Chapter 4

Two Decades of Game-Based Learning Research in STEM Education

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Chapter Highlights

The following highlights summarise the research landscape, growth trends, and thematic structure of game-based learning in STEM education, highlighting key developments, dominant research themes, and emerging directions, while providing evidence-based insights to inform research, educational practice, and policy decisions.

- Presents a comprehensive bibliometric analysis of 407 publications on game-based learning in STEM education (GBL-STEM) published between 2006 and March 2025, revealing a rapid annual growth rate of 16.43% in the field.
- Identifies the United States as the leading contributor in terms of publication output, with Education Sciences as the most active journal and Computers & Education as the most highly cited source in GBL-STEM research.
- Demonstrates the interdisciplinary and collaborative structure of GBL-STEM studies through analyses of key authors, institutions, influential publications, and frequently used keywords.
- Reveals five major research clusters via keyword co-occurrence network visualization, highlighting dominant themes and emerging research trends within the field.
- Provides practical implications and evidence-based insights for educators, researchers, policymakers, and stakeholders seeking to effectively integrate game-based learning into STEM education.

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Introduction

STEM education has gained global recognition as a crucial educational priority, drawing significant attention from educators and policymakers. It aims to equip students with essential twenty-first-century skills while addressing real-world challenges (Su & Yang, 2024; L. Sun et al., 2023; Takeuchi et al., 2020). Nowadays, many countries have integrated STEM education into their national strategies to drive reforms in all levels of education (Holmlund et al., 2018; Sırakaya & Sırakaya, 2022), ensuring that future generations are prepared to engage with technological and scientific advancements. However, despite its importance, the number of students pursuing STEM-related careers remains low (Vedrenne-Gutiérrez et al., 2024). Also, research indicates that many students lack motivation to engage with STEM subjects, with interest often declining as early as primary school (Hiğde & Aktamış, 2022; Potvin & Hasni, 2014; Takeuchi et al., 2020). This disinterest can result in students avoiding STEM disciplines in later educational stages, ultimately impacting workforce readiness (Sırakaya & Sırakaya, 2022; Takeuchi et al., 2020). Given these challenges, STEM education should evolve to foster student engagement (Holmlund et al., 2018; Naji et al., 2025; D. Sun et al., 2023), ensuring that learners develop the critical thinking and problem-solving skills necessary to navigate complex technological landscapes (Matindike & Ramdhany, 2024; Naji et al., 2025).

One major obstacle to STEM education is the traditional classroom setting, which often struggles to capture students' interest or provide hands-on learning experiences due to time and resource constraints (Holmlund et al., 2018). The abstract and complex nature of STEM disciplines further contributes to these difficulties (Sırakaya & Sırakaya, 2022; D. Sun et al., 2023; Winberg et al., 2019). To address these challenges, integrating digital games into STEM curricula has emerged as a promising solution (Moon et al., 2024; Stohlmann, 2023). Research has demonstrated that game-based learning (GBL) can enhance student motivation, and provide interactive opportunities for developing problem-solving skills (Hussein et al., 2025; Moon et al., 2024). By leveraging digital games, educators can create immersive and engaging STEM learning environments that better prepare students for future careers related to STEM disciplines (Arztmann et al., 2023; Zhan et al., 2024).

In recent years, GBL has gained prominence in STEM education due to its ability to create interactive and experiential learning environments (Hussein et al., 2025; L. Sun et al., 2023). The increasing accessibility of mobile devices has further expanded opportunities for students to engage with STEM subjects anytime and anywhere, particularly benefiting digital-native learners (Gao et al., 2020). Mobile games provide flexibility, allowing students to learn at their own pace while enhancing motivation, engagement, and academic achievement (Ilić et al., 2024; L. Sun et al., 2023; Tene et al., 2025; Videnovik et al., 2023). Educational games also offer a dynamic environment where students can practice problem-solving, develop critical thinking skills, and engage with real-world challenges in a simulated setting (Fante et al., 2024; Guan et al., 2024; Gui et al., 2023).

The adoption of GBL in STEM education has expanded due to its ability to provide personalized learning experiences and long-term knowledge retention (Hussein et al., 2025; L. Sun et al., 2023). By embedding educational content within games, GBL facilitates knowledge acquisition in an enjoyable and immersive manner (Arztmann et al., 2023; Tene et al., 2025; Videnovik et al., 2023). Research indicates that GBL supports student-centered learning by promoting active participation, increasing motivation, and making complex concepts more accessible (Kefalis & Skordoulis, 2025; Videnovik et al., 2023). GBL also fosters students' autonomy and social connectedness, contributing to improved their conceptual understanding and learning experiences (Arztmann et al., 2023; Kefalis & Skordoulis, 2025). Compared to traditional teaching methods, GBL provides rich instructional support and fosters STEM literacy (Arztmann et al., 2023; Fante et al., 2024; Gui et al., 2023), making it a promising pedagogical approach for 21st-century education. In other words, GBL serves as an effective method for improving students' comprehension of STEM principles. Hence, as research continues to highlight its benefits, GBL remains a valuable strategy for improving student engagement, motivation, and academic performance in STEM fields (Hussein et al., 2025; Stohlmann, 2023; L. Sun et al., 2023; Tene et al., 2025; Videnovik et al., 2023).

Although research on GBL has gained momentum, with a rising number of studies focusing on STEM education over the past decade, prior reviews have generally examined a limited number of documents (Arztmann et al., 2023; Gui et al., 2023; Kefalis & Skordoulis, 2025). These studies are often confined to specific educational levels and subject areas (Fante et al., 2024; M. C. Li & Tsai, 2013; Videnovik et al., 2023) and are restricted in their temporal scope (Gao et al., 2020; Ilić et al., 2024; Tene et al., 2025). Despite the increasing adoption of GBL in STEM education, a comprehensive bibliometric review that synthesizes recent developments in this field remains unavailable. Although the body of literature on GBL continues to expand, a holistic understanding of its contributions to STEM education across different academic levels is also still lacking. To address existing gaps in the literature, quantitatively evaluate research productivity and impact, and offer valuable insights to various stakeholders, this study aims to present a comprehensive overview of the current state of GBL in STEM education. This review distinguishes itself from previous studies in several ways. First, it specifically focuses on GBL within STEM education, differentiating it from broader analyses of GBL. Second, it encompasses research published from the emergence of the first relevant study in 2006 up to 2025, ensuring a comprehensive temporal coverage. Finally, to maintain academic rigor, this review exclusively includes peer-reviewed journal articles, guaranteeing the reliability and credibility of the analyzed literature.

The study seeks to guide future research and practical applications in this rapidly evolving field. The key contribution of this paper lies in its broad examination of GBL-STEM research trends. Furthermore, it identifies leading scholars and their contributions, highlights influential countries and institutions, and traces the field's development over the past two decades. This information can be particularly beneficial for researchers, enabling them to focus on the most prominent topics within the discipline.

Methodology

Design

This study employed bibliometric analysis to explore recent developments in research on game-based learning in STEM education (GBL-STEM). A combination of quantitative methods, such as performance analysis, and qualitative approaches, including co-authorship and co-occurrence analysis, was utilized (Donthu et al., 2021). The analysis was conducted using two software tools: VOSviewer (van Eck & Waltman, 2010) and Bibliometrix (Aria & Cuccurullo, 2017). Through quantitative analysis, this study provides a comprehensive assessment of GBL-STEM research using various bibliometric indicators. Meanwhile, qualitative analysis reveals the intellectual framework of the field, incorporating keyword analysis and trend exploration. This includes frequently occurring keywords, keyword mapping, temporal keyword trends, thematic network analysis, and thematic evaluation.

Database

The data for this study were collected from the Scopus database, which offers a substantial number of academic publications with rich citation data. Scopus serves as an integrated research database, enabling scholars to systematically explore and assess relevant literature (Elsevier, 2023).

After selecting the database, a set of relevant keywords was determined to efficiently search for studies aligned with the research scope. The search was conducted within the titles, abstracts, and author keywords of publications. The search string used in this study was: TITLE-ABS-KEY ((“game-based learning” OR “gamification” OR “gamified” OR “game-based” OR “gamify” OR “digital game” OR “video game” OR “mobile game” OR “educational game” OR “learning game” OR “serious game” OR “game*” OR “augmented reality” OR “virtual reality”) AND (“STEAM education” OR “STEM education” OR “Science, Technology, Engineering, and Mathematics”)).

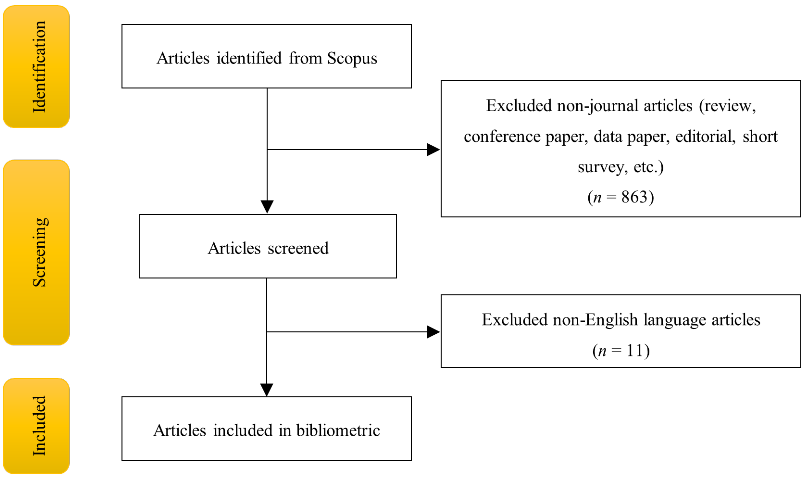

Figure 1. PRISMA diagram

To ensure a relevant dataset, the search was restricted to studies published between January 2006 and March 2025. Data extraction took place on March 22, 2025, yielding an initial dataset of 1,281 publications. The study focused exclusively on original research articles published in English, excluding review papers, conference proceedings, book chapters, comments, editorials, and letters. As of March 2025, 407 eligible articles were retrieved from Scopus and underwent a full-text analysis for bibliometric evaluation. The PRISMA protocol (Page et al., 2021) was followed to systematically assess the selected studies, as illustrated in Figure 1.

Inclusion and Exclusion Criteria

To systematically analyze the collected literature, specific inclusion and exclusion criteria were established. The inclusion criteria required that studies: (1) focus explicitly on GBL-STEM research, (2) be written in English, and (3) be published in peer-reviewed journals. Applying selective criteria for academic journals within this research domain ensures a manageable dataset while maintaining search quality. To uphold the study's methodological rigor, the following exclusion criteria were applied: (1) studies published in languages other than English, and (2) publications that do not belong to the category of journal articles.

Bibliometric Analysis

The bibliographic dataset was extracted from Scopus in .csv format for analysis. The Bibliometrix R package (Aria & Cuccurullo, 2017) was installed and performed to facilitate bibliometric assessment. Bibliometrix offers a range of analytical tools, enabling researchers to conduct a thorough bibliometric investigation. The .csv file was uploaded to the Biblioshiny interface for further processing. Additional data files in Excel (.csv) and image format (.png) were also obtained for analysis based on the study's objectives. In addition, VOSviewer was employed to generate and visualize bibliometric maps (van Eck & Waltman, 2010). Several bibliometric techniques were applied, including co-authorship and co-occurrence network analysis, to provide an in-depth examination of GBL-STEM research. Co-authorship analysis was used to map collaborative networks among researchers and countries. Furthermore, keyword co-occurrence analysis identified frequently associated terms within the same documents. Performance analysis was conducted to evaluate the contributions of various research entities—such as publications, journals, authors, institutions, and countries—to the GBL-STEM domain.

Results

Main Information

The research landscape on GBL-STEM has experienced significant growth over nearly two decades (Table 1). With a total of 407 documents published in 222 different journals, the field demonstrates a robust and expanding body of knowledge. The annual growth rate of 16.43% highlights the increasing interest and relevance of this research area, aligning with the broader trends in digital and interactive learning. The document average age of 4.29 years suggests that the field is relatively dynamic, with new findings frequently emerging. Additionally, an average of 22.04 citations per document indicates strong academic engagement and the impactful nature of these studies within the scientific community. The high number of keywords, both from keywords plus (1,242) and authors' keywords (1,183), reflects the diverse themes explored in GBL for STEM education.

Table 1. Preliminary information

Description	Results
Timespan	2006 to March 2025
Journals	222
Documents	407
Annual growth rate %	16.43
Document average age	4.29
Average citations per doc	22.04
Keywords plus	1242
Author's keywords	1183
Authors	1424
Authors of single-authored docs	37
Single-authored docs	37
Co-authors per doc	3.9
International co-authorships %	21.62

Authorship patterns also provide insights into research collaboration. A total of 1,424 authors contributed to these publications, with only 37 documents being single-authored. This suggests that research in this domain is predominantly collaborative, supported by the average of 3.9 co-authors per document. Furthermore, the international co-authorship rate of 21.62% highlights the global nature of GBL research, indicating cross-border academic cooperation and knowledge exchange. In conclusion, the study of GBL-STEM has seen substantial and continuous growth, with an increasing number of collaborative and widely cited publications. The expanding research network and high international co-authorship rate demonstrate the global interest in leveraging GBL for STEM education. Moving forward, this field is expected to evolve further, integrating emerging technologies and interdisciplinary approaches to enhance the effectiveness of STEM education through gamified learning experiences.

Trend in Scientific Production

The trend of research articles on GBL-STEM from 2006 to March 2025 demonstrates a significant increase in publication volume over time (Figure 2). According to Scopus, the number of articles remained relatively low from 2006 to 2014, with fewer than five articles per year. However, a notable rise began in 2015, reaching its peak in 2024 with 76 published articles. Despite this growing interest, the mean total citation per article exhibits a different pattern. The highest mean citation per article occurred in 2016 (82.82), followed by 2014 (64.67) and 2018 (54.20). These peaks suggest that the articles published in these years had a substantial impact on the academic community. However, from 2019 onward, the mean citation per article gradually declined, with a sharp drop observed in 2023 (8.79) and 2024 (2.47). The most recent data from 2025 shows an even lower citation count (0.44), which is expected as citations accumulate over time.

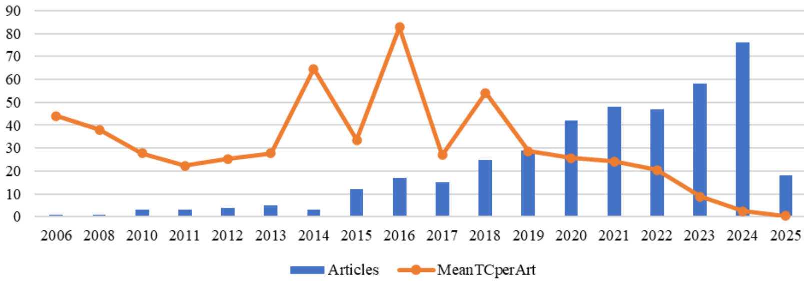

Figure 2. Publications and citations trends over time

The increase in publication volume in recent years may be attributed to the growing recognition of GBL as an effective approach in STEM education. While interest in GBL-STEM has grown exponentially, the citation impact of individual articles has diminished. This could be due to the longer time required for citations to accumulate.

Most Productive Authors

The analysis of the most prolific authors, those with the highest number of publications (NP) and total citations (TC) in GBL-STEM provides significant insights into the scholarly impact of this research field. Identifying leading authors in a specific field is crucial. Their publications serve as key references for the academic community. Table 2 and Figure 3 highlight the ten most influential authors who have made significant contributions to this area of study. Among the most productive authors, Lavicza, Z. from Johannes Kepler University Linz, Austria, leads with eight publications, followed by several authors with four contributions each, including Muntean, G.M., Muntean, C.H., Johnson-Glenberg, M.C., Jeong, J.S., and others. Lavicza, Z. published his first paper (FP) in 2021 titled "*Integrated STEAM approach in outdoor trails with elementary school pre-service teachers*" (Haas et al., 2021)we moved our on-campus STEAM (Science, Technology, Engineering, Arts and Mathematics in *Educational Technology and Society* (SJR: 1.56, Q1). Despite having fewer publications, some authors have achieved a substantial academic impact through citation counts and h-index (H), indicating the quality and influence of their work.

Table 2. Top 10 most productive authors

Author	NP	TC	H	Country	Institution	FP
Lavicza, Z.	8	94	18	Austria	Johannes Kepler University Linz	2021
Christopoulos, A.	4	237	14	Finland	University of Turku	2020
González-Gómez, D.	4	62	33	Spain	Universidad de Extremadura	2021
Jeong, J.S.	4	62	24	Spain	Universidad de Extremadura	2021
Johnson-Glenberg, M.C.	4	187	20	US	Arizona State University	2021
Muntean, C.H.	4	84	17	Ireland	National College of Ireland	2020
Muntean, G.M.	4	99	45	Ireland	Dublin City University	2020
Cotten, S.R.	3	96	40	US	Clemson University	2014
Din, R.	3	35	10	Malaysia	Universiti Kebangsaan Malaysia	2018
Fenyvesi, K.	3	39	7	Finland	University of Jyväskylä	2021

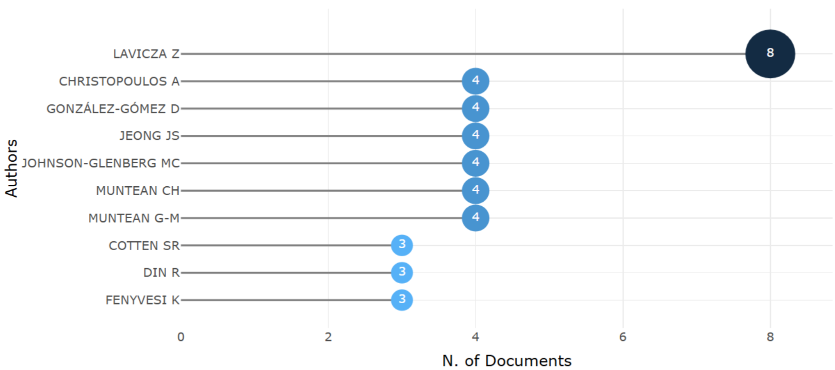

Figure 3. Most relevant authors

The highest total citation belongs to Christopoulos, A. from University of Turku (Finland) with 237 citations, demonstrating strong recognition of his work on learning analytics in virtual reality STEM applications. This is followed by Johnson-Glenberg, M.C. from Arizona State University (US) with 187 citations, whose research emphasizes embodied learning in STEM education, highlighting the importance of platform differences between 2D desktop and 3D virtual reality learning experiences. Muntean, G.M., from Dublin City University (Ireland), despite having only four publications, has garnered 99 citations, indicating a notable impact, particularly in the area of adventure-based 3D solar system games for primary school students. The highest h-index is attributed to Muntean, G.M. (45), followed by Cotten, S.R. (40) and González-Gómez, D. (33). The h-index serves as an indicator of consistent academic influence over time, suggesting that these scholars have produced high-quality work that has been frequently cited. Muntean, G.M. stands out as the most established researcher in this domain, with a strong academic footprint extending beyond game-based STEM education. Among the ten most prolific authors, Cotten, S.R. from Clemson University, US, was the first researcher to publish an article in this field. Her work revealed that the frequency of playing computer games was associated with higher self-efficacy in STEM. Geographically, the leading researchers are affiliated with institutions in Europe and the United States, with Austria, Ireland, Finland, Spain, and the US being prominent contributors. The presence of researchers from Johannes Kepler University Linz, Universidad de Extremadura, Dublin City University, and Arizona State University underscores the international interest in GBL within STEM.

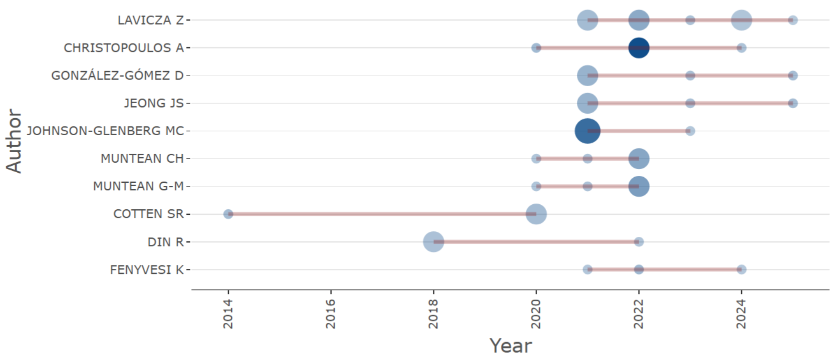

Figure 4. Authors' production over time

To present a comprehensive overview of the most influential authors in GBL-STEM research, taking into account their productivity trends over time, Figure 4 illustrates the total number of articles they have published from 2006 to 2025. The results illustrate the annual distribution of published papers, represented by circle dimensions, with each circle corresponding to an author's continuous publication activity. A larger circle signifies a higher number of articles published in a specific year, while a darker shade indicates a greater number of citations received within that period. Additionally, the connecting lines depict the duration of an author's publishing activity over time.

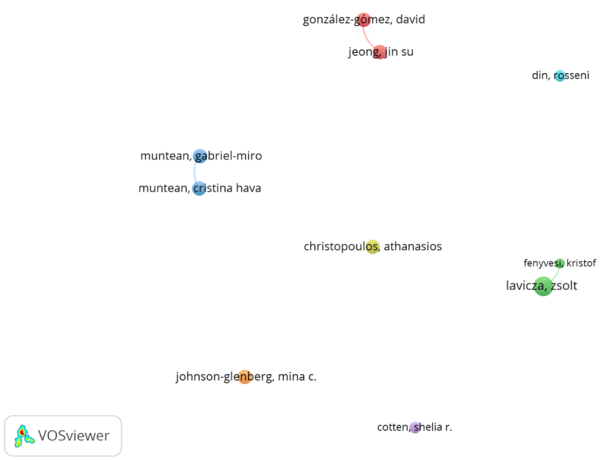

Figure 5. Authors' collaboration network of the top 10 most productive authors

The collaborations among the ten most productive authors are categorized into seven distinct clusters, indicating the presence of multiple research groups engaged in collaborative efforts. The size of each node represents the number of publications by an author, while the thickness of the connecting lines between two authors signifies the intensity of their collaboration (Figure 5). The figure reveals that the red (González-Gómez, D. and Jeong, J.S.), green (Lavicza, Z. and Fenyvesi, K.), and blue (Muntean, C.H. and Muntean, G.M.) clusters—each consisting of two authors—demonstrate a strong collaborative relationship. Meanwhile, the remaining four clusters comprise only a single author each. It indicates the need for greater collaboration among researchers worldwide in the field of GBL in STEM education.

Researchers exhibit varying levels of productivity in their scholarly output. This productivity can be analyzed using Lotka's law in bibliometrics, which estimates the scientific contribution of authors within the field of GBL-STEM. The findings, generated through Bibliometrix, are illustrated in Figure 6. The results indicate that a small proportion of authors are responsible for producing the majority of documents, whereas the number of publications decreases as the number of contributing authors per document increases. In summary, a limited number of authors generate a substantial portion of the publications, while the majority of authors contribute only a few documents. Specifically, 1,291 authors (90.7%) have authored only a single document on GBL-STEM, whereas only one author (0.10%) has contributed eight publications in this domain.

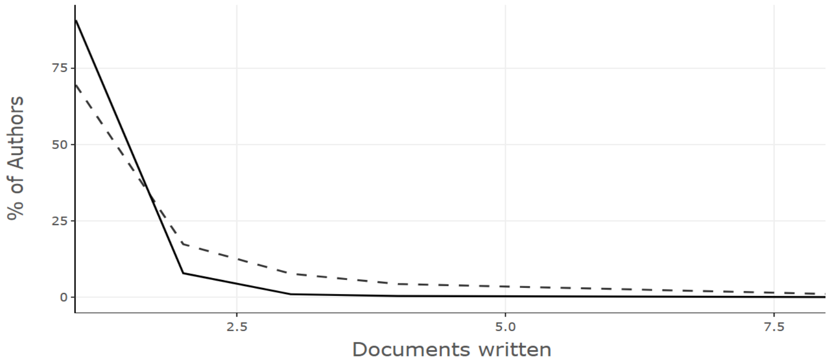

Figure 6. Author productivity through Lotka's law

Most Productive Countries

The analysis of GBL research in STEM education reveals significant contributions from various countries. The United States leads in the number of publications, with 149 papers, reflecting its strong research ecosystem and continuous advancements in this area. Despite its high publication count, the U.S. has an average article citation (AAC) of 24.91, suggesting widespread but moderately influential studies in this domain. The country's earliest contribution dates back to 2006 with Bhargava et al.'s (2006) study on a web-based virtual torsion laboratory, published in *Computer Applications in Engineering Education*, which laid the groundwork for subsequent research on GBL applications.

Spain, despite having only 30 publications, stands out with a remarkably high average article citation of 36.63, indicating that its contributions are highly influential within the academic community. The country's first significant paper in this field, conducted by Rodán et al. (2016)Technology, Engineering, and Mathematics and published in *Frontiers in Psychology* in 2016, examined how computerized mental rotation training influenced the visuospatial abilities of students aged 14 to 15 based on their experience with videogames to reduce the visuospatial gap between genders in STEM education. Malaysia has also made notable contributions, with 26 publications. However, its total citations (215) and average article citation (8.27) are relatively lower, suggesting that while research output is growing, the impact of its studies is not as extensive as in other leading countries.

Malaysia's first publication in 2015 by Sanmugam et al. (2015), which reviewed gamification as an educational tool, indicates the country's focus on motivational aspects in STEM education through GBL.

Table 3. Top 10 most productive countries

Country	NP	TC	AAC	FP
United States	149	3711	24.91	2006
Spain	30	1099	36.63	2016
Malaysia	26	215	8.27	2015
Taiwan	24	575	23.96	2015
United Kingdom	21	1013	48.24	2011
Australia	19	1075	56.58	2011
China	18	430	23.89	2015
Germany	15	268	17.87	2011
Singapore	12	210	17.50	2017
Canada	12	128	10.67	2015
Austria	12	872	72.67	2016

Beyond these three leading contributors, Austria stands out with the highest average article citation (72.67), despite having only 12 publications. This suggests that Austria's research, particularly Potkonjak et al.'s (2016) concepts such as distance learning, and open universities, are now becoming more widely used for teaching and learning. However, due to the nature of the subject domain, the teaching of Science, Technology, and Engineering are still relatively behind when using new technological approaches (particularly for online distance learning review on virtual laboratories in science, technology, and engineering education, published in *Computers and Education*, is exceptionally influential, possibly due to its comprehensive nature and broad applicability in STEM educational settings. Additionally, the United Kingdom and Australia exhibit strong citation performance, with average article citations of 48.24 and 56.58, respectively. Their early contributions in 2011 focused on virtual reality's role in education and immersive STEM experiences, underscoring the growing emphasis on interactive and experiential learning methods.

The collaborative relationships among the ten most prolific countries are categorized into three distinct clusters (Figure 7), comprising a total of 30 connections with an overall link strength of 51. In this network, the size of each node corresponds to a country's publication output, while the thickness of the connecting lines represents the strength of their research collaboration. The United States and Germany are both part of the blue cluster, signifying their prominent roles in fostering academic partnerships within this field. The United States, which has contributed 149 publications and accumulated 3,711 citations, maintains eight connections with a total link strength of 21, underscoring its extensive collaboration with other top ten nations. Meanwhile, Spain, positioned in the green cluster with 30 publications and 1,099 citations, has five connections and a total link strength of 8. The significant citation impact of the United States highlights its considerable influence on GBL-STEM research.

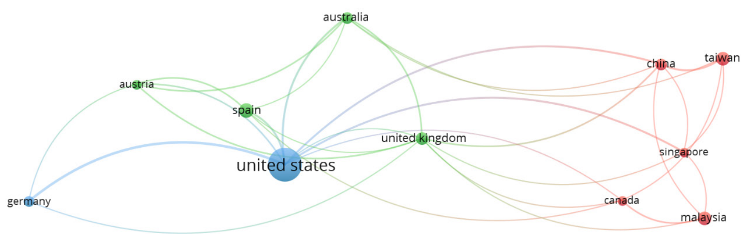

Figure 7. Country collaboration network of the top 10 most productive countries

Figure 8 indicates that over time, countries such as the United States, Spain, and Malaysia have made substantial contributions to research output. Notably, the United States has experienced a sharp rise in publications in recent years.

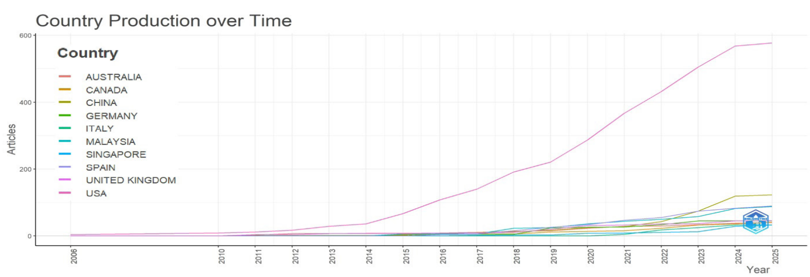

Figure 8. Countries' production over time

The three-field plot illustrates the connections between countries (left), author keywords (center), and journals (right) in GBL-STEM research. Larger rectangles signify elements with the highest number of relationships, while the thickness of the links represents the intensity of information flow between different values. Figure 9 presents Sankey diagrams depicting data from 10 countries, author keywords, and journals. The visualization highlights that researchers from the United States, China, Spain, and Malaysia have contributed significantly to shaping key research topics in GBL-STEM.

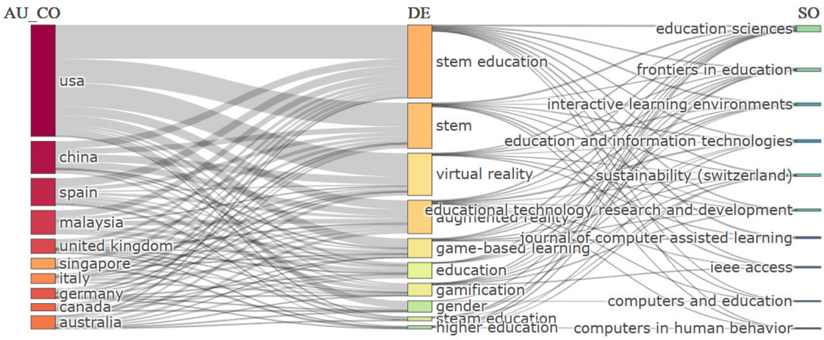

Figure 9. Three-field plot

It was found that countries with a higher volume of publications predominantly incorporated five key terms—STEM education, STEM, virtual reality, augmented reality, and game-based learning—highlighting their relevance in this field of study. The data further indicate that the United States is the leading contributor to nearly all of the top 10 keywords identified in the dataset. In addition to the US, China, Spain, and Malaysia also make significant contributions to publications associated with these keywords. Among these nations, the US demonstrates the most substantial influence on the keywords "STEM education," "STEM," and "virtual reality," though other countries also make notable contributions. Moreover, an analysis of the correlation between countries and academic journals reveals that publications from the US on "STEM education" and "augmented reality" are fairly distributed across various journals.

Most Productive Institutions

The research landscape on GBL-STEM has seen significant contributions from various institutions worldwide. Among them, Nanyang Technological University leads with ten publications, closely followed by Universiti Kebangsaan Malaysia with nine, and Arizona State University and Johannes Kepler University Linz with eight each. This indicates a strong commitment to GBL research in STEM education within these institutions, particularly in Southeast Asia, North America, and Central Europe.

Table 4. Top 10 most productive organizations

Institution	Country	NP	TC	AAC	FP
Nanyang Technological University	Singapore	10	191	19.10	2017
Universiti Kebangsaan Malaysia	Malaysia	9	111	12.33	2018
Arizona State University	US	8	447	55.88	2010
Johannes Kepler University Linz	Austria	8	94	11.75	2021
National Institute of Education	Singapore	7	180	25.71	2017
National Taiwan Normal University	Taiwan	7	301	43.00	2015
Michigan State University	US	7	211	30.14	2014
Pennsylvania State University	US	5	121	24.20	2020
NC State University	US	5	140	28.00	2014
Universidad de Extremadura	Spain	5	113	22.60	2020
University of Central Florida	US	5	95	19.00	2013
National College of Ireland	Ireland	5	84	16.80	2020

However, when considering total citations, a different trend emerges. Arizona State University has the highest total citation count (447), significantly surpassing other institutions. This suggests that its contributions have had a major impact on the academic discourse surrounding GBL in STEM. In contrast, Nanyang Technological University and Universiti Kebangsaan Malaysia have garnered 191 and 111 citations, respectively, reflecting a moderate but still influential presence in the field. A more refined metric, Average Article Citation (AAC), highlights the influence of individual publications. Arizona State University again stands out with the highest AAC (55.88), indicating that its research is not only widely recognized but also deeply influential. National Taiwan Normal University (Taiwan) follows closely with an impressive average citation count of 43.00, demonstrating strong academic engagement with its work. Michigan State University (US) also shows a high impact with an AAC of 30.14. These institutions have likely produced foundational studies that have shaped further research in game-based STEM learning.

The timeline of the first published articles from these institutions also provides insights into the evolution of this research area. Arizona State University published one of the earliest influential papers in 2010, titled A Next Gen Interface for Embodied Learning: SMALLab and the Geological Layer Cake, which appeared in the International Journal of Gaming and Computer-Mediated Simulations. This early contribution may have helped set the stage for subsequent studies. In contrast, Nanyang Technological

University and the National Institute of Education (both in Singapore) entered the field in 2017 with their research on problem-solving for STEM learning using games, while Universiti Kebangsaan Malaysia followed in 2018 with an augmented reality-based STEM learning approach. More recent contributions, such as those from Johannes Kepler University Linz (Austria) in 2021, indicate a continued and growing interest in integrating emerging technologies such as Augmented Reality and 3D Printing with GeoGebra in STEAM practices.

Most Relevant Journals

The research landscape on GBL-STEM reflects a growing interest across 222 academic journals, with notable contributions from different countries. Table 5 and Figure 10 present the top 10 active journals that published research in this field. When examining the number of publications, *Education Sciences* leads with 17 articles, followed by *Frontiers in Education* with 11 and *Sustainability Switzerland* with 10. These journals, particularly those published by MDPI, emphasize interdisciplinary approaches that integrate game-based strategies into STEM learning. The first recorded publication in this dataset appeared in 2011 in the *International Journal of Emerging Technologies in Learning*, discussing virtual reality as an educational tool.

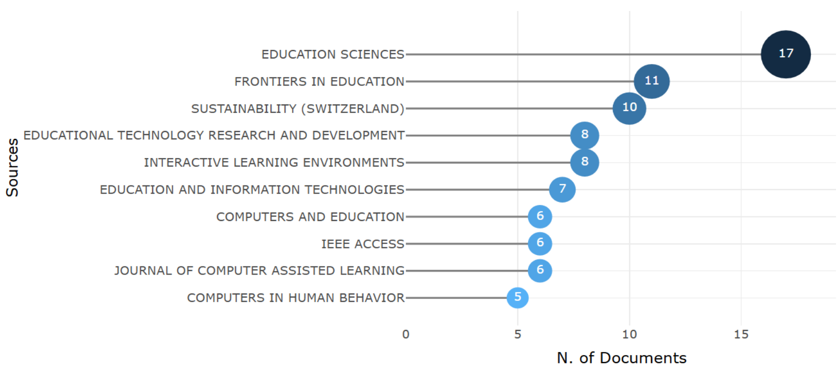

Figure 10. Most relevant sources

In terms of citation impact, *Computers and Education*, published by Elsevier, exhibits the highest total citation count (1149), underscoring its significant influence in the field. This is followed by *Educational Technology Research and Development* (329) and *Education Sciences* (319). The high citation numbers indicate the central role of technology integration in STEM learning and the sustained interest in understanding its impact on students' cognitive and affective development. Notably, the paper by Shank and

Cotten (2014)but little research has investigated the relationship between technology and empowerment for this population. We investigate how different aspects of technology use and ownership could empower urban youth through increasing their self-efficacy. Instead of simply a general measure of self-efficacy, we focus on several important domains related to STEM (Science, Technology, Engineering, and Mathematics in *Computers and Education* explores the empowering effect of technology on urban youth in STEM subjects, reflecting a broader interest in the intersection of technology, equity, and self-efficacy in education. *Computers and Education* also demonstrates the highest H-index (232), reinforcing its long-term impact in the field. Similarly, *IEEE Access* and *Computers in Human Behavior* also show strong academic recognition, with H-indices of 242 and 251, respectively. These values highlight the journals that have significantly shaped the research on game-based STEM learning. These journals are not only highly cited but also hold high SJR rankings, reflecting their prestige and rigorous peer-review processes.

Table 5. Top 10 most relevant sources

Journal	NP	TC	H	SJR(Q)	Publisher
Education Sciences	17	319	53	0.67(Q2)	MDPI
Frontiers in Education	11	87	40	0.63(Q2)	Frontiers Media S.A.
Sustainability Switzerland	10	167	169	0.67(Q1)	MDPI
Interactive Learning Environments	8	104	68	1.31(Q1)	Routledge
Educational Technology Research and Development	8	329	109	1.71(Q1)	Springer
Education and Information Technologies	7	267	76	1.30(Q1)	Springer
Journal of Computer Assisted Learning	6	389	114	1.84(Q1)	John Wiley and Sons
IEEE Access	6	70	242	0.96(Q1)	IEEE
Computers and Education	6	1149	232	3.65(Q1)	Elsevier
Journal of Science Education and Technology	5	245	80	1.60(Q1)	Springer
International Journal of Emerging Technologies in Learning	5	117	46	N/A	International Federation of Engineering Education Societies
Information Switzerland	5	146	59	0.70(Q2)	MDPI
IEEE Transactions on Education	5	169	76	0.79(Q1)	IEEE
Educational Technology and Society	5	184	111	1.56(Q1)	International Forum of Educational Technology and Society
Computers in Human Behavior	5	336	251	2.649Q1)	Elsevier

In terms of publishers, MDPI emerges as a major publisher in this domain, housing journals such as *Education Sciences, Sustainability Switzerland, and Information Switzerland*. This suggests a strong emphasis on open-access dissemination, making research more widely available. However, high-impact studies are more frequently published in well-established publishers such as Elsevier (*Computers and Education*, *Computers in Human Behavior*), Springer (*Education and Information Technologies*, *Journal of Science Education and Technology*), and Wiley (*Journal of Computer Assisted Learning*), indicating that these outlets attract research with sustained academic influence. The dominance of MDPI, Springer, Wiley, and Elsevier in this regard suggests that well-established publishers continue to shape the research on GBL in STEM.

Figure 11 illustrates the progression of top 10 journals over time, highlighting notable growth in *Education Sciences, Frontiers in Education,* and *Sustainability Switzerland*, particularly from 2017 onward. The *International Journal of Emerging Technologies in Learning* was the first to publish research on this topic in 2011. However, in recent years, *Education Sciences* has shown the most significant growth, with the number of publications in 2025 being four times higher than in 2020.

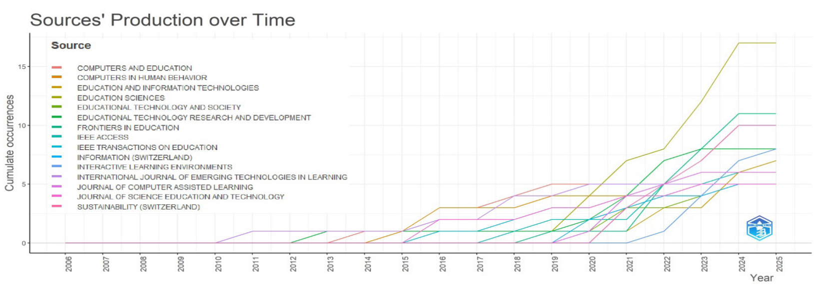

Figure 11. Sources' production over time

The distribution of document sources can be examined using Bradford's law, a bibliometric analysis principle. According to this law, the sources are categorized into three zones, with Zone 1 representing the core sources. These zones indicate the relative importance of sources within the studied field. As illustrated in Figure 12, the core zone consists of the most prolific sources. This figure highlights the primary sources, referring to the most prolific publication venues in the studied field. Within the core zone (Zone 1), a total of 22 journals were identified, accounting for 9.91% of the overall 222 journals analyzed. The most influential journal in this category is *Education Sciences*, which has published 17 articles and accumulated 319 citations. Meanwhile, Zone 2 comprises 66 journals, representing 29.73% of the total, while Zone 3 includes 134 journals, contributing 60.36% to the overall distribution.

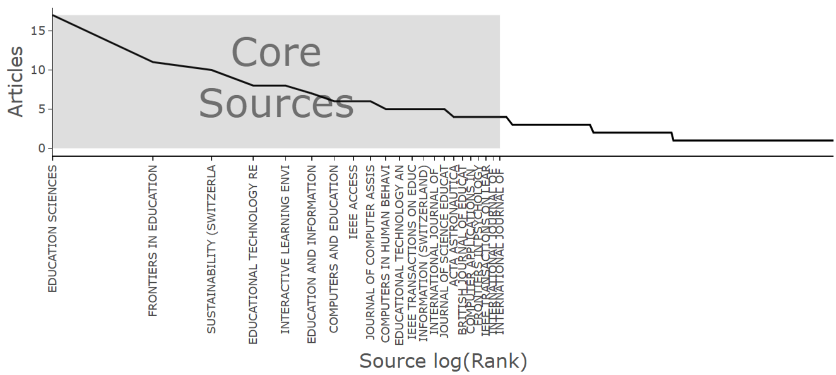

Figure 12. Bradford's law

Most Frequently Cited Manuscripts

Table 6 and Figure 13 present a detailed overview of the ten most highly cited journal articles, organized based on total citation count. Among the most influential works in this domain, three studies stand out based on the highest total citations, total citations per year, and overall impact on the field. One of the most cited studies is by Potkonjak et al. (2016)concepts such as distance learning, and open universities, are now becoming more widely used for teaching and learning. However, due to the nature of the subject domain, the teaching of Science, Technology, and Engineering are still relatively behind when using new technological approaches (particularly for online distance learning, titled "*Virtual laboratories for education in science, technology, and engineering: A review*," published in *Computers and Education*. With 677 citations and an annual citation rate of 67.70, this review paper systematically evaluates the role of virtual laboratories in STEM education. The study highlights the potential of virtual laboratories in supporting STEM learning. By synthesizing key technological advancements and pedagogical frameworks, this work has been foundational in shaping research and practice in digital laboratory simulations.

Table 6. Top 10 most cited documents

Author	DOI	Journal	TC	TCY
Potkonjak et al. (2016)	10.1016/j.compedu.2016.02.002	Comput. Educ.	677	67.70
Ibáñez & Delgado-Kloos (2018)	10.1016/j.compedu.2018.05.002	Comput. Educ.	609	76.13
Johnson-Glenberg (2018)	10.3389/frobt.2018.00081	Front. Robot. AI	236	29.50
Leonard et al. (2016)	10.1007/s10956-016-9628-2	J. Sci. Educ. Technol.	192	19.20
Aladé et al. (2016)	10.1016/j.chb.2016.03.080	Comput. Hum. Behav.	158	15.80
Mystakidis et al. (2022)	10.1007/s10639-021-10682-1	Educ. Inf. Technol.	147	36.75
Repenning et al. (2015)	10.1145/2700517	ACM J. Trans. Comput. Educ.	141	12.82
Lester et al. (2014)	10.1016/j.ins.2013.09.005	Inf. Sci.	122	10.17
Jesionkowska et al. (2020)	10.3390/educsci10080198	Educ. Sci.	118	19.67
Cooper et al. (2019)	10.1080/09523987.2019.1583461	Educ. Media. Int.	114	16.29

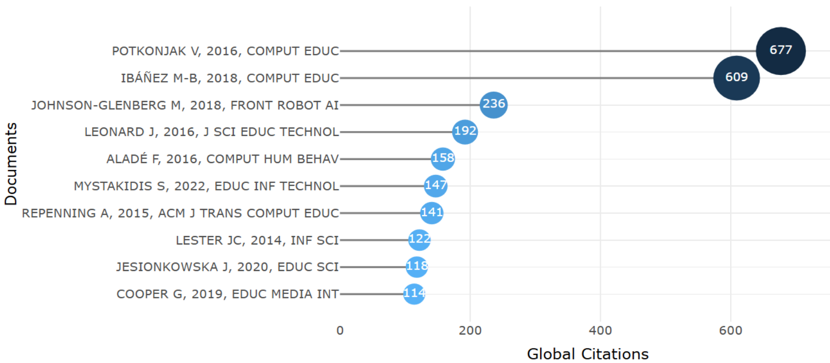

Figure 13. Top 10 most cited documents

Another highly influential study is by Ibáñez and Delgado-Kloos (2018), titled "*Augmented reality for STEM learning: A systematic review*," also published in *Computers and Education*. This paper surpasses Potkonjak et al. (2016)concepts such as distance learning, and open universities, are now becoming more widely used for teaching and learning. However, due to the nature of the subject domain, the teaching of Science, Technology, and Engineering are still relatively behind when using new technological approaches (particularly for online distance learning in terms of citation rate, with an impressive 76.13 citations per year and a total of 609 citations. Their review provides a comprehensive analysis of augmented reality (AR) applications in STEM education, emphasizing AR's potential to enhance conceptual understanding and affective learning outcomes. Johnson-Glenberg (2018) also made a significant contribution with the article "*Immersive VR and education: Embodied design principles that include gesture and hand controls*," published in *Frontiers in Robotics & AI*. While this paper has a lower total citation count (236), it stands out due to its high citation rate of 29.50 per year. This study focuses on the integration of virtual reality (VR) in STEM education, advocating for embodied learning through gesture-based interaction and hand controls. The paper provides empirical evidence on how VR environments can improve student engagement and retention by enabling active participation in STEM learning experiences. In terms of the most productive journal, *Computers and Education* emerges as a leading platform for research in game-based STEM learning. This journal has published two of the most highly cited articles in the dataset, reinforcing its reputation as a key venue for disseminating research on educational technology innovations.

Keywords Analysis

Figure 14 highlights the top 10 most commonly used author keywords. In this graph, the size of each keyword corresponds to its frequency of occurrence, with larger keywords appearing more frequently and smaller ones appearing less often. Among them, "STEM education" appears most frequently, with a total occurrence of 111 times. The second most frequent keyword is "STEM," which is mentioned 76 times, followed by "virtual reality," which appears 63 times.

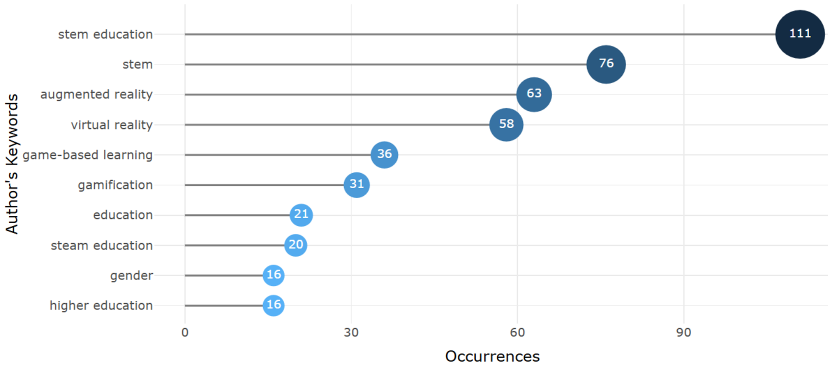

Figure 14. Most frequent words

Figure 15 displays a word cloud highlighting the most significant keyword combinations associated with GBL-STEM. This visualization displays the 50 most commonly appearing keywords in the analyzed documents, with "STEM Education" emerging as the most prevalent term. By leveraging this diagram, researchers can efficiently identify relevant studies based on keywords and analyze trends in the implementation of GBL within STEM education.

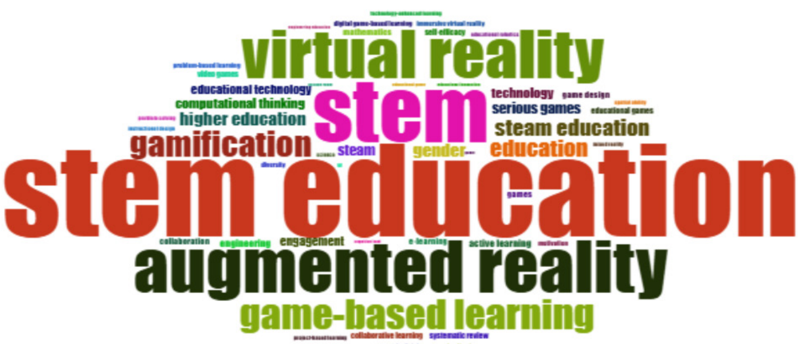

Figure 15. Word cloud by author keyword

Figure 16 presents the evolutionary trend of the author's keywords, with key milestones highlighted by the largest circles. The graph illustrates the thematic evolution of GBL-STEM research since its initial emergence in 2006. Notably, studies incorporating gamification, STEM, and education began to appear in 2021 and have shown a gradual upward trajectory, continuing to the present. Over time, an analysis of different periods allows us to identify the shifting research focus, particularly on the progressive exploration of GBL applications in STEM education.

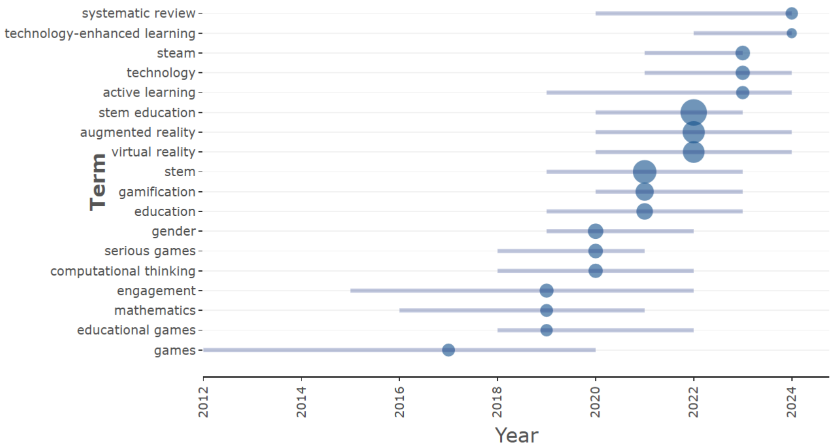

Figure 16. Trend topics of the GBL-STEM research

For the thematic evolution analysis, two cutoff points were selected, allowing us to generate a map of research interests across three distinct periods (Figure 17). During the first period (2006–2017), studies primarily focused on the integration of GBL and video games within STEM education, with an emphasis on game design and augmented reality to enhance educational experiences. Studies explored the potential of digital games as effective learning tools and investigated their impact on student engagement and knowledge acquisition. In the second period, between 2018 and 2021, the research focus shifted towards augmented reality and game design as innovative approaches to enhance learning motivation in STEM education. This period saw an increasing emphasis on interactive and immersive learning experiences that leverage games to improve student engagement and conceptual understanding. Between 2022 and 2025, recent research highlights the role of GBL and educational games in fostering learning motivation and engagement in STEM education. The integration of augmented reality continues to be a key focus, with studies exploring its potential to create more immersive and effective learning environments.

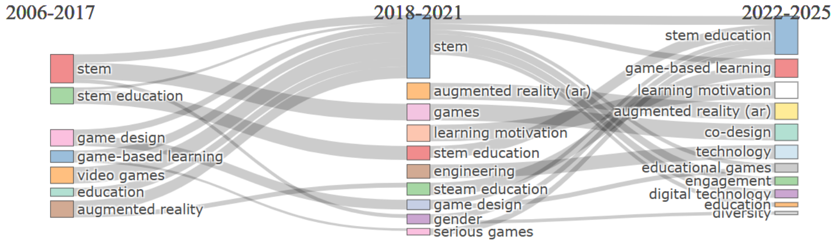

Figure 17. Thematic evolution of GBL-STEM research

Figure 18 illustrates the findings of the multiple correspondence analysis, highlighting a prominent red cluster that encompasses keywords such as "gamification," "augmented reality," and "educational technology." This clustering indicates a strong interrelation among these concepts.

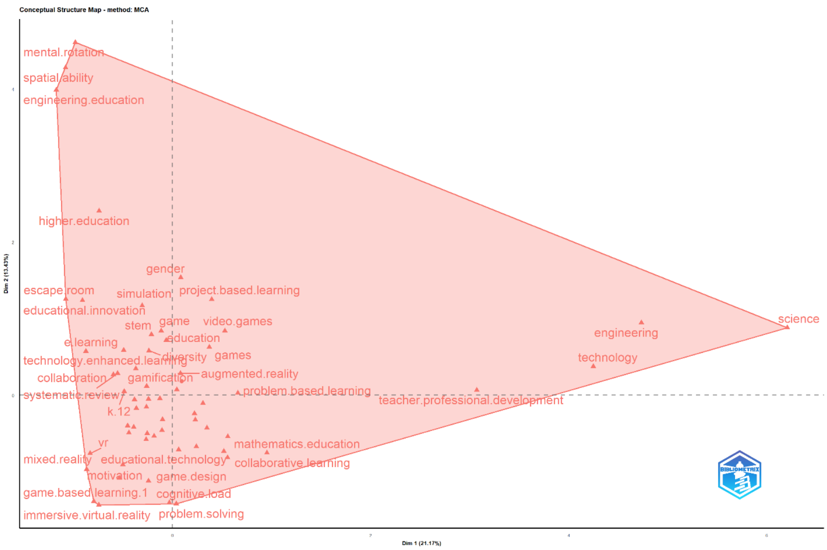

Figure 18. Multiple correspondences analysis

The thematic map is categorized into four distinct areas, each comprising four clusters arranged based on their density and centrality. These clusters consist of multiple keywords, as illustrated in Figure 19. The selection of the algorithm for keyword grouping determines both the number of clusters and their distribution within the thematic map. In this study, the Walktrap algorithm was applied. The results are visualized in four distinct quadrants, representing "motor themes," "niche themes," "emerging or declining themes," and "basic themes." This analysis seeks to explore and pinpoint relevant research topics from 2006 to 2025, highlighting shifts in themes and advancements in GBL within STEM education.

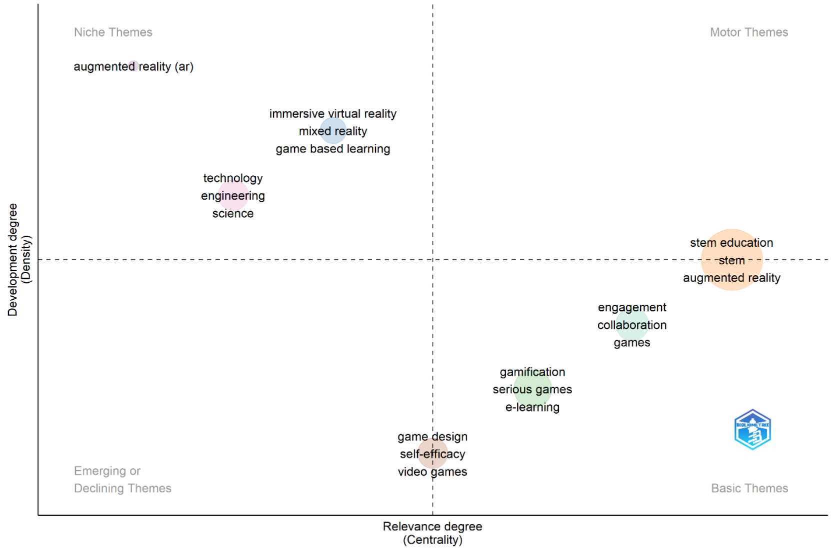

Figure 19. Thematic map for GBL-STEM research

- Motor themes: These themes (upper right quadrant) are both highly developed and central to the field, serving as fundamental drivers of research progress. Themes such as "STEM education", "STEM", and "augmented reality", remain essential yet continue to evolve in complexity and depth. Positioned between basic and motor themes, they highlight the diversity of ongoing research. For example, El Bedewy and Lavicza (2025) provided a comprehensive analysis of teacher professional development through GeoGebra visualization integrated with augmented reality. Their work is in line with the themes identified in this study, emphasizing the crucial role of AR games in STEM education.
- Niche themes: Although well-developed and specialized, these themes (upper left quadrant) have limited connections to the broader research landscape. Clusters such as "augmented reality", "virtual reality", "game-based learning", "technology", "engineering", and "science" are categorized as niche themes. For example, Singh and Sun (2025) explored the impact of GBL on STEM education, highlighting their role in enhancing empathetic engagement, minimizing negative social experiences, and fostering behavioral involvement among undergraduate and postgraduate students.
- Emerging or declining themes: Themes in this quadrant (lower left quadrant) exhibit low centrality and density, indicating either emerging research areas or those losing prominence. "Game design",

“self-efficacy”, and “video games” clusters are identified within this category, with their future trajectory depending on developments in the field. Ball et al. (2020) found that video game experience can influence STEM attitudes through the mediating role of computer self-efficacy. These themes, including “game design,” “self-efficacy,” and “video games,” have emerged as prominent research topics and are currently gaining increasing attention (Ortiz-Rojas et al., 2025; Petzel et al., 2024)progress towards gender parity in science, technology, engineering, and mathematics (STEM.

- Basic themes: These themes (lower right quadrant) are central to the research domain but remain underdeveloped, offering potential for further exploration. The “engagement”, “collaboration”, “games”, “gamification”, “serious games”, and “e-learning” clusters fall within this quadrant, signifying foundational yet evolving aspects of GBL-STEM research. In an empirical study, Wen (2021) examined the impact of augmented reality on learners’ cognitive engagement in language learning and recommended its use to enhance young learners’ involvement in the learning process.

The analysis of keyword co-occurrence plays a crucial role in identifying key research areas and provides a comprehensive overview of a research field, offering valuable insights into the topics explored and their interconnections. In this study, VOSviewer software was employed to perform a keyword co-occurrence analysis, as illustrated in Figure 20. The analysis was conducted using 407 documents retrieved from the Scopus database.

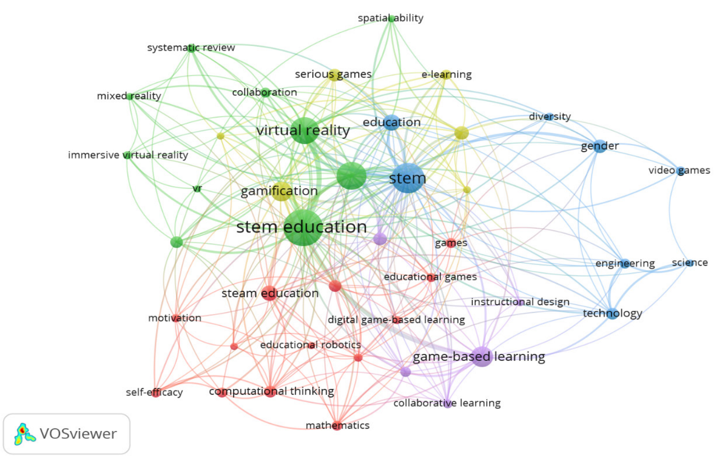

Figure 20. Co-occurrence of the author keywords

Figure 20 was generated by setting a minimum criterion of five keyword co-occurrences, which led to the identification of 42 keywords in total. These keywords were subsequently categorized into five distinct clusters—red, green, blue, yellow, and purple—illustrating their interconnections.

- Cluster 1 (13 items, red): *Engagement in STEAM Education* – focuses on the integration of STEAM education with game design to enhance student engagement and computational thinking through educational games. This cluster includes themes such as "STEAM education", "engagement", "computational thinking", "educational games", and "game design".
- Cluster 2 (10 items, green): *STEM Education and Emerging Technologies* – explores the role of augmented reality and virtual reality in STEM education, emphasizing the impact of educational technology on immersive and interactive learning experiences. The themes within this cluster include "STEM education", "augmented reality", virtual reality", and "educational technology".
- Cluster 3 (8 items, blue): *Gender Perspectives in STEM Education* – examines the intersection of STEM education, gender differences, and engineering through video games, highlighting inclusivity and representation in digital learning environments, covering topics such as "STEM", "gender", "education", "engineering", and "video games".
- Cluster 4 (6 items, yellow): *Gamification in Higher Education* – relates to the application of gamification and serious games in higher education, particularly within e-learning environments, to improve student motivation and learning outcomes. The themes associated with this cluster include "gamification", "serious games", "higher education", and "e-learning".
- Cluster 5 (5 items, purple): *Game-Based Learning in STEAM Education* – focuses on game-based learning approaches in STEAM education, emphasizing active and collaborative learning strategies to enhance student engagement and knowledge retention. This cluster includes concepts such as "game-based learning", "STEAM", "active learning", "instructional design", and "collaborative learning".

Figure 21 illustrates the evolving presence of key terms from January 2006 to March 2025, highlighting significant developments in GBL-STEM research. The analysis indicates that in 2011, the terms "augmented reality" and "virtual reality" appeared with relatively low frequency, suggesting that these topics received minimal attention at the time. However, their usage gradually increased over the years, reaching peak occurrences of

63 and 58, respectively, by 2025. This trend underscores the growing role of AR and VR games in STEM education. Furthermore, the terms "STEM education" and "STEM" have shown a marked rise in frequency, reflecting the expanding integration of STEM-related activities in educational settings. The increasing prominence of these keywords emphasizes the critical role of GBL in STEM instruction.

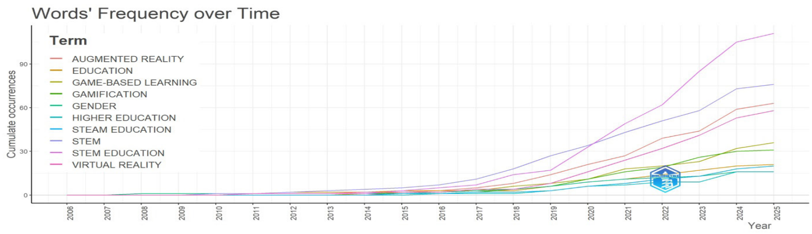

Figure 21. Words' frequency over time

Conclusion

The research on GBL-STEM in the period 2006-2025 has shown a significant increase in the number of published articles over the years, particularly after 2015. This suggests a growing academic interest in the integration of GBL within STEM education. In general, while Lavicza, Z. is the most prolific author in terms of publication count, Christopoulos, A. and Johnson-Glenberg, M.C. have made substantial impacts through citation numbers, suggesting that their work resonates deeply within the academic community. Meanwhile, Muntean, G.M. emerges as a highly influential researcher with the highest h-index, indicating sustained contributions to the field. These findings highlight the evolving landscape of GBL-STEM, where both publication quantity and citation influence play critical roles in shaping research directions. Overall, the findings indicate that while the United States dominates in publication volume, European countries such as Spain, Austria, and the United Kingdom demonstrate higher research impact per article. Meanwhile, Asian nations, including Malaysia and Taiwan, show growing engagement in GBL research, contributing valuable perspectives on gamification and virtual learning environments. This trend underscores a global shift toward innovative, technology-driven STEM education methodologies, with significant variations in research influence across regions.

In terms of institutions, Nanyang Technological University (Singapore), Universiti Kebangsaan Malaysia (Malaysia), and Arizona State University (US) stand out as the top three institutions in terms of the number of publications. The data highlight that GBL-STEM has been a growing research focus globally, with particularly strong contributions from institutions in the US, Singapore, and Malaysia. While the number of publications provides an overview of research activity, citation metrics reveal the depth of impact these studies have had. Arizona State University emerges as a leading institution in terms of influence, whereas National Taiwan Normal University and Michigan State University also demonstrate strong academic engagement. The research trend suggests that early contributions from the 2010s laid the foundation for the field, with continued innovation and new approaches being explored in recent years. As technology evolves, the impact and scope of GBL-STEM are likely to expand further, integrating newer advancements such as virtual and augmented reality into pedagogical frameworks.

Among the journals with the highest number of publications, *Education Sciences* leads with 17 articles, followed by *Frontiers in Education* (11 articles) and *Sustainability Switzerland* (10 articles). While these journals have contributed the most studies, the highest total citations are observed in *Computers and Education* (1,149 citations across 6 articles), *Journal of Computer Assisted Learning* (389 citations across 6 articles), and *Educational Technology Research and Development* (329 citations across 8 articles). This discrepancy suggests that although some journals publish more frequently on the topic, others have greater academic influence, as indicated by higher citation rates. GBL-STEM has experienced substantial growth, with MDPI and Springer leading in publication volume, while Elsevier and Wiley maintain high citation influence. The most impactful studies appear in journals with strong citation records, suggesting that while quantity matters, the depth of contribution ultimately defines the field's trajectory.

In recent years, digital educational games have become increasingly prevalent, establishing GBL as a major trend in STEM education (Kefalis & Skordoulis, 2025; Tene et al., 2025). However, there remains no clear consensus among researchers regarding its effectiveness. The integration of mobile technology into educational games has expanded opportunities for personalized and flexible learning (Fante et al., 2024; Gao et al., 2020), allowing students to engage with STEM subjects anytime and anywhere (Gao et al., 2020; Tene et al., 2025). Compared to conventional teaching methods, GBL has demonstrated the potential to enhance student motivation and comprehension of STEM concepts (Fante et al., 2024; Videnovik et al., 2023). The growing presence of video games in students' lives has also encouraged educators to explore their use beyond entertainment, incorporating them into educational settings to improve learning outcomes (Arztmann et al., 2023; Gui et al., 2023; Tene et al., 2025).

Gamified learning environments have proven to be valuable in STEM education by simulating real-world scenarios, enabling students to apply theoretical knowledge in practical contexts (Kefalis & Skordoulis, 2025; Videnovik et al., 2023). This experiential approach enhances comprehension and fosters a deeper connection to STEM subjects (Fante et al., 2024; Ilić et al., 2024). By creating interactive and engaging learning spaces, educational games encourage active participation while promoting the development of critical thinking and problem-solving skills (Gao et al., 2020; Moon et al., 2024). As a result, GBL has been recognized as an effective strategy for achieving STEM education goals (Gui et al., 2023), helping students not only grasp theoretical content but also understand its real-world applications.

Numerous studies suggest that GBL positively impacts student achievement, motivation, and engagement (Gao et al., 2020; K. Li et al., 2023; Moon et al., 2024). In STEM education, digital games facilitate the exploration of complex scientific phenomena that may be difficult to observe in traditional learning environments (Fante et al., 2024). Additionally, digital games allow students to virtually explore otherwise inaccessible locations or conduct experiments in simulated environments (Moon et al., 2024). Furthermore, GBL offers structured guidance and contextual support (Kefalis & Skordoulis, 2025), fostering essential skills such as problem-solving (Tene et al., 2025; Videnovik et al., 2023), which are crucial for success in STEM fields. As research continues to highlight its benefits, GBL remains a promising pedagogical tool for enhancing STEM education (Ilić et al., 2024; Stohlmann, 2023; Tene et al., 2025).

This study has some limitations, primarily due to the exclusive use of Scopus-indexed papers, which may have led to the exclusion of relevant publications indexed elsewhere. Although Scopus is a widely recognized and reliable database, integrating it with other sources, such as Web of Science (WOS), could enable a more comprehensive bibliometric analysis. Future studies should consider expanding the data sources to gain a broader perspective on the GBL-STEM field. Additionally, this study focused solely on journal articles, omitting other types of publications such as books, reviews, etc. Despite these limitations, the findings offer valuable insights into the landscape of GBL-STEM research.

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