



Mapping Research on Digital Game-Based Learning in Science Education: A Scientometrics Review

B. K. PRAHANI, I. A. RIZKI, Z. MIRTOSHEV

ABSTRACT

Introduction. Digital Game-Based Learning (DGBL) has gained increasing attention as an innovative approach to improving students' engagement, motivation, and conceptual understanding in science education. Although previous bibliometric studies have examined DGBL in general educational contexts, limited studies specifically focus on science education. In addition, previous reviews often relied on limited databases or analytical tools. Therefore, this study aims to map the research trends, thematic development, and knowledge structures of DGBL in science education to identify research gaps and future research directions.

Study participants and methods. This study employed a bibliometric review using the Scopus database. A total of 171 publications consisting of journal articles and conference papers published over the last two decades were selected through search, screening, and synthesis stages. Only English publications relevant to digital games in science education were included. Data were analysed using the Bibliometrix R-package to examine publication trends, citation performance, keyword co-occurrence, thematic evolution, co-citation networks, and collaboration patterns.

Results. The findings show a significant growth of DGBL research in science education, particularly after 2011. The United States and China were identified as the most productive countries. Highly cited studies mainly focus on experimental research examining learning achievement, engagement, and critical thinking skills. The keyword analysis revealed six major thematic clusters, including immersive technologies, computational thinking, pedagogical strategies, and psychological aspects of learning. Knowledge structure analysis also shows increasing interdisciplinary collaboration and the emergence of adaptive and immersive learning technologies.

Conclusion. This study provides a comprehensive overview of the research landscape of DGBL in science education and highlights important directions for future research, including integration with emerging technologies and more longitudinal intervention studies. However, the limitation of using only the Scopus database suggests future studies should incorporate multiple databases to provide a more comprehensive analysis.

KEYWORDS

bibliometric analysis, digital game-based learning, science education, scientometrics, bibliometrix, research trends, knowledge structure

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INTRODUCTION

Science education curricula worldwide share common goals but exhibit significant differences in structure, content, and teaching approaches. Typically, these curricula aim to develop scientific literacy, critical thinking, and problem-solving skills among students, encompassing the study of biology, chemistry, physics, and earth sciences, with an increasing emphasis on integrating technology and hands-on learning experiences. Despite the diversity in curricula, several common problems persist in science education globally. Many students find traditional science teaching methods unengaging and abstract, leading to a lack of interest and motivation in the subject [1]. There is often a gap between theoretical knowledge and practical application, with limited opportunities for hands-on experiments and real-world problem-solving [2]. Additionally, teachers may lack the necessary training and resources to effectively teach complex scientific concepts and engage students in inquiry-based learning [3].

On the other hand, bibliometric review found that technological advancements have transformed various sectors, including science education, over the past few decades [4]. The integration of technology into science education has led to significant changes in teaching methodologies, learning experiences, and educational outcomes [5]. This transformation is driven by the proliferation of digital tools, the internet, and the increased accessibility of smart devices. These changes have paved the way for innovative educational approaches, such as Digital Game-Based Learning (DGBL). Hussein et al. [6] explained that DGBL improves students' critical thinking skills in elementary science learning, while Chen et al. [7] showed that inquiry-enhanced digital game-based learning positively affects students' conceptual understanding and game performance.

Previous studies have conducted bibliometric analyses in various educational settings and subject-specific, shedding light on trends, patterns, and impacts of DGBL. For example, [8] performed a bibliometric evaluation of scientific studies on educational digital games in mathematics education, underscoring the field's importance in guiding future educational technology research and development. Most previous studies investigated bibliometric analyses of DGBL in general educational settings rather than specifically in science education. Hwang and Chen [9] focused on clustering and forecasting game-based learning trends, Schöbel et al. [10] examined game concepts in digital learning environments over two decades, while Trinidad et al. [11] analysed broader gamification research across educational contexts. A study closely related to the present research was conducted by Chen et al. [12], who performed an integrated bibliometric and systematic review of game-based learning in science and mathematics education. However, the limitation of their studies lay in their limited database (i.e., Web of Science), software analysis (i. e., VOSviewer), and not just involving digital games specifically (i. e., traditional games were also included). Thus, the recent study moves further by using other databases and software, and specifies the exclusive inclusion of digital games in the selected paper, which is explained in more detail in the methodology chapter. By doing so, it provides insights into the specific contributions and challenges of integrating DGBL in science education, setting it apart from the existing literature. Our proposed research questions are mentioned as follows:

RQ1: What are the information and thematic development of DGBL in science education publications?

RQ2: What are the knowledge structures of DGBL in science education publications?

THEORETICAL BACKGROUND

DGBL is an innovative educational approach that incorporates digital games into the curriculum or learning process. This method utilises games' engaging and interactive nature to enhance students' motivation and learning outcomes [13]. DGBL can make learning more enjoyable and engaging by incorporating game elements such as challenges, rewards, and storytelling, which help sustain students' interest in science subjects. Behnamnia et al. [14] highlighted that game-based learning improves learners' engagement through interactive experiences, while Hussein et al. [15] showed that DGBL in science education supports students' motivation and active participation. Past empirical evidence showed that the application of DGBL in science instruction can significantly enhance students' learning outcomes and motivation. Alrehaili and Al Osman [16] found that virtual reality

role-playing games improve experiential learning, while Rose et al. [17] reported that gamification elements in physics classes increase student engagement and motivation, technology acceptance [18], and self-efficacy [19]. Other studies have also found that this kind of technology can reduce students' cognitive load and learning anxiety. Tsai and Hsu [20] demonstrated that guided digital detective games support science learning while lowering cognitive burden, whereas Verkijika and De Wet [21] found that technology-assisted learning environments help reduce students' learning anxiety.

As a result, the recent interest in DGBL research within science education has grown significantly over the past decade, as evidenced by the increasing number of publications on the topic [22]. However, despite this growing body of literature, the research remains fragmented, with studies often focusing on isolated aspects rather than providing a comprehensive overview. This fragmentation presents a challenge in identifying overarching trends and gaps that need to be addressed. To address this, bibliometric analysis can help synthesise the existing research, reveal correlations, and determine future research directions. Donthu et al. [23] explained bibliometric analysis as a systematic approach for identifying research trends and influential studies, while Lizano-Mora et al. [24] demonstrated its usefulness in mapping the evolution of scientific fields and revealing knowledge structures. It is a valuable tool for analysing the research landscape and assessing the impact of scientific literature. It also quantitatively analyses academic publications to uncover patterns, trends, and relationships within a specific area. By examining publication data, citation networks, and research themes, bibliometric analysis provides a comprehensive overview of the current state of research, highlighting influential works, key contributors, and emerging topics [25]. Thus, this approach is particularly effective for identifying research gaps and guiding future studies towards areas that require further exploration.

RESEARCH METHODS

In order to pinpoint and chart research trends in the area of DGBL in science education, this study employed a bibliometric review. Yang et al. [26] explained that bibliometric analysis is useful for identifying research patterns and scientific knowledge mapping, while Chen et al. [27] demonstrated its effectiveness in visualising research trends and thematic developments in educational studies. Bibliographic databases are necessary for bibliometric studies to supply data about scientific publications, including titles, authors, abstracts, keywords, and references. Scopus, which was well-known for being one of the most prominent curated citation and abstract databases, was one of the databases appropriate for this use [28]. On a regional and international level, it provided comprehensive coverage of scientific journals. Only high-quality data were indexed because of the database's strict content selection and reevaluation procedures [29]. Furthermore, Scopus offered support for a number of platforms and formats for data analysis.

This study focused on publications from the last two decades and limited the document types to journal articles and conference proceedings because these are the most prevalent and representative forms of scientific publications, they typically included original research findings that could be analysed and compared using bibliometric methods and indicators. This selection process was adapted from H. E. Chen et al. [27], consisting of three stages: search, screen, and synthesis. Furthermore, only articles written in English were included during the selection process. Following that, a number of articles were vetted to remove duplicates and assess their applicability to the research question. For instance, articles that focused on gaming activities rather than pedagogical and taught subjects other than science education were eliminated and excluded. Ultimately, this bibliometric review included and reviewed 171 articles. The entire article selection process is presented in Figure 1.

Software called Bibliometrix was used to visualise the data. A wide range of bibliometric indicators, including publication and citation counts, co-authorship networks, and keyword co-occurrence networks, could be analysed due to the software's extensive set of data analysis features [30]. Furthermore, the software facilitated the use of uniform and standardised bibliometric metrics and indicators, guaranteeing the validity of the data analysis and its comparability with previous research in the field of DGBL in science education.

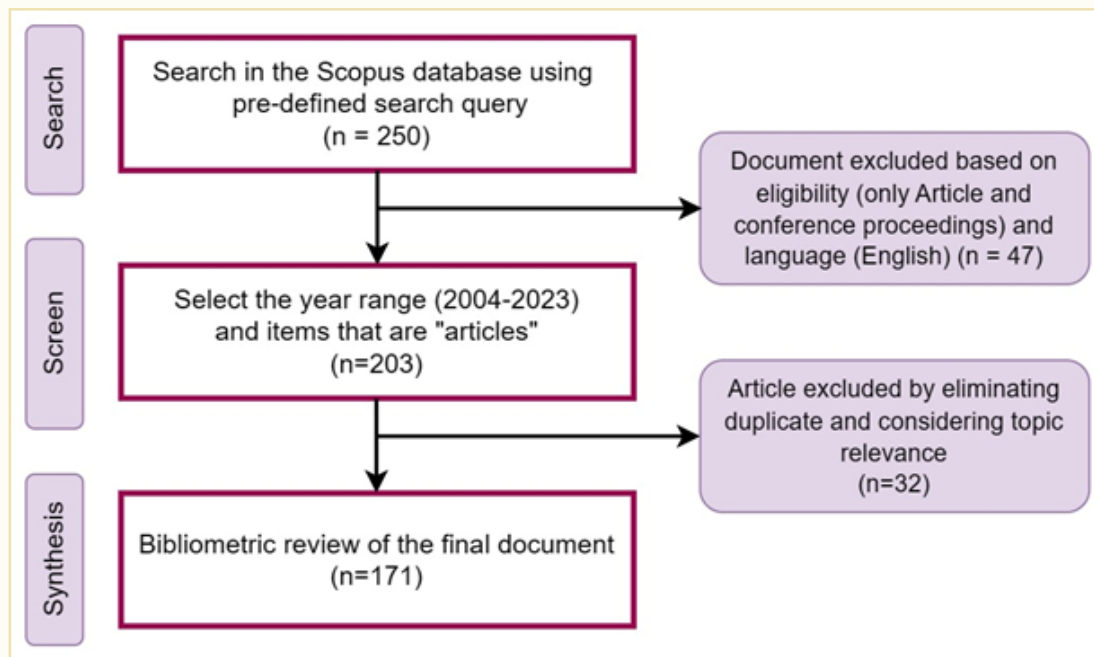


Figure 1 Article selection process and methods

RESULTS

2.1 Information and Thematic Development of DGBL in Science Education

Figure 2 presents a visualised representation of prolific scholars, their countries, and specific areas of interest within the field of DGBL in science education. Among the countries, the USA has the most author affiliations, with nine authors connected to the country. In terms of scientific publications by country, the USA is the most active in publishing articles on the topic of DGBL. China ranks second, the prominence of the USA and China in this field is due to their substantial contributions to educational technology.

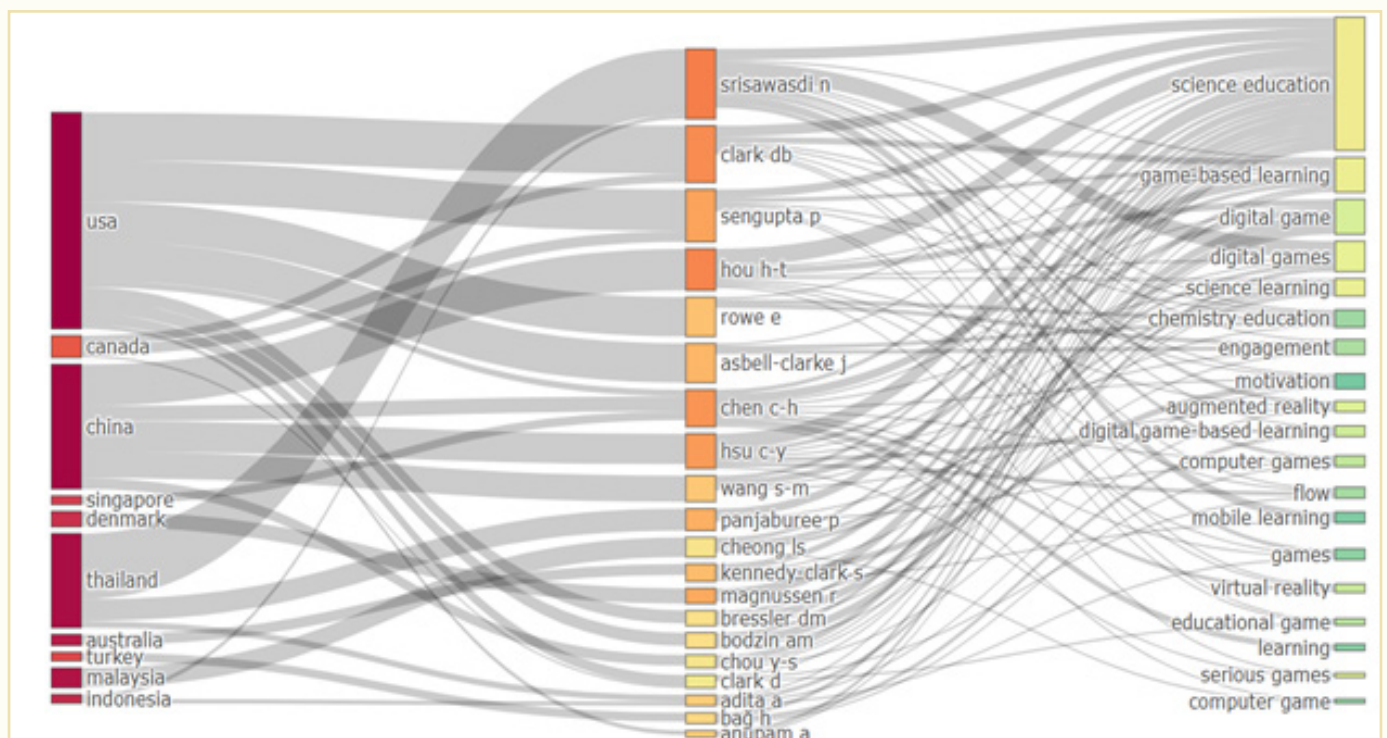


Figure 2 A three-field plot of countries, authors, and themes of DGBL in science education

Table 1 Most highly cited DGBL in science education studies

Total Citation	TC per Year	Author(s)	Source
368	20.44	(Squire & Jan, 2007) [31]	J SCI EDUC TECHNOL
142	14.20	(Hou, 2015) [32]	COMPUT HUM BEHAV
137	9.13	(Johnson & Mayer, 2010) [1]	COMPUT HUM BEHAV
127	21.17	(Liao et al., 2019) [3]	COMPUT EDUC
105	13.13	(Khan et al., 2017) [2]	EDUC INF TECHNOL
96	5.33	(Wong et al., 2007) [33]	ACM INT CONF PROC SER
86	14.33	(Hussein, Ow, Cheong, Thong, et al., 2019) [6]	IEEE ACCESS-a
72	9.00	(Kao et al., 2017) [34]	COMPUT EDUC
61	4.36	(Kennedy-Clark, 2011) [35]	COMPUT EDUC
55	3.93	(Hsu et al., 2011) [36]	J SCI EDUC TECHNOL

In Table 1, Highly cited articles in the field of DGBL in science education predominantly employ experimental research methods. Johnson and Mayer [1] investigated self-explanation principles in game-like multimedia environments, while Squire and Jan [31] explored scientific argumentation through augmented reality games. Hou [32] examined learners' behavioural patterns in simulation games, Wong et al. [33] evaluated serious video game effectiveness, Kao et al. [34] focused on customised scaffolding in physics game-based learning, and Kennedy-Clark [35] analysed pre-service teachers' perspectives on virtual worlds in science education, Qualitative and classroom-based studies were also significant. Khan et al. [2] examined the effects of digital game-based learning and gamification on student engagement and gender differences in secondary science education, while Hsu et al. [36] investigated how the Prediction-Observation-Explanation strategy supported preschoolers' scientific knowledge construction through computer games, review-based and analytical studies were also influential. Liao et al. [3] examined the effects of video interactivity and collaboration on learning achievement and intrinsic motivation, whereas Hou [32] analysed learners' flow and behavioural patterns within simulation-based science learning environments. DGBL is believed to enhance science learning by improving conceptual understanding [1], increasing engagement [2], and enhancing problem-solving and critical thinking skills [6]. It also positively impacts learning achievement, intrinsic motivation, and cognitive load [3]. Squire and Jan [31] made a significant contribution to this field by exploring instructional strategies in DGBL and comparing collaborative and individual learning approaches. Offering optional hints and clarifying challenges can reduce students' stress and promote a deeper understanding of the game's content [34].

2.2 Evaluation of Knowledge Structures

Three primary types of research questions can be addressed by bibliometric analysis for scientific mapping [37], (1) The conceptual structure, (2) The intellectual structure, and (3) The social network structure. To explore about Evaluation of Knowledge Structures based providing the following insights: (1) The conceptual structure, which makes it easier to analyse the cutting edge of research within a given theme or field of study; (2) The intellectual structure, which is used to pinpoint the body of knowledge that underpins a theme or field of study; and (3) The social network structure, which makes it possible to pinpoint the output from a particular scientific community.

2.2.1 Conceptual Structure

A visual depiction of the connections between keywords in a collection of publications is given by the co-occurrence network of DGBL in science education publications, as shown in Figure 3. Six thematic clusters make up the co-occurrence network; each cluster represents a collection of related terms that point to common themes and future areas for research. Analysis of this network is represented in Table 2.

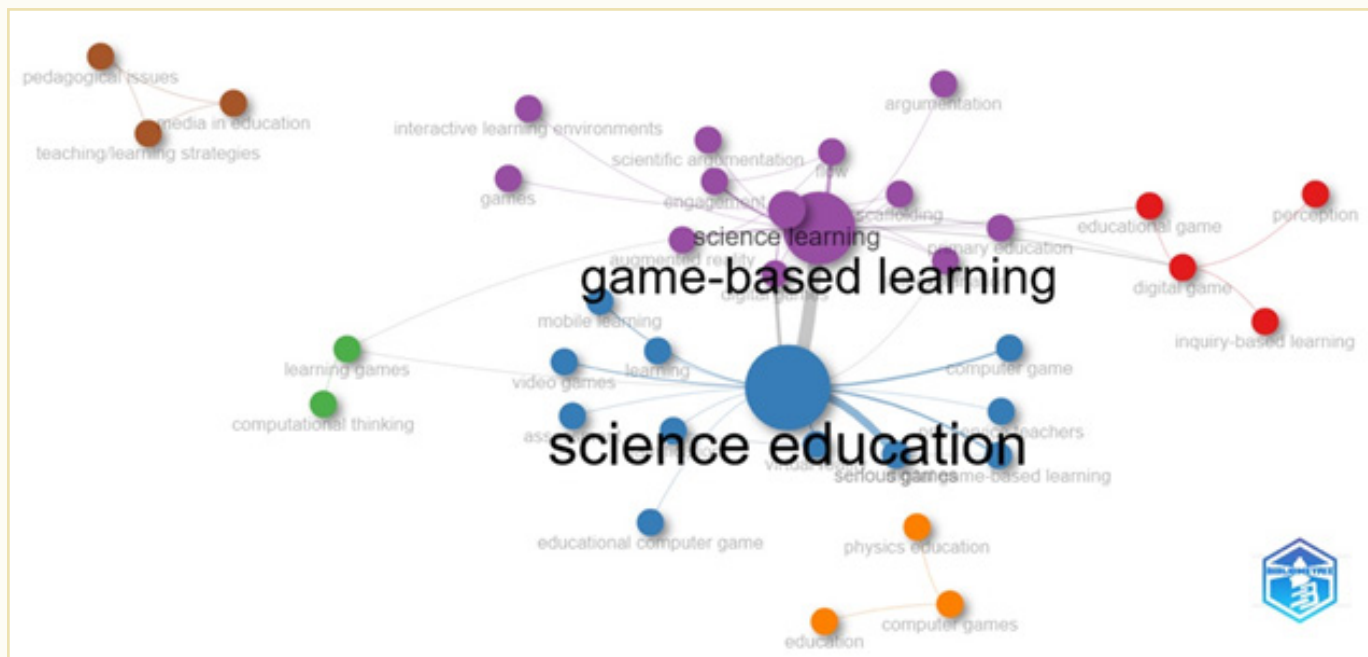


Figure 3 Co-occurrence network

Table 2 Clusters in DGBL in science education research and their insights

Cluster (Colour)	Key Insights
1 (Red)	This cluster indicates a foundational interest in the types of games used and their impact on investigative learning methods and student perceptions. This foundational cluster reflects the early stages of integrating game-based strategies into educational settings.
2 (Blue)	This cluster reflects the advanced applications and methodologies being explored, such as the integration of virtual reality and gamification techniques. The variety of keywords also indicates the broad applications and target audiences for DGBL.
3 (Green)	Learning games play a pivotal role in connecting different research areas. There is a focus on enhancing problem-solving and logical reasoning skills through computational thinking.
4 (Purple)	Emphasis is on making an immersive and engaging learning environment. Key topics include cognitive processes and critical thinking skills, supported by technologies like AR.
5 (Yellow)	This cluster highlights the traditional use of games in teaching specific subjects, suggesting their fundamental role in educational contexts.
6 (Brown)	It reflects the importance of pedagogical strategies and the role of media in education in maximizing the effectiveness of DGBL.

The thematic map of DGBL in science education is another analysis carried out in this research. The objective of conducting this map is to gain an understanding of the field's current state and potential for sustainability. Researchers and stakeholders can benefit from this analysis by learning about the possibilities for thematic area research development in the future within a field [38]. Figure 4 depicts the thematic map of the DGBL in the science education field, divided into four quadrants (Q1 to Q4).

Figure 5 illustrates a thematic dendrogram that effectively visualises the division of dimensions in accordance with the dimensions determined by Petchey & Gaston [39]. It illustrates how the main DGBL in science education terms are still intimately related while also emphasising the distinctive qualities of particular terms and ideas, ultimately resulting in a more thorough comprehension of the fundamental framework of the research.

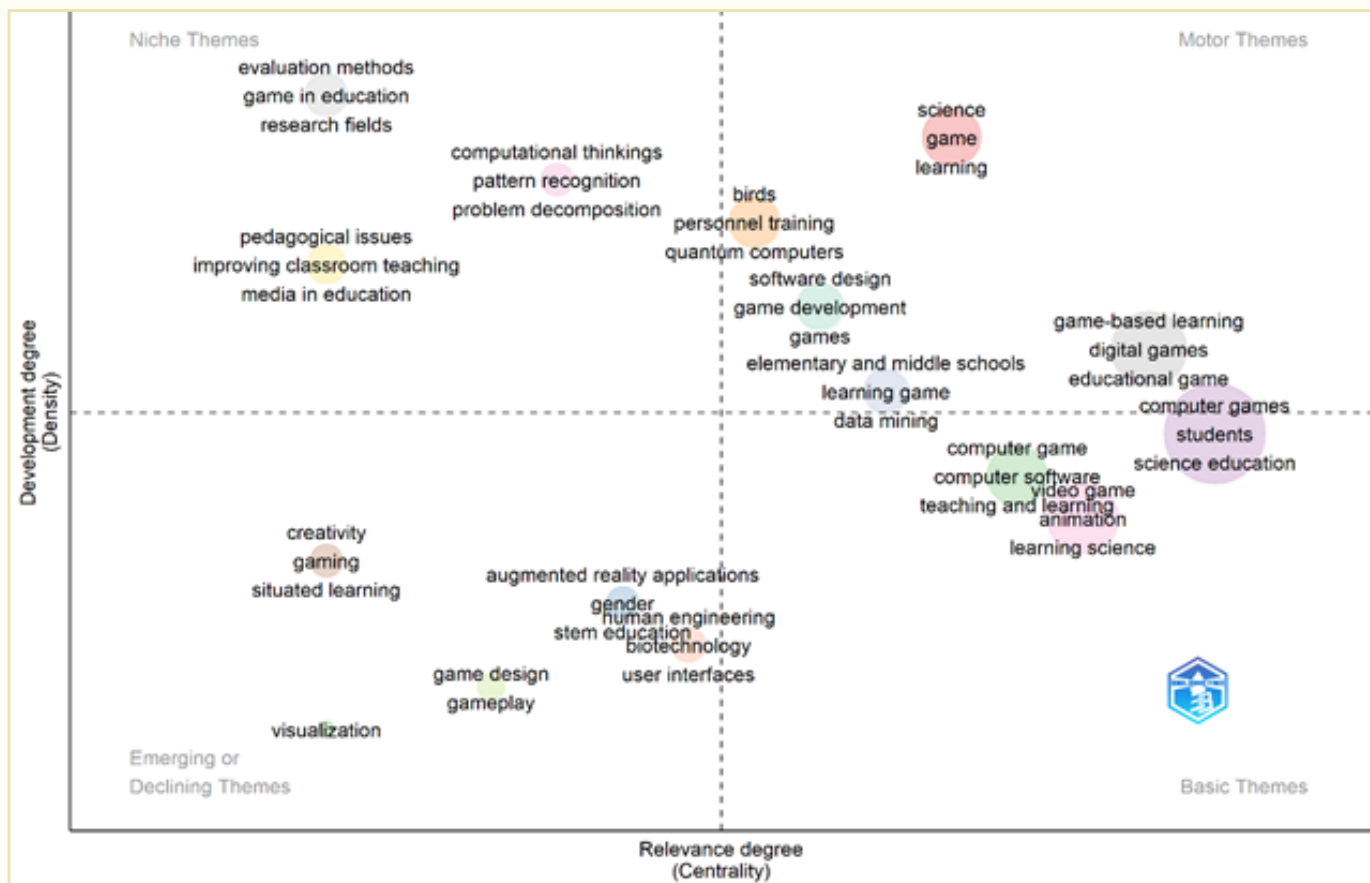


Figure 4 Thematic map

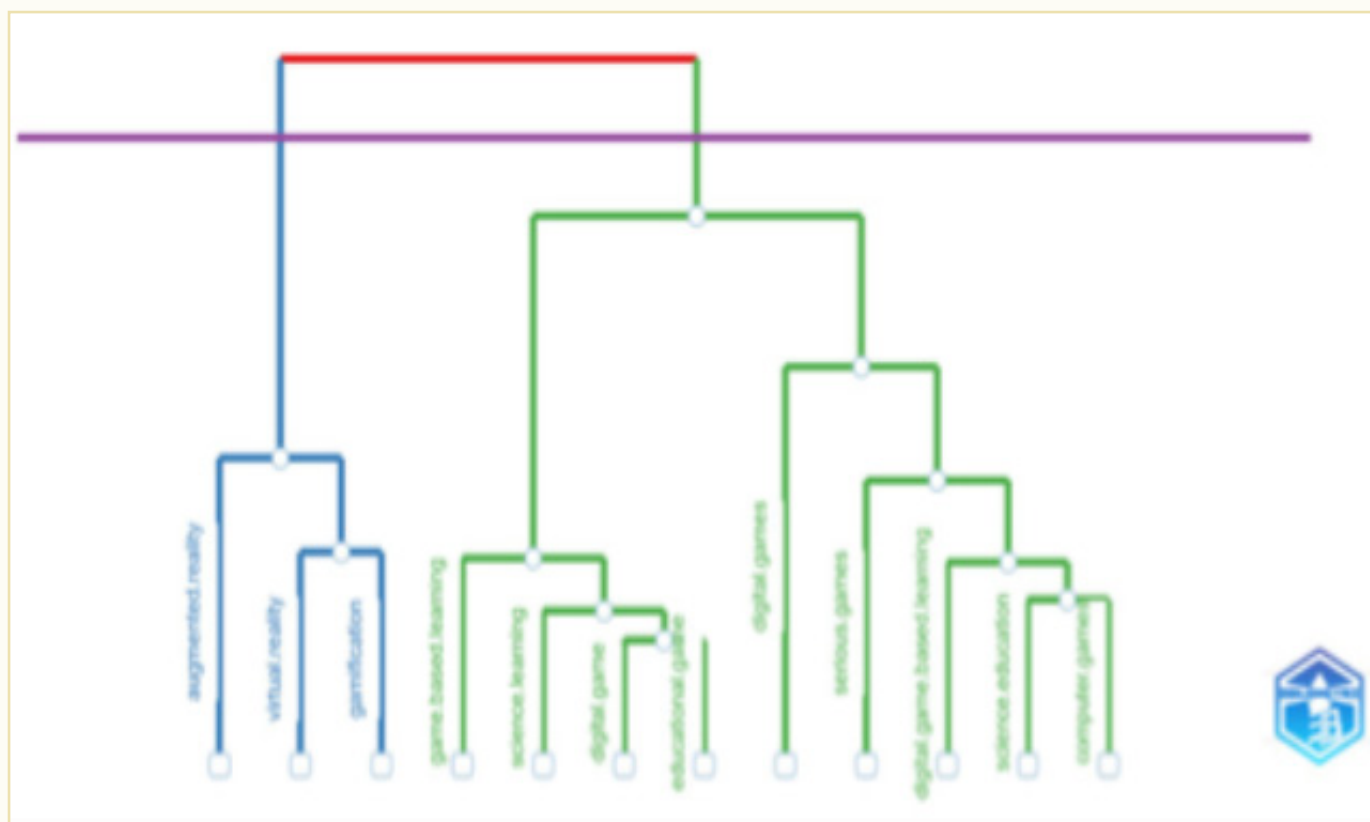


Figure 5 Thematic dendrogram of DGBL in science education

2.2.2 Intellectual Structure

Historiographies and co-citation networks are valuable tools for evaluating the intellectual structure of the literature on DGBL in science education. Figure 6 presents the co-citation network, which shows the occurrence of two publications being cited together in a third publication. According to the visualisation, three distinct clusters have formed, each cluster represents a substantial body of related literature and reflects major intellectual foundations within the field. The co-citation network reveals five major intellectual clusters representing influential foundations of DGBL research. Cluster 1 (red) includes studies by Dorji et al. [40] and Kim et al. [41], which focus on educational computer games, energy conservation learning, and metacognitive strategies in game-based learning. Cluster 2 (blue), represented by Wouters et al. [42], highlights the cognitive and motivational effects of serious games through meta-analysis. Cluster 3 (green) consists of foundational theoretical works by Gee [43], Lave [44], and Vygotsky [45], emphasizing situated learning, communities of practice, and social constructivism in learning processes. Cluster 4 (purple) is represented by Prensky [46], whose work strongly shaped the conceptual foundation of digital game-based learning. Cluster 5 (orange) includes Cohen [47], whose methodological contribution supports the statistical and analytical rigor of educational research. Although less central, Cohen's work provides important methodological contributions supporting the field's research framework.

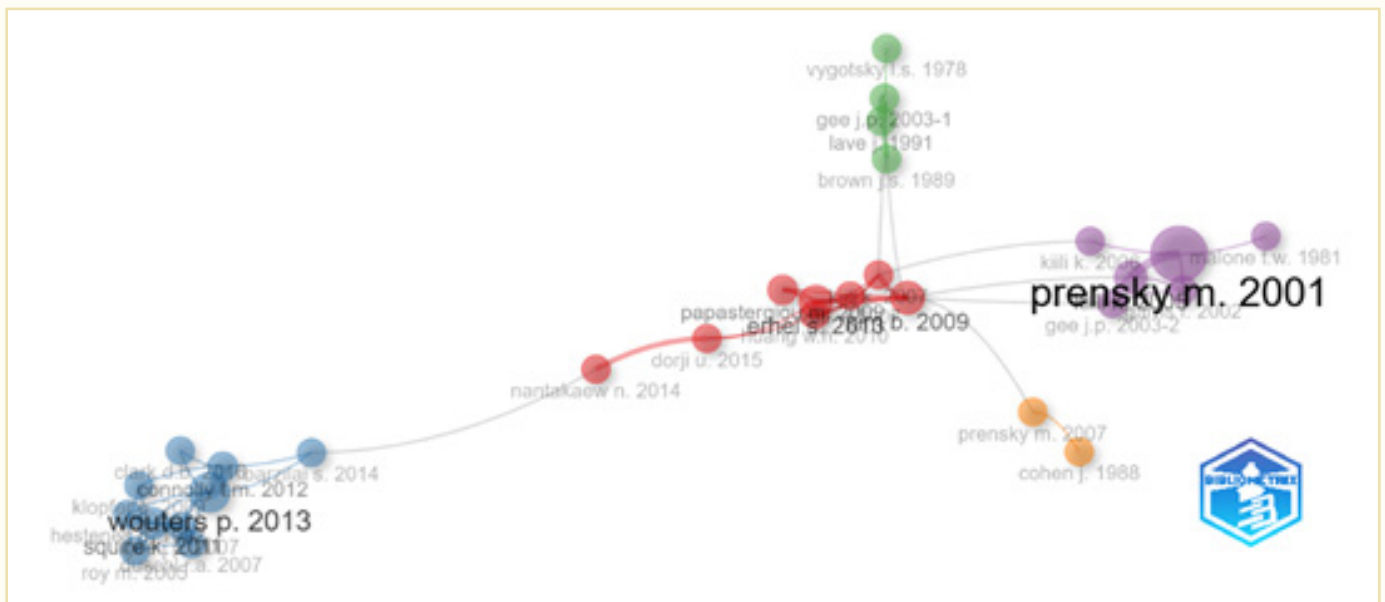


Figure 6 Co-citation network

The historiography map analysis (Figure 7) shows the trajectory of studies and notable authors across various timeframes. Examining the historiographic map over time also reveals the progression and development of DGBL in science education, illustrating how research focus and themes have evolved. Early foundational studies from 2013 to 2015, such as Hsu & Tsai [48] and Eastwood & Sadler [49], explored the integration of cognitive strategies and game-based curricula, highlighting the need for effective teacher training and aligning game design with pedagogical goals. During the mid-development phase from 2016 to 2019, research expanded to include adaptive learning technologies and their impact on student engagement, as seen in Clark et al. (2016) [50] and Wilson et al. (2018) [51]. This period also saw the introduction of augmented reality and collaborative mobile games, reflecting a growing interest in creating immersive educational experiences. Recent advances from 2020 to 2023, such as those by C.-H. Chen et al., 2020 [12], 2023 [27] and Hussein, Ow, Cheong, & Thong (2019) [15], focused on the effects of inquiry-enhanced digital games and adaptive scaffolding, demonstrating a sophisticated understanding of DGBL. These studies emphasised adaptive learning, systematic reviews, and comparative analyses, suggesting a maturation of the field.

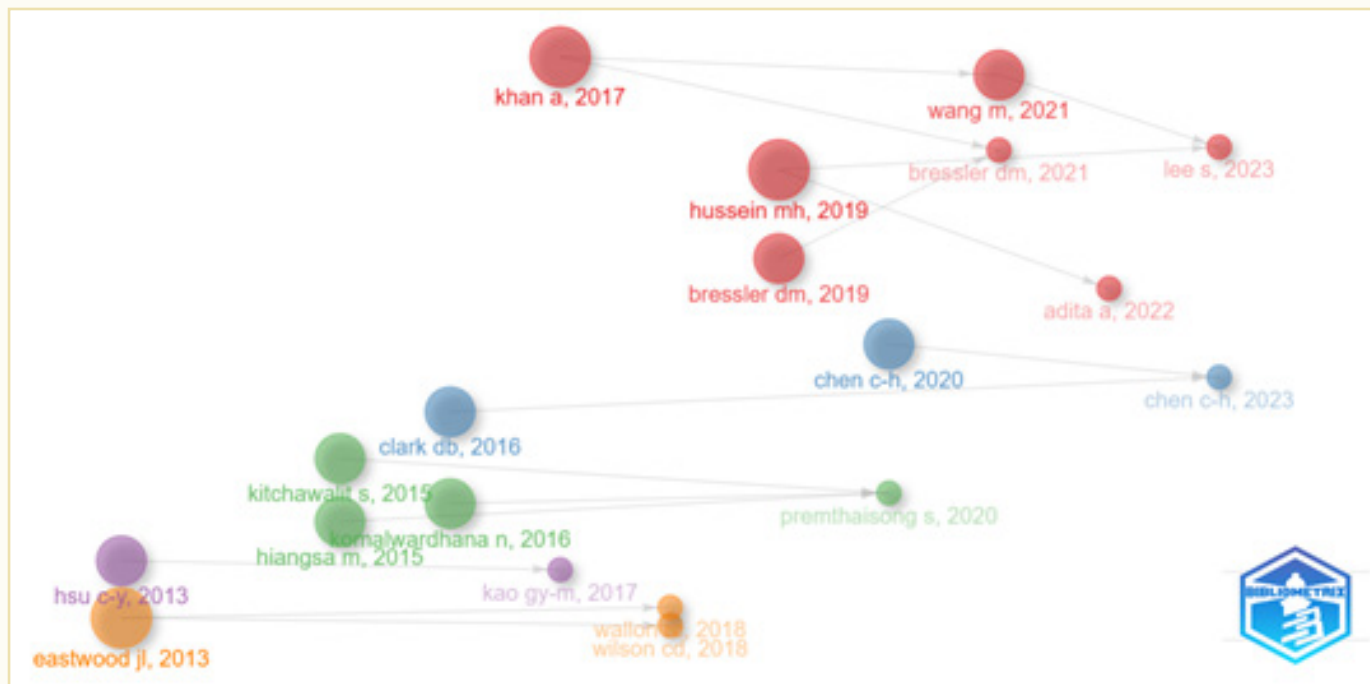


Figure 7 Historiograph map

2.2.3 Social Structure

A collaborative map among nations and an analysis of the co-author network are used to analyse the social structure. The authors' collaboration network, as depicted in Figure 8, is a reflection of the analysis performed on the co-author network. The complex relationships between authors in the DGBL in the field of science education are identified by this analysis. Understanding these network dynamics can aid in identifying key collaborators and influential figures, which can be valuable for fostering future research collaborations and enhancing the overall impact of DGBL in science education.

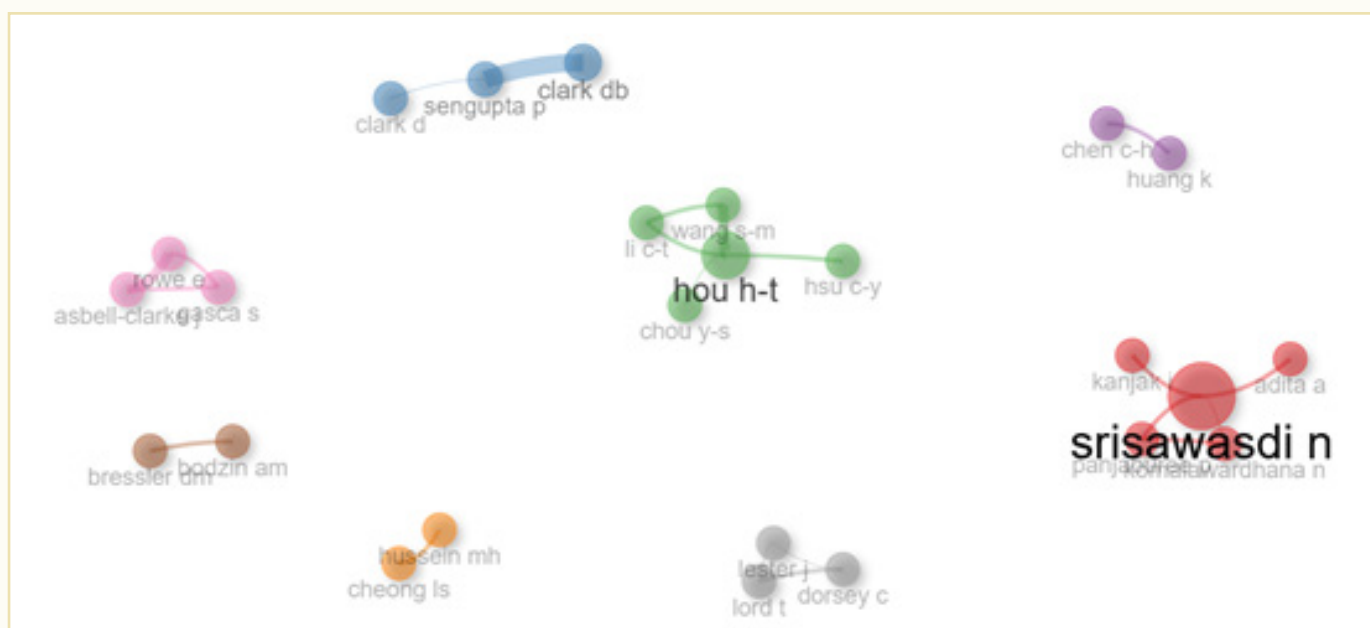


Figure 8 Collaboration network

DISCUSSION

The development of DGBL in science education indicates a growing body of research, especially post-2011, with notable peaks in 2015 and 2017, highlighting increasing recognition of DGBL's educational potential. The researchers' profiles show prolific contributions from scholars like Srisawasdi, N. and Clark, D.B., primarily affiliated with the USA, China, and Thailand, and publications often appear in prominent educational journals. Highly cited articles underscore DGBL's impact on conceptual understanding, engagement, and critical thinking. The USA and China are the most productive countries, with leading institutions driving this research forward. Keyword trends underscore a strong interest in how the technologies can be effectively utilised in educational settings to support science learning and teaching. Finally, the knowledge structures reveal interconnected themes and collaborations, with significant contributions from specific scholars and countries shaping the research landscape.

For implications, several important directions for future research in DGBL in science education can be identified based on previous studies. These studies not only provide supporting evidence but also explain how digital games can be more effectively integrated into science learning environments.

- *Combining specific learning approaches with digital games:* In using digital games in the science classroom, the instructor needs to determine how the material is delivered and the role of digital games in assisting it. Coleman and Money [52] explained that student-centred digital game-based learning encourages active participation and engagement because students actively explore, experiment, and solve problems within the game environment. Similarly, Wardani et al. [54] found that inquiry-based digital games improve critical thinking and learning outcomes in science classrooms.
- *Integration with other emerging technologies:* The use of advanced technology can enrich the science learning environment through immersive and engaging experiences, like AR and VR. Anderson and Barnett [55] found that digital game simulations help students understand physics concepts more effectively, while Rizki et al. [56] showed that augmented reality combined with digital games improves students' critical thinking skills and learning motivation.
- *"Science" computational thinking in DGBL:* Recently, computational thinking is not limited to computer science but extends to other fields, including science. Garneli and Chorianopoulos [57] investigated how constructing video games improves students' computational thinking skills and motivation in science education, highlighting the importance of integrating programming-based contexts into DGBL.
- *Effect of DGBL on students' psychology and behavioural aspects:* Since it is generally known that DGBL positively improves students' motivation, engagement, and achievement, research into both aspects may still be limited. Plass et al. [58] explained that emotional design elements such as colour, expression, and character appearance influence students' affective engagement during gameplay. Yang et al. [59] also found that students' behavioural patterns significantly affect their learning performance in educational games. However, in-depth research on this area still needs to be explored further.
- *Practical subject-specific teaching and intervention:* Lack of practical studies on the implementation of DGBL in science education, and there were few longitudinal studies or follow-up evaluations to determine the long-term impact of SCDGBL interventions. Coleman and Money [52] highlighted the lack of long-term evaluations in DGBL implementation, while Nieland et al. [60] emphasised the importance of teacher-centred perspectives in classroom implementation. Therefore, more practical and longitudinal studies are needed to establish the effectiveness of DGBL interventions.

CONCLUSION

This study greatly advances the comprehension of DGBL trends in science education and advances research knowledge. It is believed that researchers are going to employ it as a reference when organising curriculum activities in the technological age. However, this bibliometric review has several limitations. For example, the use of only the Scopus database might not fully capture the breadth and depth of existing literature. Therefore, the addition of other databases, such as WoS, ERIC, or ProQuest, ensures a thorough review of the literature. We also suggest increasing the exploration of co-citation relationships between authors and regions.

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Authors

Binar Kurnia Prahani
[Corresponding Author]
(Indonesia, Surabaya City)
State University of Surabaya
E-mail: binarprahani@unesa.ac.id
ORCID ID: 0000-0002-5606-6629

Zavkiddin Mirtoshev
(Samarkand, Uzbekistan)
Samarkand State University
E-mail: zmirtoshev@samdu.uz
ORCID ID: 0000-0001-5206-5787

Iqbal Ainur Rizki
(New Zealand, Wellington City)
Victoria University of Wellington,
Email: iqbal.rizki@vuw.ac.nz
ORCID ID: 0000-0001-8618-5592

Authors contribution

Binar Kurnia Prahani: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Funding acquisition
Iqbal Ainur Rizki: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization
Zavkiddin Mirtoshev: Data Curation, Writing - Review & Editing, Supervision

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