Article

Gamification and Eco-Literacy: A Bibliometric Analysis of Research Trends

Paola Julie Aguilar-Cruz[1] and Esther Julia Olaya-Marín[2]

[1]*Facultad de Educación, Doctorado en Educación y Cultura Ambiental, Universidad de la Amazonia, Florencia, Colombia;* [2]*Facultad de Educación, Doctorado en Educación y Cultura Ambiental, Universidad de la Amazonia, Florencia, Colombia*
paolaaguilarcruz@gmail.com; es.olaya@udla.edu.co

Abstract

Environmental challenges demand innovative educational approaches to foster eco-literacy. Gamification, the use of game design elements in non-game contexts, has gained attention as a strategy to enhance engagement and learning. However, its role in eco-literacy education remains underexplored. The purpose of our bibliometric analysis is to investigate research trends, key contributions, and thematic developments in the application of gamification for promoting eco-literacy from 2018 to 2024. Drawing on data from the Scopus database, we addressed five key questions: What are the main research trends? How is gamification integrated into eco-literacy education? Who are the main contributors? What are the dominant themes? And what research gaps remain? Using bibliometric techniques, we mapped the scientific landscape of this interdisciplinary field. The findings reveal a growing academic interest in the topic, with an increasing number of publications and the emergence of dominant themes such as sustainability education, serious games, and digital learning tools. However, the results also highlight gaps in empirical studies assessing the effectiveness of gamification in enhancing eco-literacy outcomes. These insights contribute to a better understanding of how gamification can be implemented to strengthen eco-literacy and provide a foundation for future research in this field.

1. Introduction

Gamification and eco-literacy are two key concepts that have gained increasing attention in educational research, particularly in the context of education. Gamification refers to the application of game-design elements, such as points, rewards, challenges, and narratives, in non-game contexts to enhance motivation and engagement [1-3]. When implemented in educational settings, gamification has been shown to improve learning outcomes by fostering active participation and increasing students' intrinsic motivation[4]. In the context of environmental education, gamification offers an innovative approach to making sustainability topics more interactive and engaging for learners[5].

Additionally, terms such as "game," "educational games," and "serious games" are often used in similar contexts, but they have different meanings. A game refers to any structured form of play, typically for entertainment purposes, while educational games are designed with the primary aim of achieving specific learning outcomes [4], [6]. Serious games, on the other hand, are a subset of educational games that focus on real-world problems, often aiming to change attitudes or behaviour towards specific issues [4], [7], [8]. It is important to note that while these terms are related, our focus in this study is on gamification, which, as previously stated, involves incorporating game-like elements into non-game contexts to enhance engagement and learning without necessarily creating an entire game. For the purposes of this research, gamification is considered the core approach to promoting eco-literacy.

On the other hand, eco-literacy, is the ability to understand the basic principles of ecological systems and apply this knowledge to promote sustainable practices [9], [10]. As noted by [11], eco-literacy involves developing an awareness of the interconnectedness between humans and the environment, enabling individuals to make informed decisions that contribute to environmental conservation. In educational settings, fostering eco-literacy is crucial for shaping responsible citizens who can actively participate in addressing global environmental challenges.

In this context, gamification in eco-literacy processes represents an innovative and necessary approach to strengthening students' environmental education, as it transforms traditional learning into a dynamic, meaningful, and participatory experience. The use of game elements—such as challenges, rewards, missions, and narratives—encourages intrinsic motivation and active student engagement, facilitating a deeper understanding and ownership of sustainability and conservation principles [1], [5]. To this respect, [12] highlight that gamification not only energizes educational processes but also connects students with global conservation networks, developing a sense of shared responsibility toward the environment. Thus, in a context characterized by urgent environmental issues and generations with new ways of learning and communicating, gamification stands as a key pedagogical strategy to promote transformative eco-literacy, capable of generating awareness and action in favour of the planet.

Therefore, the integration of gamification into eco-literacy education offers a promising approach to increasing student engagement with sustainability topics while deepening their understanding of ecological systems. Despite the growing interest in this interdisciplinary field, a comprehensive analysis of existing research is needed to identify key trends, influential contributions, and thematic developments. In this regard, bibliometric analysis serves as a valuable tool for mapping the scientific landscape of gamification and eco-literacy, offering insights into research evolution, dominant themes, and future directions.

The most recent bibliometric analysis on gamification was conducted by [13], exploring its growth and applications across various fields, including education, based on research published between 2011 and 2019. Likewise, [14] carried out a bibliometric analysis focused on the role of gamification in higher education, covering research from 2013 to 2022. Regarding eco-literacy, [15] analyzed research trends from 2013 to 2023, highlighting key developments in environmental education. Similarly, [16] conducted a bibliometric analysis using VOSviewer to explore the scientific landscape of environmental literacy research from 2010 to 2020. Although these bibliometric analyses provide valuable insights into the development of gamification and eco-literacy research, they have not explored the intersection of these two fields in educational contexts. This leaves a gap in understanding how game-based learning strategies can enhance environmental education. Therefore, our bibliometric analysis aims to provide a systematic overview of how gamification has been applied to promote eco-literacy, investigating

research trends, key contributions, and thematic developments from 2018 to 2024 to enhance educational practices in this field.

2. Methodology

This study employs a bibliometric analysis to investigate the role of gamification in fostering eco-literacy within the context of education. The analysis follows a structured approach using the Bibliometrix R package to process and visualize data retrieved from the SCOPUS database. SCOPUS was chosen as it is a curated, high-quality bibliometric data source widely used in academic research for the quantitative analysis of science [17]. The study aimed to answer the following questions:

RQ1: What are the main research trends in the application of gamification for promoting eco-literacy from 2018 to 2024?

RQ2: How has gamification been integrated into educational strategies to enhance eco-literacy and sustainability awareness?

RQ3: Which academic sources, authors, and countries have contributed the most to research on gamification and eco-literacy?

RQ4: What are the dominant themes and keyword co-occurrences in studies on gamification and eco-literacy?
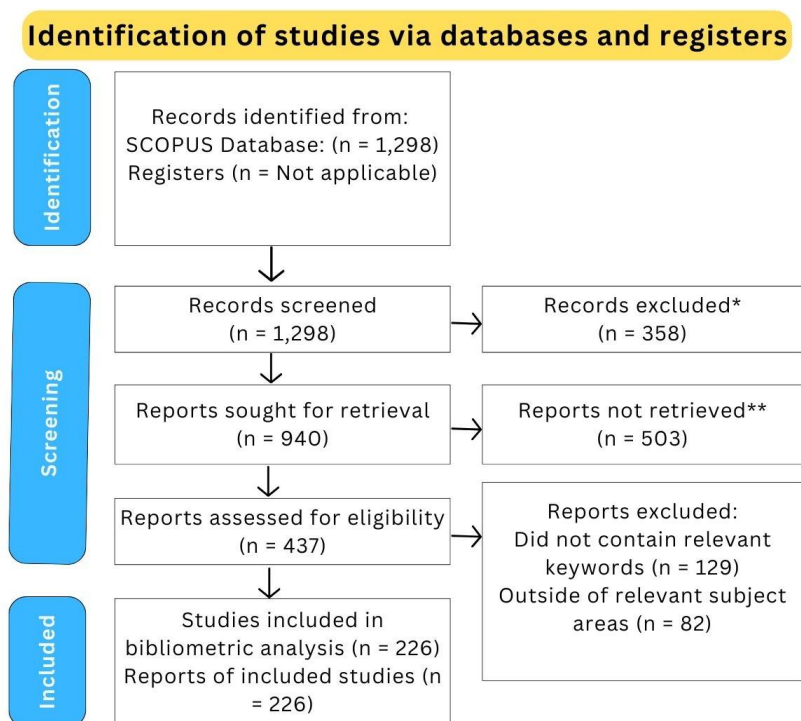
RQ5: What research gaps exist in the literature regarding the use of gamification to develop eco-literacy skills?

2.1   Data collection

The initial data search was conducted in SCOPUS using the following query:

("gamification" OR "game-based" OR "game") AND ("teaching" OR "instruction" OR "education" OR "learning") AND ("eco-literacy" OR "environmental literacy" OR "sustainability" OR "ecological awareness")

This search yielded a total of 1,298 documents. Figure 1 presents the PRISMA flow diagram, which outlines the selection process, including the identification, screening, eligibility, and final inclusion of studies in the analysis. To ensure a relevant and high-quality dataset, specific inclusion and exclusion criteria were applied during this process.

Identification of studies via databases and registers

Identification	Records identified from: SCOPUS Database: (n = 1,298) Registers (n = Not applicable)

↓

Screening	Records screened (n = 1,298) →	Records excluded* (n = 358)
	Reports sought for retrieval (n = 940) →	Reports not retrieved** (n = 503)
	Reports assessed for eligibility (n = 437) →	Reports excluded: Did not contain relevant keywords (n = 129) Outside of relevant subject areas (n = 82)
Included	Studies included in bibliometric analysis (n = 226) Reports of included studies (n = 226)	

*Studies published before 2018 or after 2024 were excluded.
**Only peer-reviewed journal articles were included. Non-peer-reviewed sources such as conference proceedings, book chapters, and grey literature were excluded.

Figure 1. PRISMA flow diagram for the selection of studies on gamification and eco-literacy.

2.2   Data processing and analysis

This section describes the methodological approach used to process and analyze the dataset retrieved from SCOPUS. The data was exported in CSV format and imported into Bibliometrix in R for bibliometric analysis. Several analyses were conducted to explore different aspects of the research landscape on gamification and eco-literacy from 2018 to 2024.

To identify publication trends, annual scientific production was analysed (RQ1), providing insights into the growth and evolution of the field. Trend topics and thematic evolution were examined to highlight frequently discussed themes and track the progression of research areas over time (RQ2). Additionally, the most relevant sources, authors, and countries were identified to determine influential researchers, and geographical distribution of contributions (RQ3).

To understand dominant themes and keyword relationships, a keyword co-occurrence tree map was created, alongside a word cloud visualization of the most prominent terms in the dataset (RQ4). Finally, a thematic map categorized research topics based on their centrality and density, offering insights into research gaps and areas for future exploration (RQ5). Overall, our analysis provides a comprehensive overview of key contributors, emerging trends, and potential directions for advancing gamification in eco-literacy education. Figure 2 illustrates the workflow followed in our study to ensure a systematic and rigorous research process.
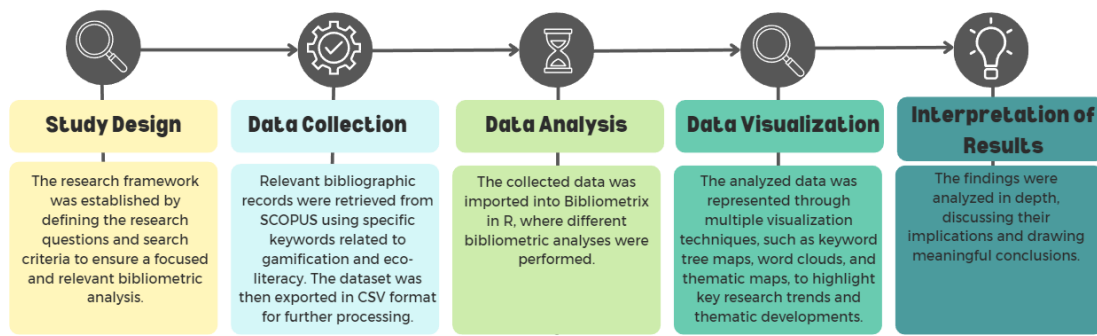
Figure 2. Workflow to clarify the research process. (Own work)

3. Results

This section presents the findings of the bibliometric analysis on gamification and eco-literacy, focusing on research trends, key contributors, thematic patterns, and gaps in the literature. The results are structured according to the study's research questions. Hence, we provide insights into research trends and the integration of gamification into eco-literacy education, key academic sources, authors, and countries contributing to the field, dominant themes and keyword co-occurrence patterns, and existing research gaps in the literature. Accordingly, the following subsections present the results for each research question. In each subsection, we offer a detailed analysis of the graphs generated in the bibliometric analysis, focusing on the intersection of gamification and eco-literacy.

3.1 RQ1: What are the main research trends in the application of gamification for promoting eco-literacy from 2018 to 2024?

This section explores the key research trends in the application of gamification for promoting eco-literacy from 2018 to 2024. Figure 3 illustrates the annual scientific production on this topic, showcasing the progression of research output over the years. The data reveal a steady increase in publications, highlighting the growing academic interest and the expanding role of gamification in sustainability education.

In 2018, the number of published articles was relatively low, with just over ten publications. However, a notable upward trend emerged between 2018 and 2020, as the number of studies increased to approximately 25. This growth continued at a moderate pace, reaching around 30 publications in 2022. Finally, a slight fluctuation was observed between 2022 and 2023, where the research output remained relatively stable.
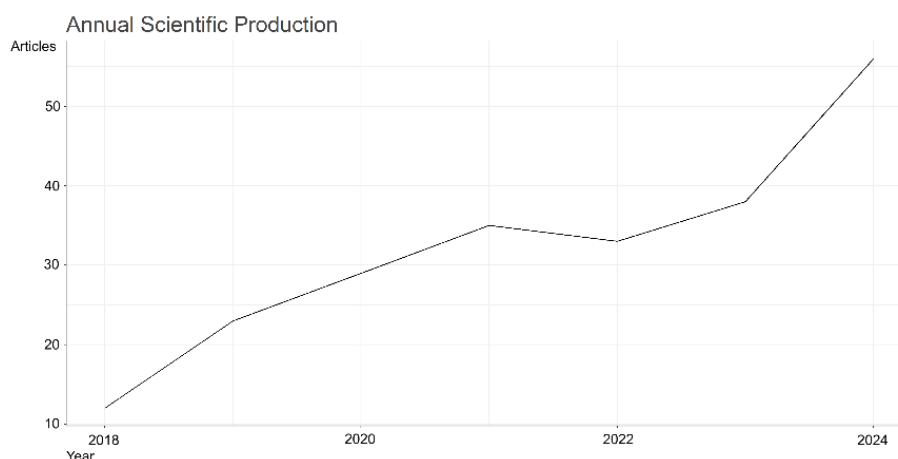

Figure 3. Annual scientific production on gamification and eco-Literacy (2018–2024)

It is notable that a significant rise occurred from 2023 to 2024, with the number of publications exceeding 50, marking the highest point in the dataset. Therefore, this sharp increase suggests an increased focus on the integration of gamification into eco-literacy and sustainability education, highlighting its growing relevance in academic discourse.

The overall trend emphasizes the expanding body of research in this interdisciplinary field, indicating that scholars are increasingly recognizing gamification as a valuable pedagogical tool for promoting environmental awareness and literacy.

3.2 RQ2: How has gamification been integrated into educational strategies to enhance eco-literacy and sustainability awareness?

This section presents the findings related to the integration of *gamification* into educational strategies to enhance *eco-literacy*. The analysis is structured based on the bibliometric analysis of *Trend Topics* and *Thematic Evolution*, which illustrate the progression of key research themes over time.

The trend analysis (see Figure 4) presents an overview of the evolution of key research topics in gamification and eco-literacy. The figure highlights a strong presence of terms such as *sustainability, learning,* and *education*, which have shown consistent research interest over time. This finding suggests that scholars continue to explore the intersection between environmental awareness and educational practices.

Notably, *serious games* and *environmental education* have gained visibility, particularly in recent years. This indicates a growing academic focus on the use of interactive and experiential learning tools to foster sustainability education. The presence of *educational development* and *higher education* suggests that much of this research is concentrated within formal academic institutions, emphasizing the role of universities and structured curricula in integrating sustainability principles. However, the lack of focus on high school suggests a research gap in sustainability education at this level.
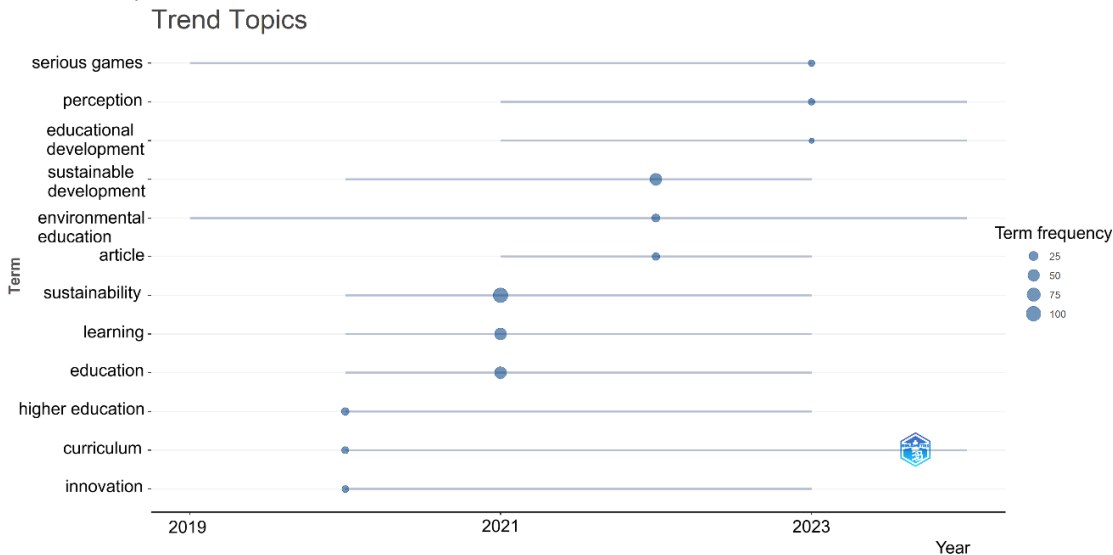
Figure 4. Trend topics in Gamification and Eco-Literacy Research.

Additionally, *curriculum* and *innovation* appear in the trend topics, reinforcing the idea that educational models are evolving to incorporate new pedagogical strategies. The continued relevance of *sustainable development* within the dataset points to the alignment of educational initiatives with global sustainability goals.

Overall, the trends suggest a progressive integration of sustainability concepts into educational frameworks, with increasing attention to digital and interactive methodologies, particularly through serious games. Future research may further investigate how these

approaches contribute to long-term behavioural and cognitive engagement with sustainability issues.

Figure 5. Thematic evolution of research trends in gamification and eco-literacy.

The evolution of research trends in education and sustainability over time reveals a growing focus on *gamification* and *sustainable development*. Figure 5 illustrates how previous topics, such as *game-b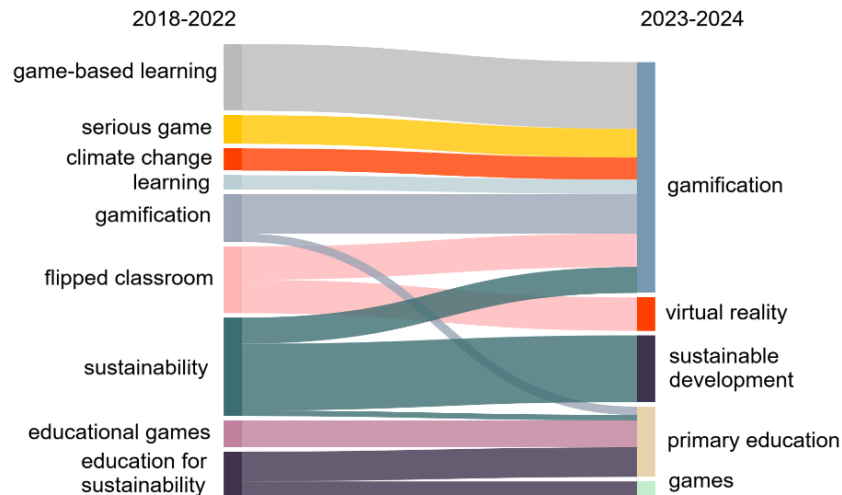ased learning* and *educational games*, have merged into *gamification*, highlighting an increasing academic interest in applying gaming mechanics to educational contexts. This shift suggests that researchers are prioritizing engagement-driven methodologies to enhance learning experiences.

Sustainability-related topics have also experienced a transformation. Earlier themes like *sustainability* and *education for sustainability* have evolved into *sustainable development*, reflecting a broader and more interdisciplinary approach. However, the emphasis on *primary education* without mention of *secondary* or *middle school* suggests a gap in research at these levels, indicating an opportunity for further exploration.

Additionally, the emergence of *virtual reality* as an evident topic highlights the growing role of immersive technologies in education. Meanwhile, *games* appearing alongside *gamification* suggests that research is distinguishing between using games as standalone learning tools and integrating gamified strategies into teaching.

Overall, the trends point toward a shift from specific pedagogical methodologies to more holistic and technology-driven approaches, emphasizing sustainability, interactive learning, and digital integration. However, the limited focus on *secondary* and *middle school* education indicates a potential area for further study.

3.3 RQ3: Which academic sources, authors and countries have contributed the most to research on gamification and eco-literacy?

To address this research question, we present an analysis of the most influential academic contributors in the field of gamification and eco-literacy. This includes an overview of the most relevant sources, identifying the top journals publishing research on this topic, as well as a description of the most relevant authors, highlighting the leading researchers shaping the discourse.

Figure 6 presents the most relevant sources contributing to the research on *gamification*, *eco-literacy*, and *sustainability awareness*. The number of documents published by each source is indicated by the size of the circles. According to the figure, *Sustainability (Switzerland)* is the most prominent, contributing 90 documents. This suggests that *Sustainability (Switzerland)*

is a key journal in the field, providing extensive research on the integration of *gamification* into sustainability education.
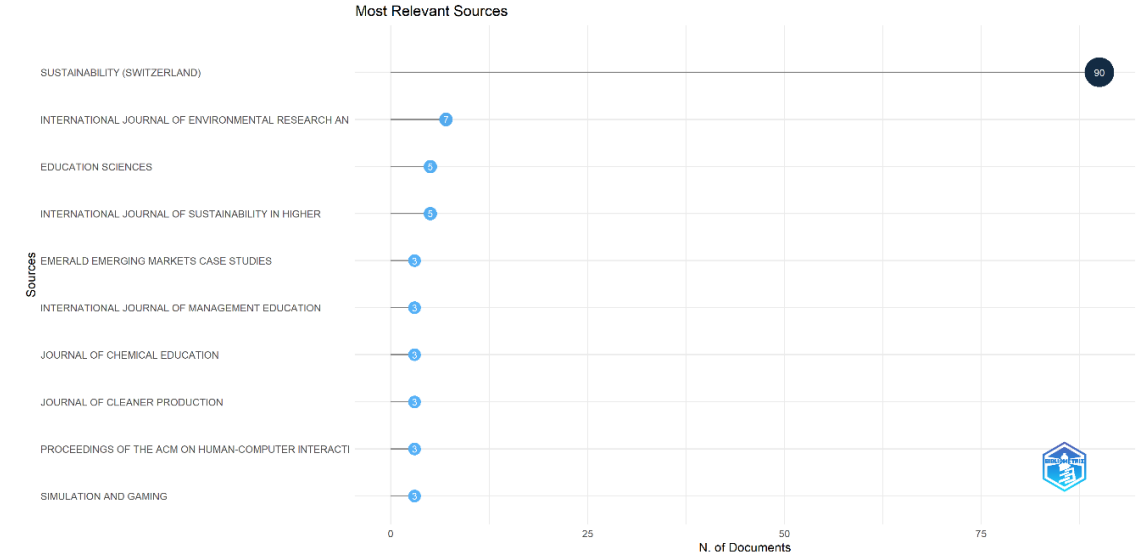
Figure 6. Most relevant sources in gamification and eco-literacy research.

Other significant sources include the *International Journal of Environmental Research and Public Health* (7 documents), *Education Sciences* (5 documents), and the *International Journal of Sustainability in Higher Education* (5 documents). These sources indicate that research on *gamification* and sustainability is multidisciplinary, encompassing fields such as education, environmental sciences, and management.

Additionally, sources like the *Journal of Cleaner Production* and *Simulation and Gaming* highlight the role of gamification in fostering sustainable practices and innovative learning strategies. The diversity of sources implies that the topic is being explored from different perspectives, reinforcing the relevance of *gamification* as a tool for promoting *eco-literacy* and sustainable behaviour.

The distribution of publications evidenced in Figure 7 suggests that a small but influential group of researchers is driving the conversation on gamification and eco-literacy. The dominance of Kim S, Park S, and Hamari J points to specialized expertise in the field, with a particular emphasis on gamification methodologies and their applications in environmental education.

Figure 7. Most relevant authors in gamification and eco-literacy research.

Several of the top contributors, including Kim, Park, Lo, Ng, and Su, indicate a strong research presence from East Asia, particularly South Korea, China, Hong Kong, or Taiwan. This suggests that institutions in these regions are actively exploring the role of gamification in fostering eco-literacy. Addition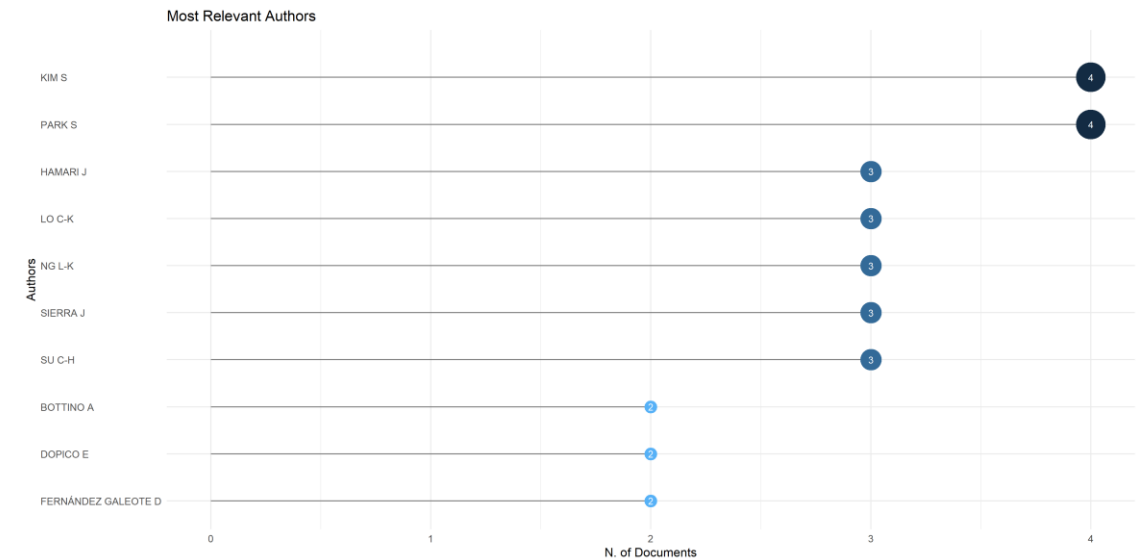ally, the presence of Hamari J is noteworthy, as he is widely recognized for his work in gamification studies. His inclusion in the list reinforces the relevance of gamification strategies in promoting environmental awareness and sustainable practices.

Notably, there are no Latin American researchers among the most relevant authors. This suggests that despite the growing global interest in gamification and eco-literacy, Latin America has not yet emerged as a major contributor to the academic discourse in this specific area. This gap highlights an opportunity for researchers from the region to engage more actively in the field and contribute perspectives grounded in Latin American environmental and educational contexts.

Country Scientific Production
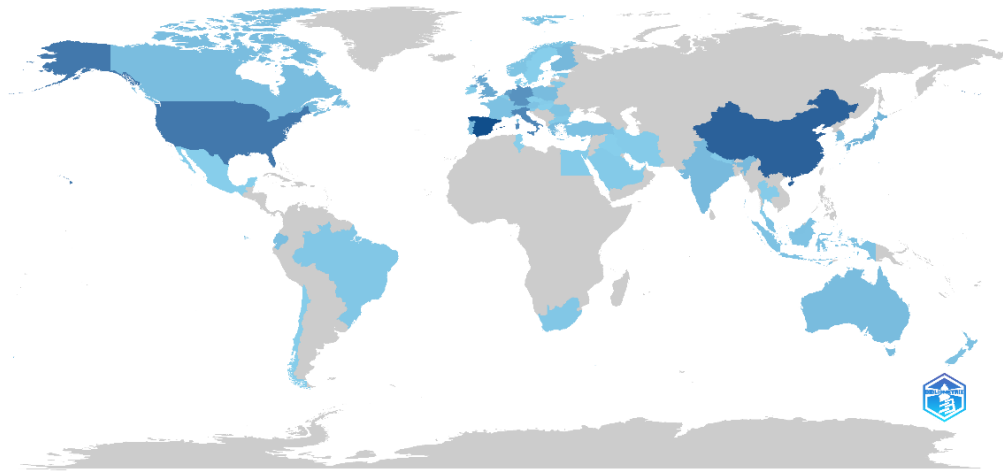
Figure 8. Country scientific production in gamification and eco-literacy research.

To further support the previous analysis, Figure 8 illustrates country scientific production in the field. The map highlights that North America, Europe, and East Asia emerge as the primary contributors of academic research, with the United States, China, and several European nations leading the field. This trend suggests that institutions in these regions have greater access to research funding, established academic networks, and high-impact publication opportunities. Conversely, Latin America, Africa, and parts of Southeast Asia display a much weaker presence, as indicated by their lighter shading or complete absence from the map. The lack of substantial contributions from these regions, particularly Colombia, implies barriers such as limited research funding, fewer international collaborations, and lower visibility in high-impact journals. This reinforces the need for more initiatives to support and integrate Latin American scholars into the global research landscape of gamification and eco-literacy.

3.4   RQ4: What are the dominant themes and keyword relationships in studies on gamification and eco-literacy?

To explore the dominant themes and keyword relationships in research on gamification and eco-literacy, we employ two visualization techniques: tree maps and world clouds.

The tree map (see Figure 9) represents keyword co-occurrences in studies related to gamification and eco-literacy, with larger blocks indicating higher frequencies of appearance. The most dominant theme is *sustainability* (100 occurrences, 14%), highlighting its central role in discussions within this research field. Additionally, *education* and *learning* (both with 55

occurrences, 7%) emerge as key themes, reinforcing the pedagogical focus of the studies. The presence of *sustainable development* (53 occurrences, 7%) further emphasizes the connection between environmental awareness and educational strategies. Other frequently occurring keywords, such as *student* (42 occurrences, 6%) and *teaching* (35 occurrences, 5%), suggest a strong focus on learners and instructional approaches.

Beyond these primary themes, the tree map reveals different methodological and conceptual frameworks used in the field. Terms like *climate change* (15 occurrences, 2%), *game theory* (15 occurrences, 2%), and *gamification* (14 occurrences, 2%) indicate a growing interest in integrating interactive and game-based learning strategies into eco-literacy education. Meanwhile, keywords such as *serious games*, *simulation*, and *virtual reality* point to the use of digital tools in this domain. Additionally, words like *perception*, *innovation*, and *decision-making* suggest an analytical focus on how gamification influences learning outcomes and behavioural changes. The presence of geographical terms such as *Spain*, *China*, *Taiwan*, and *Australia* imply that research in this field has regional trends or case studies.

Figure 9. Keyword co-occurrence tree map in gamification and eco-literacy research.

Despite the significant presence of sustainability and education-related terms, the relatively lower frequency of *gamification* (2%) and *digitalization* (1%) suggests that gamification is not yet a dominant framework in eco-literacy studies. The inclusion of *COVID-19* as a keyword (1%) further indicates that some research has explored the impact of the pandemic on education and sustainability learning.

The word cloud visualization (see Figure 10) highlights the most frequently occurring themes in research related to gamification and eco-literacy. The most prominent terms include *education, sustainable, and development,* indicating that these concepts are central to the field. Other significant keywords such as *learning, environmental, student, and teaching* suggest a strong emphasis on educational frameworks and their role in promoting sustainability.

Figure 10. Word cloud representing gamification and eco-literacy research.

Additionally, terms like *simulation, design, game, and gamification* appear but in smaller sizes, suggesting that while game-based approaches and digital tools are present in the discourse, they are not the dominant focus. The presence of words like *innovation, perception, and decision-making* also hints at the integration of cognitive and behavioural aspects within the research. Overall, the word cloud reinforces the idea that the primary research focus is on education and sustainable development, with gamification playing a supporting role in enhancing learning experiences.

3.5 RQ5: What research gaps exist in the literature regarding the use of gamification to develop eco-literacy skills?

The thematic map (see Figure 11) highlights *sustainable development, ecosystem services*, and *meta-evaluation* as niche themes in a single cluster at the top. This suggests that these topics are emerging in educational research but are not yet widely interconnected with other dominant themes. In contrast, *high school, systems thinking,* and *computational thinking* are positioned more centrally, indicating that they are more established research areas. The presence of *systems thinking* and *computational thinking* near *high school* education suggests a growing emphasis on problem-solving and digital literacy in secondary education.

Additionally, the thematic map (see Figure 11) highlights *game-based learning, board games,* and *engineering education* as a central cluster within the motor themes. Their position near the middle suggests that these topics are well-developed and play a significant role in driving educational research. The strong link between *game-based learning* and *engineering education* indicates a growing emphasis on interactive and problem-solving approaches in STEM fields. Additionally, the inclusion of *board games* within this cluster suggests a continued interest in using non-digital gaming methods to support learning processes.

A second cluster, positioned above the first but still close to the central axis, includes *gamification, environmental education*, and *serious games*. Their proximity to the core of the map suggests that these themes are highly relevant and widely interconnected with other research areas. The combination of *gamification* and *serious games* reflects an ongoing shift towards participation-focused learning and teaching strategies, while their connection to *environmental education* highlights the increasing use of interactive digital tools in sustainability education.

The positioning of these motor themes indicates that *game-based learning* approaches are becoming essential in modern educational methodologies, with applications ranging from

STEM education to environmental awareness. Their strong presence on the thematic map suggests that they will continue to shape the evolution of pedagogical strategies in the coming years.
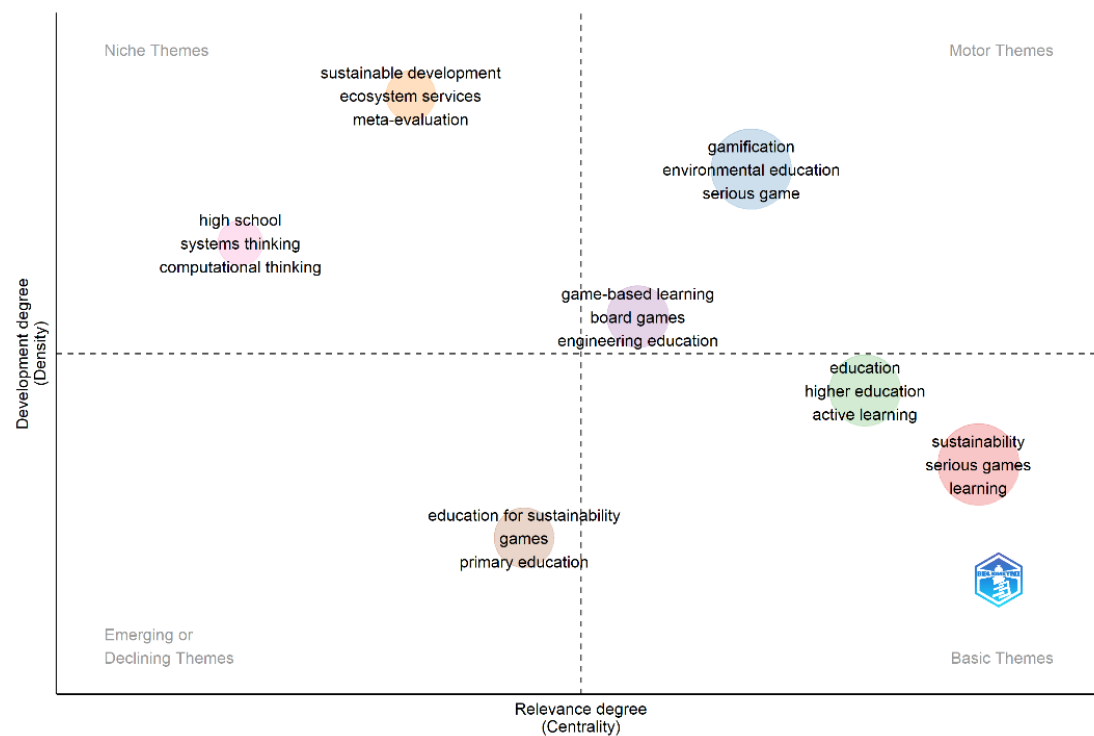

Figure 11. Thematic map of research trends in gamification and eco-literacy.

In the emerging or declining themes, the thematic map (see Figure 11) positions *education for sustainability*, *games*, and *primary education* near the midpoint of the relevance degree (centrality) line. This placement suggests that these themes are in a transitional phase, either gaining traction as new research interests or losing prominence within the broader academic discourse. The presence of *education for sustainability* in this quadrant indicates a fluctuating level of scholarly attention. While sustainability remains a critical global issue, its positioning here suggests that its integration into educational research might still be evolving, with shifting priorities influencing its relevance. Similarly, the placement of *games* and *primary education* in this category reflects the ongoing debate about their role in pedagogy. This suggests that while game-based learning continues to be a topic of interest, its application in primary education may still be developing or facing challenges in widespread adoption. The intersection of these three themes suggests the potential for innovative pedagogical approaches that merge sustainability education with game-based methodologies at the primary education level. However, their positioning in this quadrant suggests that further research is needed to solidify their place within mainstream educational frameworks.

Regarding the basic themes, the thematic map (see Figure 11) highlights the placement of *education, higher education*, and *active learning* near the development degree (density line), indicating that these themes are well-established yet continue to evolve and expand within educational research. Their central placement indicates their foundational importance in shaping pedagogical approaches, particularly in fostering student engagement and academic improvement. Further down along a diagonal trajectory, *sustainability, serious games,* and *learning* emerge as interconnected themes. The presence of *sustainability* alongside *serious games* highlights an increasing interest in developing interactive and immersive learning methodologies to address environmental challenges and promote sustainability education. This suggests a pedagogical shift towards experiential and game-based strategies that enhance

student motivation and conceptual understanding of real-world issues. Additionally, the close association with *learning* reinforces the role of these innovative approaches in strengthening cognitive development and knowledge retention within diverse educational contexts.

4. Discussion

We investigated the intersection of gamification and eco-literacy through a bibliometric analysis, identifying key research trends, influential contributions, and thematic developments. The bibliometric analysis revealed an increasing interest in this interdisciplinary field, with a notable rise in publications from 2018 to 2024, as described in the response to RQ1. This increase may be attributed to the growing global concern over environmental crises and the heightened emphasis on education for sustainable development. A report by UNESCO [18] emphasize the urgent need to integrate sustainability into educational curricula, which may explain the surge in research on eco-literacy and gamification. Additionally, international initiatives such as the United Nations' Sustainable Development Goals (SDG 4: Quality Education and SDG 13: Climate Action) may have encouraged the incorporation of gamification into environmental education. Furthermore, UNESCO [19] highlights the role of gamification in intensifying learning experiences, suggesting that interactive and game-based strategies can enhance student engagement and motivation in sustainability education. This notable rise suggests that researchers are increasingly recognizing the potential of game-based learning strategies to enhance environmental awareness and literacy. This trend aligns with the findings of [15], which also highlights a growing emphasis on environmental literacy, indicating a shared global concern for improving education.

The trend topics analysis (RQ2) highlighted recurring themes such as game-based learning for sustainability [16-24], environmental awareness through digital tools [29], and serious games for ecological education[26-31]. Additionally, the thematic evolution analysis revealed a shift from general gamification concepts to more specialized applications in eco-literacy education[32-35]. This shift suggests that research is moving beyond theoretical discussions to more applied and interdisciplinary approaches that implement digital tools and pedagogical frameworks to enhance eco-literacy. These findings corroborate the analysis of [16], which highlights education as the most frequently researched topic, followed by environment, literacy, and environmental literacy.

In terms of academic influence, we identified the most relevant sources, authors, and countries contributing to this field (RQ3). Our findings align with [14], which highlights *Sustainability*, a journal published by MDPI in Switzerland, as the most productive in this area. Regarding authors, the recurring presence of [20], [24], [40]is noteworthy, as was also presented in the bibliometric analysis in gamification made by [1]. Finally, in our analysis we found that while some countries in North America, Europe, and East Asia have emerged as leading contributors, research output remains unequally distributed. Latin America, Africa, and parts of Southeast Asia display a much weaker presence suggesting potential for broader global collaboration. A previous bibliometric analysis in gamification presents USA, Spain and Germany as the most productive countries [13]. Similarly, studies on eco-literacy highlight Spain, the United States, and the United Kingdom [14], reflecting their commitment to sustainability education and environmental policies. Additionally, [15] underscores China, Indonesia, and Malaysia as key contributors to eco-literacy research, possibly driven by regional environmental challenges and government initiatives promoting sustainability education. The imbalance in global research contributions

highlights the need for increased investment and collaboration in underrepresented regions to foster a more inclusive and diverse discourse on gamification and eco-literacy.

The analysis of dominant themes and keyword relationships in gamification and eco-literacy research (RQ4) highlights the strong emphasis on sustainability and education, as evidenced by their high frequency in both the tree map and word cloud visualizations. The prevalence of terms such as *sustainable development*, *education*, and *learning* underscores the pedagogical orientation of this research area, reinforcing the role of instructional strategies in promoting environmental awareness. These findings align with those of [15], whose bibliometric analysis revealed that the most interconnected research themes include *sustainable development, environmental literacy, environmental education, sustainability, literacy*, and *education for sustainable development*.

However, despite the integration of game-based learning methods, we found in our bibliometric analysis that the relatively lower occurrence of *gamification* and *digitalization* suggests that gamification is not yet a central framework within eco-literacy studies. One possible explanation is the limited number of empirical studies demonstrating its effectiveness in fostering environmental awareness[41]. Additionally, educational resistance to incorporating digital tools into formal education [42], along with teachers' resistance to implement gamification in education [43] may also play a role, as many teachers struggle to design effective gamified lessons.

Additionally, the presence of keywords like *simulation*, *serious games*, and *virtual reality* indicates growing interest in digital tools, while terms such as *perception*, *innovation*, and *decision-making* highlight the cognitive and behavioural dimensions of eco-literacy research. Additionally, the inclusion of geographical terms implies regional trends in publication patterns, reflecting the global but uneven distribution of studies in this field. These findings are also consistent with the bibliometric analysis of gamification research conducted by [13], who identified the expansion of gamification beyond educational contexts, with emerging applications in *crowdsourcing, sustainability, health, management,* and *software engineering*. This suggests that while gamification in eco-literacy remains an evolving area, its interdisciplinary potential continues to grow, offering new avenues for research and application.

Despite the growing body of literature on gamification and eco-literacy, our bibliometric analysis highlights a significant gap in research explicitly exploring their integration in educational settings (RQ5). Our findings reveal that most existing studies focus on higher education, with limited research on its application in primary and secondary education. This gap is critical, as early exposure to environmental education could have long-term benefits in shaping students' sustainable behaviours. However, empirical studies assessing how gamified approaches influence young learners' eco-literacy skills and sustainability awareness remain scarce. This is also evident in the bibliometric analysis of [14]. Despite growing interest in gamification and eco-literacy, research gaps persist, particularly in understanding how interactive learning strategies can be effectively implemented in early education. This lack of empirical research may be due to the challenges of designing and implementing gamified interventions in school curricula [44], as well as the absence of standardized frameworks for assessing their effectiveness [45], [46]. The limited exploration of game-based approaches in primary and secondary education, as well as the underdevelopment of interdisciplinary frameworks combining educational technology, and environmental science, highlights the need for further empirical studies.

5. Conclusions

Based on our bibliometric analysis, we conclude that research on gamification for promoting eco-literacy has steadily increased from 2018 to 2024, with a notable rise in

recent years (RQ1). However, its application remains primarily concentrated in higher education, where serious games and game-based learning strategies are widely used to enhance sustainability awareness (RQ2). The limited research on primary and secondary education highlights a gap in understanding how younger students engage with gamified eco-literacy initiatives.

Additionally, our analysis demonstrates that the most influential contributions to this field originate from North America, Europe, and East Asia, while Latin America, Africa, and Southeast Asia remain underrepresented (RQ3). This highlights the need for more diverse perspectives and global collaboration to enrich the discourse on gamification and eco-literacy. Furthermore, thematic and keyword analysis reveals that sustainability, education, and learning are dominant research themes, while gamification is often treated as a supplementary approach rather than a central focus (RQ4). Therefore, game-based learning, serious games, and environmental education emerge as core areas of study, while education for sustainability and primary education remain in a transitional phase, reflecting their evolving role in pedagogy.

Despite the growing body of literature, we also confirm that a significant research gap remains in explicitly integrating gamification into eco-literacy education, particularly in primary and secondary education (RQ5). Most studies focus on higher education, and there is a lack of empirical research assessing how game-based elements influence students' eco-literacy skills and sustainability awareness.

To bridge these gaps, future research should prioritize empirical studies that evaluate the effectiveness of gamification in fostering eco-literacy across different educational levels. A mixed-methods approach combining quantitative and qualitative research would provide a more comprehensive understanding of its impact. Future studies could focus on designing and implementing gamified educational strategies that integrate eco-literacy into different subjects, assessing their effectiveness through both experimental and observational research. Additionally, exploring teachers' and students' perceptions of gamification and eco-literacy could offer valuable insights into its practical application and challenges. Longitudinal studies could further examine the long-term effects of gamification on students' environmental awareness and behavior. Through the adoption of diverse research methodologies, future studies can contribute to a more robust framework for integrating gamification into eco-literacy education.

While our bibliometric analysis provides valuable insights into the trends and themes of gamification in eco-literacy education, there are several limitations to consider. First, the study relies on data from the Scopus database, which may not capture all relevant publications, particularly those in less widely indexed journals or non-English language sources. Additionally, as a bibliometric study, we only included published articles, excluding unpublished or gray literature that could offer alternative perspectives. Finally, our analysis does not address the empirical effectiveness of gamification in promoting eco-literacy at various educational levels. This gap in empirical data highlights the need for future studies that explore the practical impact of gamified learning strategies on eco-literacy skills across different educational contexts.

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