as an emerging or declining theme. Finally, exothermic and endothermic reactions (centrality = 0; density = 75) represent a highly specialized niche theme within chemistry education.

Gamification (a basic theme) has shown positive effects, including improved performance and increased participation in the classroom and on discussion forums. In addition, gains in motivation to perform more complex and challenging activities and in the quality of the artifacts produced were observed (Bouchrika *et al*., 2019). Introducing game mechanics such as badges, levels, and scores reinforces this positive effect. Although gamification is considered a basic theme, a highly connected yet still not fully developed topic, authors report a lack of robust empirical evidence on its effectiveness in motivating learning compared to traditional methods, reinforcing the need for more rigorous studies (Rivera and Garden, 2021; Bouchrika *et al*., 2019).

Gamification, a basic term in this field, is an alternative to traditional learning that promotes an active approach. Using games or game elements improves educational outcomes by providing more engaging learning experiences, developing cognitive skills, decision-making capacity, and problem-solving skills, and fostering cooperation in teaching (Zohari *et al*., 2022). Furthermore, these benefits have practical applications; such games can be used across different areas and levels of education, from basic to higher education, as supported by research with undergraduate students.

The second-year undergraduate cluster emerges as a central theme, combining high centrality and density, which indicates its structural role in the area. In exploring this theme, research shifts to consider the implementation of active learning strategies, including gamification, specifically at a stage of higher education where students have already surpassed introductory content and are ready for more complex and application-oriented activities (Sharunova *et al*., 2018; Mitchell; Danino; May, 2013; De Marcos *et al*., 2014). Therefore, the second-year undergraduate context serves as a privileged environment for testing and refining gamified methodologies, which explains its central and well-developed position on the thematic map.

In the thematic map, student engagement and interactive learning environments appear as a niche theme with high density and low centrality. This means they are well-developed but interact little with other themes, forming a cohesive yet isolated area within the field. Engagement relies on the quality of the learning environment, while interactive environments often promote active participation. Studies show that gamified or interactive environments increase student motivation, engagement, and persistence (Zainuddin *et al*., 2020). These environments create immersive experiences and strengthen behavioral, cognitive, and emotional engagement, which are key for meaningful learning and skills development (Huang, Hew; Lo, 2019; Özhan *et al*., 2020).

Exothermic and endothermic reactions appear as highly specialized niche topics, characterized by high density and minimal connectivity with other groupings on the thematic map. While these chemistry concepts are often challenging, they are frequently explored through educational games that actively engage students and support the learning of abstract or complex content (Behram; İlham, 2024). Building on this engagement strategy, Naumoska, Dimeski, and Stojanovska (2023) implemented an Escape Room approach to teach these reactions, promoting greater engagement, discussion, and cooperation among students and making chemistry learning more attractive.

These topics reveal research gaps and trends. The groupings offer a clear overview of the field, showing established areas, new opportunities, and niche investigations. This framework shows how research on gamification in science education has changed and where future work can have the most impact.

4.3. Main Sources

To identify the primary sources of research on the topic, a list of the journals with the most publications was drawn up (Table 2). The Journal of Chemical Education leads with 31 articles, followed by Education Sciences (14 publications) and the Journal of Science Education and Technology (13 documents). The Journal of Chemical Education, published by ACS, focuses on advances in chemistry teaching and educational research (ACS Publications, 2024). Education Sciences, from MDPI, is an international, open-access journal focused on academic issues (MDPI, 2024). The Journal of Science Education and Technology, from SpringerLink, addresses science education and educational technology (SpringerLink, 2024).

Table 2 - Journals with the most publications in the period.

Journals	Articles	JCR 2023	SJR 2023
Journal of Chemical Education	31	2.5	0.54
Education Sciences	14	2.5	0.67
Journal of Science Education and Technology	13	3.3	1.6
Computers & Education	11	8.9	3.65
Frontiers in Psychology	5	2.6	0.8
American Biology Teacher	4	0.3	0.23
Computers	4	2.6	0.62
Computers in Human Behavior	4	2.91	2.64
Educational Tech. Research And Development	4	3.3	1.71
Frontiers in Education	4	1.9	0.63
Interactive Learning Environments	4	3.7	1.31
International Journal of Emerging Technologies in Learning	4	1.13	0
International Journal of Game-based Learning	4	1.4	0.37
Journal of Biological Education	4	1.0	0.44
Physics Education	4	-	0.39

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

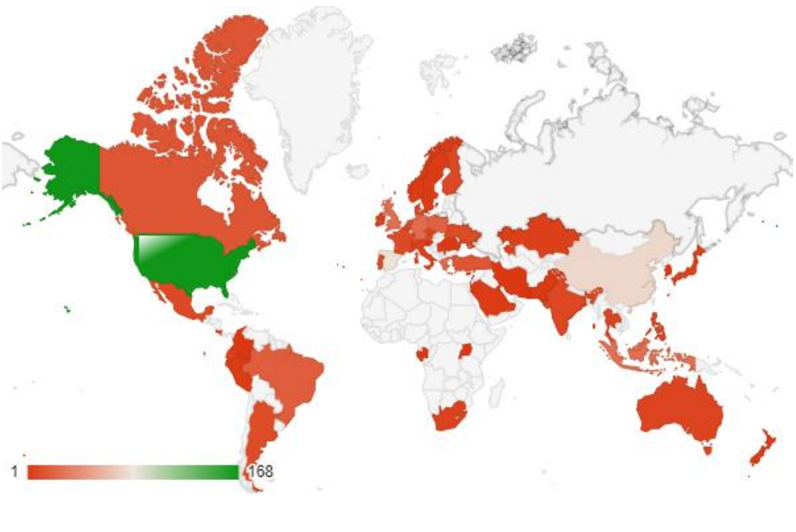
The most frequent journal is directly related to the area of Chemistry, reflecting the predominance of research on gamification in Science. This area may be experiencing a more robust development of gamification-based teaching strategies. However, to consolidate these findings, future studies must follow the evolution of research in this area. This trend can be explained by the nature of Chemistry, which involves the study of the structure, properties, and transformations of matter, requiring scientific reasoning to solve problems at different levels of education (Yulian *et al*., 2023).

4.4. Scientific Production by Country

The research identified publications on gamification in science in 58 countries during the analyzed period. Figure 5 highlights the ten countries with the most selected productions. Three countries stand out, especially the United States, Spain, and China. It can be observed that the country frequencies shown in Figure 5 were obtained using the full-count method, in which each country listed among the authors received full credit for publication. Therefore, the total number of counts exceeds the number of unique documents.

The United States leads scientific production on gamification, with 22.08% of publications, followed by Spain (11.43%) and China (10.12%). This leadership can be attributed to the consolidated use of gamification in the country, where the concept originated, gained popularity, and was widely adopted in education (Groh, 2012; Rocha *et al*., 2022). Another fact is the enthusiasm of North American students for digital games, which supports interest in their educational applications (Yunyongying, 2014). In addition, the use of game-based learning reflects an effort to engage students who are unmotivated by traditional education and the ease of use of technologies by digital natives (Wiggins, 2016).

Figure 5 – Production by Country (2007- 2023).



Country	Freq
USA	168
Spain	87
China	77
Indonesia	27
UK	27
Germany	26
Greece	26
Malaysia	25
Poland	21
Brazil	19

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

In China, the integration of games into teaching has historical roots dating back to the Song Dynasty, when schools already considered children's interests (Fang, 2023). This approach is reaffirmed in actions such as those of educator Chen Heqin, who founded a research center on Early Childhood Education and integrates games into teaching activities, believing that this approach benefits children's development (Fang, 2023). Likewise, educator Hu Shuyi encourages the use of games in the educational process (Fang, 2023). This historical legacy has driven the consolidation of games in teaching, positively impacting child development (Fang, 2023).

In Spain, educational reforms have been implemented to improve the education system (Mayorga-Fernández *et al*., 2024). In 2020, the government approved the Organic Law to Modify the Organic Law of Education (LOMLOE) to make the system more inclusive and flexible. This legislation addresses current educational challenges, highlighting the importance of personalized, inclusive education adapted to the world's constant transformations. Among its guidelines, LOMLOE encourages active methodologies, such as gamification, that significantly contribute to educational innovation.

Brazil is the 10th most productive country in gamification. Data show that interest in this topic has increased among Brazilian researchers (Pimentel; Francisco; Ferreira, 2021).

In addition to examining countries' scientific output, it is essential to assess the relevance of publications. Analyzing citations of works from the most productive countries allows us to measure the relationship between productivity and recognition, reflected in the number of citations (Table 3).

Table 3 – Citations by country.

Countries	TC
China	2036
USA	1481
Spain	435
Greece	357
Malaysia	175
Pakistan	115
Germany	104
Finland	81
Turkey	78
UK	76

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

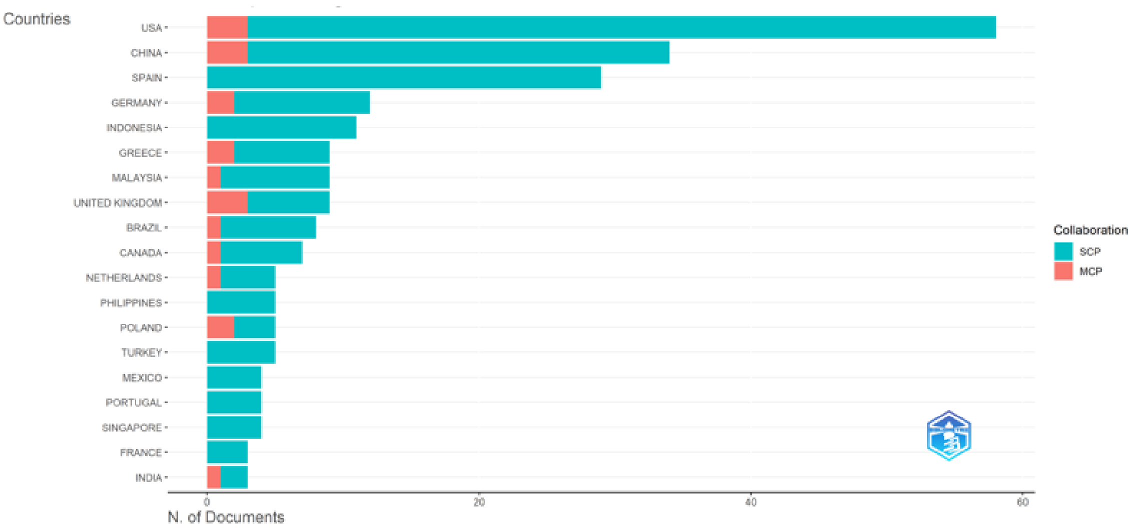
Despite being among the most productive countries, Indonesia (41 citations), Poland (25 citations), and Brazil (35 citations) are not among the countries with the highest numbers of cited articles. On the other hand, Pakistan (2 articles), Finland (9 articles), and Turkey (15 articles), which do not appear on the list of the most productive, stand out for their high citation counts. In addition, it is essential to note the average number of citations per document. Works published in Pakistan have a remarkable average of 57.5 citations per document, followed by Finland (9) and Turkey (5.2).

4.5. Scientific Collaboration

The analysis of scientific collaboration between countries reveals that the United States, a leader in the number of publications, maintains frequent partnerships with developed countries, especially China, and with European countries such as Germany, Finland, Romania, the United Kingdom, and Switzerland (Figure 6).

Researchers value scientific collaboration because it drives research development. However, some countries, such as Spain, Indonesia, the Philippines, Turkey, Mexico, Portugal, Singapore, and France, have exclusively national publications (Figure 6), characterizing Single Country Production (SCP), that is, works authored solely by authors from the same country. On the other hand, countries such as the United States, China, Germany, Greece, Malaysia, and the United Kingdom produce documents in international collaboration, defined as Multiple Country Production (MCP). This international collaboration strengthens scientific production, facilitates understanding of global trends, and promotes the dissemination of knowledge between countries.

Figure 6 – Scientific Collaboration between Countries.



Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

Table 4 presents the number of articles, the national SCP production, the international MCP production, the total publication frequency, and the proportion of collaborations (MCP ratio), calculated by dividing the MCP documents by the total number of articles (SCP + MCP).

Table 4 – Publications and collaboration metrics by country.

Country	Number of articles	Frequency	SCP	MCP	MCP rate
USA	58	0.184	55	3	0.052
CHINA	34	0.108	31	3	0.088
SPAIN	29	0.092	29	0	0
GERMANY	12	0.038	10	2	0.167
INDONESIA	11	0.035	11	0	0
GREECE	9	0.028	7	2	0.222
MALAYSIA	9	0.028	8	1	0.111
UNITED KINGDOM	9	0.028	6	3	0.333
BRAZIL	8	0.025	7	1	0.125
CANADA	7	0.022	6	1	0.143
NETHERLANDS	5	0.016	4	1	0.2
PHILIPPINES	5	0.016	5	0	0
POLAND	5	0.016	3	2	0.4
TURKEY	5	0.016	5	0	0
MEXICO	4	0.013	4	0	0
PORTUGAL	4	0.013	4	0	0
SINGAPORE	4	0.013	4	0	0
FRANCE	3	0.009	3	0	0
INDIA	3	0.009	2	1	0.333
IRELAND	3	0.009	3	0	0
ITALY	3	0.009	3	0	0
MACEDONIA	3	0.009	3	0	0
SERBIA	3	0.009	3	0	0
THAILAND	3	0.009	3	0	0
UKRAINE	3	0.009	2	1	0.333
AUSTRALIA	2	0.006	2	0	0
AUSTRIA	2	0.006	2	0	0

BELGIUM	2	0.006	2	0	0
CYPRUS	2	0.006	2	0	0
ISRAEL	2	0.006	2	0	0
KOREA	2	0.006	2	0	0
PAKISTAN	2	0.006	2	0	0
SOUTH AFRICA	2	0.006	2	0	0
SWITZERLAND	2	0.006	1	1	0.5
ARGENTINA	1	0.003	1	0	0
CZECH REPUBLIC	1	0.003	1	0	0
DENMARK	1	0.003	1	0	0
ECUADOR	1	0.003	1	0	0
FINLAND	1	0.003	0	1	1
HONG KONG	1	0.003	1	0	0
JAPAN	1	0.003	0	1	1
JORDAN	1	0.003	0	1	1
KAZAKHSTAN	1	0.003	1	0	0
KUWAIT	1	0.003	0	1	1
LITHUANIA	1	0.003	1	0	0
NEW ZEALAND	1	0.003	0	1	1
NORWAY	1	0.003	1	0	0
PERU	1	0.003	1	0	0
RWANDA	1	0.003	0	1	1
SAUDI ARABIA	1	0.003	1	0	0
SWEDEN	1	0.003	1	0	0

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

The collaboration indicators in Table 4 were based on the corresponding author counting approach, which avoids duplication and better represents international co-authorship patterns. The analysis of the corresponding authors (Figure 6 and Table 4) reveals that most researchers on the topic are from the United States (58 articles, 55 SCP, and 3 MCP), followed by China (34 articles, 31 SCP, and 3 MCP) and Spain (29 articles, 29 SCP, and 0 MCP). These countries lead scientific production (USA: 20.9%, China: 12.3%, and Spain: 10.5%). However, the United Kingdom surpasses Spain in the number of absolute international collaborations (MCP). The United States and China rank first and second in publications and scientific collaborations. An MCP rate above 50%

indicates more robust collaborations, which bring benefits such as infrastructure and knowledge sharing (Dusdal; Powell, 2021).

An MCP rate above 50% indicates more robust collaborations, with benefits such as infrastructure and knowledge sharing (Cantorani *et al*., 2025). It would be interesting for countries to maintain rates above 50% when analyzing the MCP proportion. However, this differs among the most productive countries (Table 3). Some countries have high rates but with only one publication, carried out in partnership, such as Finland, Japan, Jordan, Kuwait, New Zealand, and Rwanda, making the result unrepresentative.

4.6. Quantitative Synthesis of Benefits and Challenges

Complementing the thematic analysis, the textual counts in the abstracts reveal quantitative patterns in the benefits and barriers related to gamification. These data, derived directly from the corpus, highlight the predominance of gains in motivation and engagement (n=145 and 85, respectively), while barriers such as implementation challenges (n=76) indicate areas that are still underexplored. Tables 4 and 5 summarize these trends based on counts (n), predominant educational levels, and high-frequency themes, complementing the thematic map. Regarding the distinction between short- and long-term effects, the still-limited number of studies underscores the magnitude of the data gap and reinforces the need for longitudinal studies.

Table 5 – Reported Benefits of Gamification for Science Education.

Benefit	Evidence (term or theme)	Number of Studies (n)	Predominant Educational Level
Motivation	"motivation", "motivational"	145	Higher education (undergraduate: ~28 mentions)
Engagement	"engagement", "involvement"	85	Higher and secondary education (high school: ~44)
Performance / Achievement	"performance", "achievement"	127 (86 + 41)	Higher education (university: ~35)
Critical Thinking	"critical thinking", "problem solving"	12	Secondary and higher education
Short-Term Effects	"immediate", "initial", "brief"	16	Mixed (K–12 and higher education)
Long-Term Effects / Retention	"long-term", "retention", "sustained"	16 (3 + 12 + 1)	Higher education (graduate/undergraduate)

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

(total n = 316 articles; counts in column AB – abstracts)

Table 6 – Reported Barriers to the Implementation of Gamification.

Barrier	Evidence (term or theme)	Number of Studies (n)	Predominant Educational Level
Infrastructure / Access	"access", "internet", "device"	20	Primary and secondary education (~58 mentions)
Teacher Training	"training", "teacher preparation"	36	All levels
Implementation Challenges	"challenges", "difficulties", "limitations"	76 (34 + 9 + 33)	Higher and secondary education
Lack of Resources	"resources", "funding", "time"	20	Secondary and primary education
Short-Term Effects that Fade	"temporary effect", implied in "limitations"	~10	Higher education (undergraduate)

Source: Own elaboration in the R environment using RStudio 2024.12.0+467 and the Bibliometrix package (version 4.3.2), along with Microsoft Excel 2016.

(total n = 316 articles; counts in column AB – abstracts)

Gamification is widely associated with gains in motivation (n = 145) and engagement (n = 85), particularly in higher education. Long-term effects (n = 16) and infrastructure barriers (n = 20) remain underexplored, suggesting gaps for future applied research.

5. Conclusion

This study analyzed publications on gamification in science teaching using bibliometrics, revealing that this approach emerged in 2007 and intensified further between 2019 and 2022. The analysis showed that, from 2019 onwards, there was significant growth in research and the adoption of active methodologies, indicating that educators are seeking new strategies to improve teaching and learning, and that gamification is prominent in this context.

The study analyzed trends and gaps in scientific research on gamification. The results indicate increased production and consolidation of central themes such as second-year undergraduate and gamification. Emerging topics, such as undergraduate studies, were also identified. These findings show that this topic remains underexplored and that understanding the relationship between gamification and second-year undergraduate students can benefit learning. A deeper understanding of how gamification strategies influence the engagement and learning of students with low levels of teaching could strengthen future research. In addition, the need to expand this approach in higher education is highlighted. The terms analyzed offered more precise insights into advances and declines in areas of knowledge.

The main academic advances are taking place in the United States of America, which leads scientific production on the topic. Although the term *gamification* was initially coined by the British designer Nick Pelling in 2002 (UK), the United States has played a central role in popularizing the concept and consolidating research in the field. The United States has also established relevant partnerships with China and European countries. Although China is not the country with the most publications, it stands out as the one with the highest average citations per document, at 26.44. In contrast, the United States, which leads in productivity, averages only 8.81 citations per document.

The journals with the highest number of publications on the subject – Journal of Chemical Education, Education Sciences, and Journal of Science Education and Technology, underscore the positive role of gamification in Chemistry education. The gamification can effectively enhance student engagement and learning outcomes in Chemistry by promoting critical thinking, problem-solving, collaboration, and academic performance.

Studies on gamification primarily focus on short-term outcomes, such as gains in motivation and engagement, particularly in higher education. The limited number of studies on long-term effects and infrastructural barriers highlights gaps for future applied research. Furthermore, for future research, it is recommended that in-depth studies be conducted on the evolution of the most researched topics in gamification, as well as on those that have shown a decline in interest.

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