Article

Navigating the Evolution of Game-Based Educational Approaches in Secondary STEM Education: A Decade of Innovations and Challenges

Chiara Fante, Fabrizio Ravicchio and Flavio Manganello *

Institute for Educational Technology, National Research Council, 16049 Genoa, Italy;
chiara.fante@itd.cnr.it (C.F.); fabrizio.ravicchio@itd.cnr.it (F.R.)
* Correspondence: manganello@itd.cnr.it

Abstract: The need to support science, technology, engineering, and mathematics (STEM) learning in secondary education is reflected in the ongoing investigation of innovative pedagogical practices, including game-based learning (GBL). Using an analysis of scholarly publications based on word co-occurrence, this study aimed to identify the main research themes addressed in the past decade by the scholarly community on game-based teaching and learning solutions in the context of STEM education in secondary schools, their evolution over time, and the key issues addressed in recent years. After a systematic selection, the titles and abstracts of the publications were collected in a text corpus and analyzed using T-LAB software version 7.2.1.4 (2022). A preliminary visual exploration of the keywords was performed to obtain an overall view of the issues addressed by the research. Specificity analysis was then applied to identify, for each subset of the corpus identified by the years of publication, the evolution of themes reflected in a change in the frequency of lemma use. Finally, to explore the most recent topics, the main thematic clusters of publications in the last three years were identified (thematic analysis of elementary contexts). The results suggest some changes in the issues addressed over the past decade, such as a shift in focus from the specific technologies and competitive elements of games to understanding how GBL can support engagement, motivation, and understanding of complex scientific concepts. The five key thematic clusters identified ("Experience", "Application", "Validation", "Emotion", and "Programming") also indicate a stronger emphasis by the latest publications on the experiential and emotional components of learning, the need for empirical studies, and the integration of computational thinking and coding into GBL. Overall, this study indicates that GBL has the potential to become an integrated component of STEM education, evolving with pedagogical and technological innovations.

Keywords: game-based learning; secondary STEM education; research trends; textual analysis

1. Introduction

The contemporary educational landscape in science, technology, engineering, and mathematics (STEM) is undergoing a substantial shift, largely influenced by the adoption of innovative and active pedagogical practices [1] that emphasize student-centered, collaborative, and inquiry-based approaches, moving beyond traditional lecture-based methods. This change is regarded as crucial for preparing students to successfully engage in a technology-centered world by broadening the scope of STEM subjects beyond mere technological knowledge [2]. Indeed, STEM education is essential for equipping students not only with fundamental skills but also with the capability to constructively address global challenges, thus contributing to societal progress [3]. The integration of innovative pedagogies in STEM education, therefore, represents not merely a reaction to evolving educational demands but also a proactive measure to foster a generation capable of

navigating and shaping a rapidly advancing technological landscape. Effective STEM education at this level necessitates a real-world, problem-based approach that integrates knowledge and skills across the disciplines of science, technology, engineering, and mathematics [4].

Recently, there has been a growing emphasis on promoting "scientific literacy". As defined by the Organization for Economic Co-operation and Development (OECD) [5], this concept refers to the capacity to engage with and make informed decisions about scientific questions and concepts. A key focus for researchers and stakeholders currently is the integration of disciplines through multidisciplinary, interdisciplinary, and transdisciplinary approaches [6]. In this context, STEM literacy, which involves applying STEM knowledge and skills to "increase students' understanding of how things work and improve their use of technologies", becomes crucial for addressing current and future challenges [7] (p. 1). Consequently, science literacy should be considered a lifelong-learning process, emphasizing participatory research and collaborative projects to design and implement innovative teaching practices [8]. Particularly, Ortiz-Revilla and colleagues [9] advocate for a pedagogical shift toward integrated STEM education that not only combines disciplines meaningfully but also incorporates humanistic values and a philosophical framework aimed at fostering citizenship and social justice.

Despite the increasing global demand for qualified STEM graduates, an alarming trend is emerging: declining student interest in STEM subjects [10]. This decline represents a paradox in education, occurring at a time when STEM skills are increasingly vital for meeting the challenges of the 21st century. To bridge this gap, it is imperative to make STEM education more engaging and relevant, ensuring that students are not only prepared for future technological advancements but are also motivated to pursue careers in these fields. Addressing this paradox involves rethinking and revitalizing STEM curricula to align more closely with students' interests and the demands of a rapidly evolving society. Significant changes in teaching methodologies and programs are also needed to address other critical issues concerning promoting scientific literacy, such as lower youth engagement in science fields, socioeconomic inequalities, limited access to quality educational resources, and gender stereotypes [11,12]. Enhancing STEM education and reducing attrition rates involves not only structural and pedagogical reforms but also a deeper understanding of the socio-psychological aspects that influence student engagement and success. Addressing the multifaceted challenges in STEM education requires a systemic approach that integrates institutional strategies, such as orientation programs, early warning systems, and faculty development [13].

Supporting learning in STEM, as well as maintaining and increasing students' interest, is an open challenge, especially during secondary education [13,14]. Indeed, it is at this stage that students build the foundation of their understanding in STEM fields. Therefore, this period is crucial for establishing core concepts and influencing future career ambitions [15]. Secondary education also plays a pivotal role in influencing students' decisions regarding their academic future and careers. During these educational years, different factors, including targeted interventions, peer influence, and professional engagement, influence students' interest in STEM subjects.

Targeted interventions are effective in transforming school environments and personal attitudes, thereby enhancing students' academic performance, self-perception, and self-efficacy in STEM [16]. Peer influence is another significant variable: students are more likely to choose STEM careers when surrounded by peers with a strong interest in these subjects. This evidence highlights the importance of cultivating a STEM-focused culture within science classes to positively influence students' career choices [17]. The involvement of STEM professionals in educational activities also plays a key role. Their participation makes STEM subjects more tangible and relatable, thus sustaining students' interest. This interaction provides practical insights and inspiration, enriching the educational experience [18].

Given these premises, STEM learning during secondary school requires a combination of innovative and active teaching methods that convert natural curiosity into scientific literacy. Among these approaches, game-based educational strategies have emerged as a particularly effective method in STEM education [19,20]. These strategies leverage the engaging and interactive nature of games to enhance learning experiences, making complex STEM concepts more accessible and enjoyable for students. Moreover, by integrating game-based learning (GBL) into the curriculum, educators can tap into students' intrinsic motivation and curiosity, further enriching their journey in STEM education.

1.1. Game-Based Learning and STEM Education: A Brief Overview

In recent decades, the use of games in educational contexts has grown significantly due to their potential positive impact on learning processes. Despite the heterogeneity in the use of game formats in education, research has shown that GBL can engage students and offer a personalized learning experience, promoting long-term memory and providing practical experience [21]. Wouters and colleagues [22] found that educational games outperform traditional teaching methods in improving learning outcomes, suggesting that games offer a more engaging learning experience. Similarly, Clark and colleagues [23] demonstrated that games significantly boost motivation and engagement, which are essential for effective learning. These findings highlight the value of games in making educational processes more interactive and impactful.

Different forms of games are employed in learning and pedagogy, although defining GBL and differentiating between games and non-game environments in education can be challenging [24,25]. GBL refers to a type of game with clearly defined learning outcomes and requiring a design process that balances the need to cover the learning content with the enjoyment of the game [26]. Furthermore, GBL differs from gamification, which simply involves typical game elements within learning settings, such as rewards, in traditional educational activities [27,28]. Serious games (SGs), defined as tools that aim to enhance entertainment with utility goals, including learning, are also finding wide application in the educational context [29,30].

It is usually assumed that a learning game is a digital game, but this is not always the case [25]. More precisely, digital game-based learning (DGBL) commonly refers to an instructional approach that includes any form or use of digital games in education [31] and, combined with non-digital game-based learning (NDGBL) [32], represents the broader set of GBL. Digital games have the potential to allow users to manipulate objects and test solutions to problems without cost or risk [33,34]. DGBL merges educational content with gaming to offer versatile, engaging, and effective learning experiences, supported by constructivist theory, promising enhanced student engagement, motivation, customization, and the promotion of long-term memory and practical application of knowledge [21].

Several studies, spanning from gamification to serious games and educational simulations, have explored the impact of DGBL on educational outcomes, particularly within STEM education [35]. These investigations highlight DGBL's potential to enhance learning achievements and comprehension across various educational levels, suggesting its efficacy in supporting the learning and teaching processes. Notably, DGBL has been credited with fostering engagement and the development of critical thinking and problem-solving skills, which are pivotal in STEM education [36–38]. A recent meta-analysis by Gui and colleagues [39] identified a medium to large effect of DGBL on STEM learning outcomes compared to traditional methods, further emphasizing its educational value.

Research indicates that gamified learning environments, by simulating real-world scenarios, enable students to apply theoretical knowledge in practical contexts, thereby enhancing their understanding of STEM concepts [40]. This approach not only makes learning more relevant and engaging but also highlights the practical significance of STEM education. Despite the proven effectiveness of GBL in promoting educational engagement and developing essential 21st century skills [41], recent discussions have raised questions about its qualitative impact on learning. These concerns underscore the need for ongoing

research to optimize DGBL's implementation and fully realize its benefits in educational settings.

1.2. Methodological and Theoretical Considerations in GBL Research

The field of GBL within educational contexts has experienced considerable evolution, yet it continues to grapple with significant methodological and theoretical challenges that captivate the attention of the academic community. Debates regarding the efficacy of educational games persist, with some researchers asserting that their primary benefits lie in enhancing engagement rather than facilitating deep learning [42,43]. Contemporary research is increasingly focused on refining these educational tools by integrating narrative elements, feedback mechanisms, and scaffolding strategies to enhance engagement while maintaining the integrity of the learning process [44].

The emotional and narrative dimensions of GBL also warrant careful consideration. The incorporation of storytelling within educational games is believed to increase student motivation and facilitate meaningful learning experiences [45]. However, this approach must be carefully managed to avoid cognitive overload, which can detract from learning objectives. Studies have highlighted the need to balance the complexity of educational content with the engaging nature of game design to prevent students being overwhelmed [46]. Despite mixed opinions regarding the impact of games on cognitive load [47–49], there is a trend toward the development of adaptive learning systems. These systems are designed to modify task difficulty in response to learner performance [50] and employ more accurate methods to measure cognitive load during GBL activities [51].

Recently, researchers emphasized that the effectiveness of game-based educational applications depends on adapting the game experience to different player profiles. For example, research suggests that gamer profiles based on Bartle's taxonomy [52], such as Explorer, Killer, Socializer and Achiever, are crucial for personalizing educational games to individual learning preferences. Explorers, who enjoy discovering new information, are particularly effective in engaging students in complex STEM subjects, and most educators identify with the Explorer profile, considering it the most conducive to learning [53]. Adapting educational games to these profiles improves engagement and learning outcomes by addressing different motivational factors and cognitive styles [54]. Several authors, however, have expanded Bartle's model based on the observation that it involves mutually exclusive categories for the player and has not been empirically tested. To further generalize Bartle's results, for example, Bateman and Boon [55] developed the Demographic Game Design model (DGD1) and, through empirical investigation, identified four player profiles (Conqueror, Manager, Participant, and Wanderer). Furthermore, Yee's research [56] identified ten motivations, grouped into three higher-level categories (achievement, sociability and immersion), to overcome classification into mutually exclusive profiles. In addition, recent research emphasized the importance of tailoring game mechanics to individual types of players. For example, a study conducted at the University of Lübeck identified three player profiles using Marczewski's Hexad Framework [57] and recommended specific mechanics for each profile to improve the effectiveness of educational games [58]. Despite the open debate about potential taxonomies, considering player profiles in the design of educational games can improve their effectiveness, foster deeper understanding, and support interest and engagement in STEM education [59].

Another of the contemporary challenges of GBL research is the management of the cognitive transitions between storytelling elements and educational content. Excessive narrative complexity can adversely affect learning outcomes [60]. The interaction between engagement, cognitive load, and play experience has become a crucial area of investigation in recent research, particularly in the context of teaching STEM subjects. The findings of this study suggest that well-designed learning activities and tools should minimize unnecessary cognitive load and optimize working memory, thereby enhancing knowledge acquisition [61]. These developments reflect a growing recognition of the need to

effectively align game-based educational strategies with pedagogical goals, ensuring that GBL remains a powerful tool in modern education.

The exploration of game learning analytics represents another expanding area of interest, focusing on the analysis of gameplay data to gain insights into students' learning behaviors, engagement, and performance [62]. This analytical approach is increasingly recognized for its potential to enhance the educational value of games.

Furthermore, the outbreak of the COVID-19 pandemic has prompted a reevaluation of educational technologies, including GBL, due to the widespread shift to distance learning. This transition has sparked research into the effectiveness of online learning, equitable technology access, virtual social interaction, and the adaptation of conventional teaching methods to digital platforms [63].

It has also been observed that many studies investigating the effectiveness of educational games lack rigorous experimental designs with pre- and post-test measurements, highlighting the ongoing challenge of designing games that successfully balance educational and entertainment value [64].

Amidst these developments, the broader research landscape concerning the application of gamified approaches in education is characterized by a diverse array of topics. These range from integrating emerging technologies to navigating changes in teaching and learning environments, underscored by the growing accessibility of tools like augmented reality (AR) and virtual reality (VR) that promise to enhance educational experiences and outcomes.

In this dynamic and multifaceted field—where technology, pedagogy, and social change converge—the collective inquiry into the application of games in STEM education reveals a rich mosaic of research topics, reflecting a field undergoing constant evolution and driving the future of educational practices.

This backdrop sets the stage for our specific investigation. Our study seeks to delineate the main research trends observed over the past decade in employing games for teaching and learning within secondary school STEM disciplines. By analyzing scholarly publications on the topic, we aim to contribute to the dissemination of knowledge and foster discussion on future research directions, priorities, and challenges in this dynamic area of educational technology.

Document analysis based on the co-occurrence of words is often considered a way to understand the conceptual framework of a scholarly field [65]; moreover, by studying the research output in each domain, it is possible to explore the development of trends and prevalence of key topics within a particular field or discipline [66].

Based on these premises, the present study used the titles and abstracts of academic articles from the past decade, selected from some of the major databases, for co-word (or co-occurrence) analysis and thematic mapping, with the aim of identifying key themes and trends in research on the use of GBL in secondary STEM education.

2. Methodology

This study aimed to examine the principal themes and advancements in research concerning gamified methodologies applied to STEM education in secondary schools. Specifically, it addressed the following research questions:

1. Main research trends and evolution of research issues over the past decade. What are the developments in the use of game-based educational approaches for learning and teaching STEM in secondary schools over the last ten years? This question seeks to outline a general overview of the research in this area (RQ1a) and to identify developments and changes in this field over the past decade (RQ1b).
2. Mapping of the main themes in the last three years. How have game-based educational approaches in secondary STEM education evolved in the latter part of the past decade, particularly in light of shifting educational priorities and technological advancements? This question aims to delineate the evolution of approaches and

interests over the last three years of the decade, identifying specific developments that distinguish this period from previous years.

Understanding the evolution of a scientific domain, its principal topics or fields of research, and how these topics interrelate typically constitutes the objective of bibliometric studies [67]. Various methodologies, including word analysis [68–70], have been employed in the sociology of science to define and describe a specific domain. Mapping and clustering techniques applied to texts are commonly utilized to decipher the structure of a bibliometric network and to identify the main topics of a domain, their relationships, and their prevalence over time [66,67]. Based on these premises, this investigation employed a quantitative textual analysis of academic publications focusing on game-based educational strategies in secondary STEM education to address the research questions outlined above.

2.1. Search Strategy

The research process began with a systematic collection of titles and abstracts from peer-reviewed articles, conference papers, book chapters, and reviews published between 2013 and 2022. This data were sourced in January 2023 from two major academic databases: Web of Science and Scopus.

The selection criteria were carefully formulated to ensure the relevance and quality of the research material. Keywords were deliberately chosen to encompass the broad spectrum of game-based educational approaches and their applications in STEM education. The terms related to STEM included "STEM", "math", "science", "chemistry", "biology", and "physics". The terms "gamification", "game-based learning", "edutainment", "serious game", and "applied game" were used to capture gaming aspects. These were combined with "secondary school" and "high school". Additionally, the terms "vocational", "adult education", and "adult training" were employed to filter out contributions irrelevant to the targeted learners. A final criterion for inclusion was that the materials had to be in English.

The final search strings, including additional filters for both databases, are presented in Table 1. The final searches were completed on 20 January 2023.

Table 1. Final search strings for all the databases.

Database	Final Search String
Web of Science	TS = (stem OR math OR science OR chemistry OR biology OR physics) AND TS = ("secondary school" OR "high school") AND TS = (gamification OR "game-based learning" OR edutainment OR "serious games" OR "applied games") NOT TS = (vocational OR "adult education" OR "adult training") AND PY = (2013 OR 2014 OR 2015 OR 2016 OR 2017 OR 2018 OR 2019 OR 2020 OR 2021 OR 2022) AND DT = (Article OR Proceedings Paper OR Review OR Book Chapters) AND LA = (English)
Scopus	(TITLE-ABS-KEY (stem OR math OR science OR chemistry OR biology OR physics) AND TITLE-ABS-KEY ("secondary school" OR "high school") AND TITLE-ABS-KEY (gamification OR "game-based learning" OR edutainment OR "serious game*" OR "applied game*") AND NOT TITLE-ABS-KEY (vocational OR "adult education" OR "adult training")) AND (LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022)) AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "ch")) AND (LIMIT-TO (LANGUAGE, "English"))

2.2. Selection and Screening

Following the initial identification of records from Web of Science (*n* = 258) and Scopus (*n* = 253), and after removing duplicates (*n* = 110) and irrelevant entries (*n* = 14), a total of 387 records were screened. This screening was conducted based on the titles and abstracts. Contributions not pertinent to the research question, specifically those related to studies of kindergarten and elementary school students, were excluded, leaving 331 reports for eligibility assessment. Additionally, 35 reports were excluded because they failed to concurrently focus on both GBL and STEM (17 were excluded for lacking a focus on GBL, and 18 were excluded for not addressing STEM subjects). Consequently, 286 studies were included in the review and organized into a structured dataset, which is now publicly available for further research and analysis [71]. The complete search and screening process is detailed in the PRISMA flow diagram depicted in Figure 1.
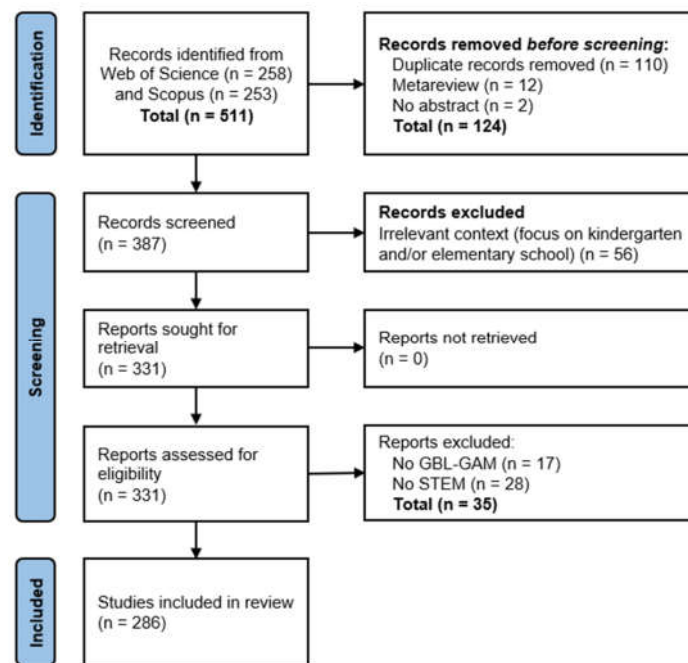

Figure 1. PRISMA flow diagram.

2.3. Data Analysis

The analysis was carried out using T-LAB version 7.2.1.4 (2022), a software equipped with linguistic, statistical, and graphical tools specifically designed for textual analysis. T-LAB itself can be characterized as a tool for exploring and analyzing the content of a text corpus by mapping the co-occurrence relationships between words (lemmas) and conducting bottom-up clustering to highlight emergent themes. At the stage of corpus import, the software undertakes an initial analytical decomposition into units of analysis: lexical units (LUs; words or lemmas) and elementary contexts (ECs; text segments of similar length that correspond to one or more sentences). Generally, the subsequent analyses utilize the values of occurrence (the frequency of each LU within the text) and co-occurrence (the number of ECs in which each LU appears alongside others). Additionally, T-LAB offers the capability to explore similarities and differences between various subsets of a text, previously defined by a variable of interest (e.g., different authors, different time periods). Here, the underlying logic employs set theory, using the statistical χ^2 test. Through this functionality, termed "Specificity Analysis", it is possible to determine how the usage of words distinguishes one subset (i.e., a portion of the text) from others within the corpus under study. As Lancia [72] noted, following an initial phase of text analysis through the

various functions provided by the instrument, a process of interpreting the results by the user is essential.

The selected titles and abstracts were then compiled into a single text file for analysis. The corpus was split according to the variable "year of publication", allowing for a chronological analysis of the data. Three sub-corpuses were created corresponding to the years 2013–2016 (sub-corpus "*years_one*"), 2017–2019 (sub-corpus "*years_two*"), and 2020–2022 (sub-corpus "*years_three*"), enabling a comparative study of the trends and developments over these periods.

The early stage of the analysis involved viewing the text to remove irrelevant lemmas, such as numerical values or proper names of games. Following this, some key steps were performed: applying an automatic list of "stop worlds" (i.e., "empty" words that do not convey meanings by themselves; e.g., adverbs, auxiliary and modal verbs, and prepositions); creating a list of "multi-words" (i.e., subsets of compound nouns or locutions; e.g., "Game- Based Learning", "Virtual Reality", "Educational Games"); grouping words and lemmas with the same meaning (e.g., "GBL", and "Game- Based Learning", "AR" and "Augmented Reality"); selecting for further analysis as "key words" only those lemmas with an occurrence in the whole corpus greater than 10; and removing additional items among the identified keywords that did not convey particular meanings of interest to the study (e.g., "results", "statistical", "aim", "finding").

The analysis was conducted in three steps to address the research questions (RQs) effectively. The first two steps aimed at answering RQ1, focusing on the main research trends and their evolution in the use of game-based educational approaches for learning and teaching STEM in secondary schools over the past decade. Firstly, in order to obtain an overall view of the issues addressed by the research in this field (RQ1a), an early visual mapping of the entire text was carried out using the "Graph Maker" tool, aimed at graphically representing the keywords with a higher frequency in the entire text. Specifically, this tool provides a visual representation of lemmas defined as "keywords" (words that have at least 1 occurrence in 10); with this tool, the user can select the desired number of keywords to be displayed in the graph, based on their frequency. In this case, the hundred keywords with the highest number of occurrences were chosen, thus reducing the number of lemmas to be visualized in the output to only those with at least 1 occurrence out of 20.

Secondly, the "Specificity Analysis" function was applied to identify, for each subset of the corpus, the words that are typically overused (those most present) or underused (those least present) compared with the remaining text under analysis, with the corresponding chi-square (χ^2) value and its significance. This analysis was used to identify any evolutions over the past decade in the research topics addressed by the publications that are reflected in a change in the frequency of the lemmas used in the abstracts and titles (RQ1b).

The third step was designed to answer RQ2, focusing on the evolution of game-based educational approaches in secondary STEM education in the last three years of the last decade. For the "years_three" sub-corpus (corresponding to publications in the years 2020, 2021, and 2022), the "Thematic Analysis of Elementary Contexts" function was applied to represent the content of the text through some significant thematic clusters. Each cluster resulted in a set of sentences (ECs) characterized by the same keyword patterns and described through the lemmas that most define it. Each emergent thematic cluster was thus defined by a set of words sharing the same reference contexts and seen as a "common thread" not immediately recognizable within the overall plot of the text. For each representative keyword, T-LAB provided the relative χ^2 value and its significance, allowing its "weight" in the corresponding cluster to be evaluated. In the present study, an unsupervised clustering focusing on a bottom-up approach was used.

3. Results

3.1. Main Research Trends over the Past Decade (RQ1)

3.1.1. Graph Maker

At the end of the preliminary stages of the corpus preparation, the keywords consisted of 426 lemmas and the entire text comprised 60,016 occurrences. The application of the "Graph Maker" tool provided an early visual representation, illustrating the most frequent keywords and their relationships (Figure 2). Particularly, this tool facilitated the exploration of co-occurrences between keywords and supported a form of preliminary network analysis. Four different areas emerged and were distinguished by colors: green, highlighting the keywords "Student", "Learning", and "Design"; orange, with "Game" prominently displayed, followed by "Teaching", "Research", "Science", and "Education"; blue, featuring "Teacher", "Gamification", "Knowledge", and "Experience"; and red, emphasizing "Development", "Educational", "Concept", and "Technology".
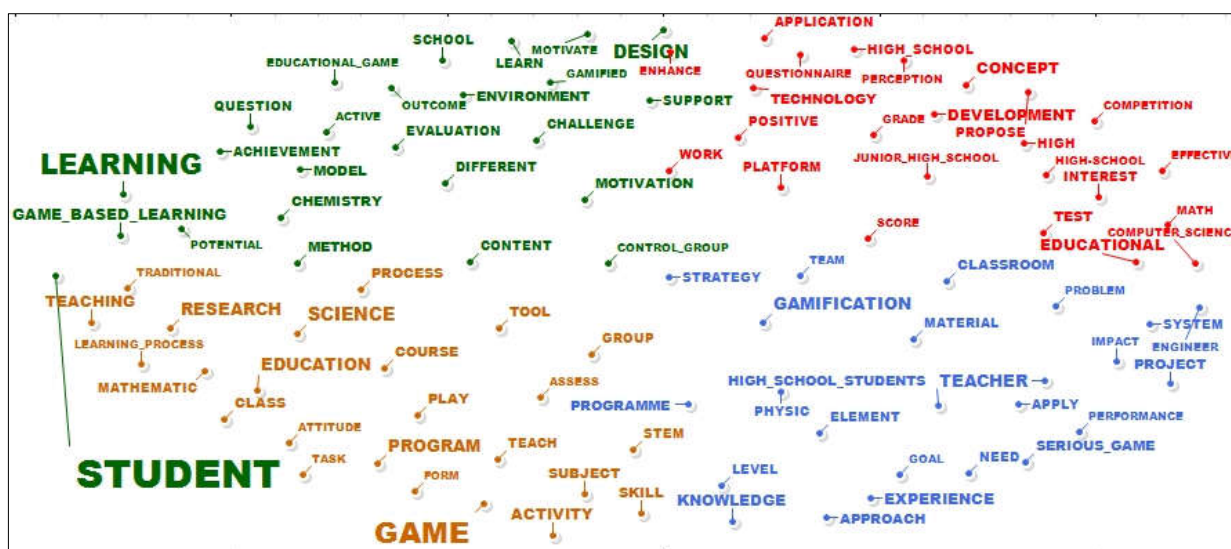

Figure 2. Graph Maker tool: keywords with the highest number of occurrences in the entire text.

3.1.2. Specificity Analysis

To investigate the evolution of the research trends in the application of educational games within STEM education over the last decade, a "Specificity Analysis" was conducted. This comparative analysis aimed to identify lemmas that were either overused or underused in each sub-corpus, as defined by the "year of publication" variable. The overused lemmas in each sub-corpus are the words that appeared most frequently in that segment of the text, statistically, compared to the entire corpus under analysis. Conversely, underused lemmas are those that occurred least frequently. For each lemma, the corresponding χ^2 value and its statistical significance were calculated and reported (Table 2).

Table 2. Underused and overused lexical units of each sub-corpus and its χ^2 value ($p \leq 0.05$).

Sub-Corpus	Overused	Underused
	Robot (25,06)	Activity (−6,94)
	Game (23,92)	periodic_table (−6,93)
	robotic (17,81)	teaching (−6,21)
2013–2016	game_construction (15,44)	COVID-19 (−5,89)
	risk (15,26)	coding (−5,19)
	peer (15,27)	student_engagment (−5,19)
	simulation (15,05)	STEM (−5,19)

	computing (12,89)	post_test (−4,5)
	Europe (12,73)	Game_Based_Learning (−4,38)
	climate (11,81)	satisfaction (−4,17)
	mechanism (10,54)	pre-test (−4,15)
	meaningful_learning (10,27)	narrative (−4,15)
	competition (9,59)	Earth (−4,15)
	child (8,35)	teacher (−4,02)
	software (7,74)	
	curriculum (7,47)	
	successful (7,24)	
	quiz (6,69)	
	serious_game (6,49)	
2017–2019	escape_room (25,02)	simulation (−27, 49)
	emotion (20,16)	energy (−22,84)
	flow (16,67)	project (−19,46)
	genetic (10,45)	competition (−10,13)
	theory (9,62)	argumentation (−8,24)
	narrative (9,06)	peer (−8,24)
	factor (9,04)	framework (−7,63)
	need (9,05)	green_chemistry (−7,55)
	session (7,12)	mobile (−7,49)
	educational (6,46)	student_engagement (−7,19)
	validity (6,31)	computational thinking (−7,17)
	board_game (6,06)	game_costruction (−6,86)
	gamification (5,66)	robot (−5,75)
	experience (5,42)	creativity (−5,02)
	in_game (4,69)	Game_Based_Learning (−4,5)
	intervention (4,64)	web (−4,04)
	virtual_reality (4,64)	ICT (−3,91)
2020–2022	Student_engagement (24,01)	Soil (−9,6)
	Game_Base_Learning (17,17)	learner (−8,88)
	argumentation (13,31)	COVID_19 (−8,6)
	discipline (13,31)	platform (−7,87)
	competence (11,47)	robotic (−7,59)
	subject (11,16)	center (−7,59)
	art (10,95)	emotion (−7,34)
	computational thinking (10,34)	social (−7,03)
	creativity (9,23)	flow (−6,58)
	inquiry_based (8,99)	genetic (−6,39)
	web (8,98)	qualitative (−5,23)
	workshop (8,91)	theory (−5,1)
	classroom (8,1)	self- efficacy (−5,06)
	laboratory (7,82)	mental (−5,06)
	STEAM (7,36)	disability (−5,06)
		learning_effectiveness (−4,89)

Analysis of the typical words in the abstracts in different years showed significant shifts in the direction of research in the field of educational games for teaching and learning STEM subjects. These shifts highlight changes in the focus, methodology, and thematic emphasis within the field. Below is a detailed analysis of each period based on the

overused and underused lemmas. Each period was named briefly according to its typical words.

(a) **Technological integration and curricular considerations (sub-corpus 2013–2016)**

Overused lemmas. The occurrences of "Robot", "robotic", and "computing" underscore a strong interest in integrating technology, particularly robotics, into educational environments. This reflects an emerging trend toward the use of hands-on, interactive tools to facilitate STEM learning, highlighting the period's focus on improving teaching through technological innovation. Terms such as "game_construction", "simulation", "software", and "serious_game" suggest an effort in terms of the mechanics of game design and development. The emphasis on constructing games and simulations points toward a growing recognition of customized educational games as valuable tools for teaching complex concepts in a more accessible and engaging manner.

The higher frequency of words such as "peer" and "competition" reflects an interest in leveraging both collaborative and competitive dynamics within educational games. This evidence may suggest a pedagogical strategy aimed at enhancing learning through social interaction, peer learning, and the motivational aspects of competition. The lemmas "Meaningful_learning" and "curriculum" also indicate a focus on ensuring that GBL is not only engaging but also pedagogically meaningful. Thus, the integration of educational games into the curriculum and the emphasis on meaningful learning experiences reveal an effort likely intended to align game-based activities with educational standards and learning objectives.

The presence of lemmas such as "climate" and "Europe" in this sub-corpus points to an acknowledgment of environmental issues and a geographical focus, respectively. It indicates a contextual application of educational games to address global challenges and foster a broader understanding of environmental science within an educational framework. The term "child" may reflect the attention paid to adapting educational games to the developmental needs and interests of younger students.

The inclusion of "game", "risk" and "mechanism" suggests a nuanced exploration of the elements that contribute to effective learning experiences within game-based environments. Risk, in this context, may relate to encouraging students to engage with challenging concepts or scenarios within a safe, controlled environment, thereby enhancing critical thinking and problem-solving skills. The term "success" can also denote a general concern for evaluating the outcomes of the use of educational games.

The overuse of the term "quiz" points toward the utilization of traditional assessment tools within a gamified context, suggesting an effort to blend conventional testing methods with the engaging aspects of GBL.

Underused lemmas. The under-utilization of the lemmas "teaching" and "teacher" suggests a potential oversight concerning the critical role educators play in integrating and facilitating game-based learning within STEM education.

The lower use of the words "activity", "student_engagement", "post_test", and "pretest" indicates that methods for assessing learning outcomes and engagement through educational games were not a primary focus in this period. This result can reveal a gap in understanding how GBL impacts student performance and engagement from a quantitative perspective in the scholar outputs of this period.

The underuse of "periodic_table" and "Earth" points to a relative lack of focus on integrating educational games with specific STEM subjects, particularly in the areas of chemistry and Earth sciences. The reduced occurrence of "coding" highlights that this triennium was probably characterized by a preliminary phase of recognition and exploration of the importance of computational thinking in STEM education through games.

The term "Game_Based_Learning", under used in this period compared to in later ones, also suggests that discussions directly concerning GBL may have taken a back seat to more specific ones concerning technology, pedagogy, or subject integration. The lower emphasis on "satisfaction" and "narrative" in this period may reveal a gap in considering

the affective outcomes of GBL, such as learner satisfaction and the potential of narrative elements in games to enhance learning experiences.

(b) **Emotional engagement and experiential learning (sub-corpus 2017–2019)**

Overused lemmas. The high frequency of words such as "escape_room" and "virtual_reality", along with "session" (which could imply online or virtual sessions), in the research outputs underscores a growing trend toward using these immersive technologies to craft compelling educational experiences. These technologies do not just capture students' attention but also envelop them in learning scenarios that closely resemble real-life challenges. At the same time, the lemmas "gamification", "board_game" and "in_game" highlight a strong shift toward incorporating game mechanics into the educational process. This trend may be indicative of a broader strategy to make learning more dynamic and fun.

The emphasis on "emotion" may be indicative of a more recent inclination to view games as tools able to generate emotional reactions such as arousal or empathy. Concurrently, the reference to "flow" and "experience" may suggest a drive toward crafting educational experiences that captivate students' full attention, guiding them into a state of flow. Furthermore, "narrative" comes into play as a pivotal element, highlighting the power of storytelling in education. This multifaceted approach, blending emotional responses, psychological state of flow, and narrative techniques, represents a significant advancement toward developing more effective and immersive learning experiences within the domain of educational games.

The lemmas "theory" and "factor" denote a move toward a systematic, research-backed methodology in creating and assessing educational games, aiming to base development on strong learning theories. Related to this aspect, there is increasing attention paid to the educational effectiveness of these games (higher frequency of "educational", "validity", and "intervention"). Furthermore, the lemma "need" could indicate a trend in personalizing learning experiences, pushing for the customization of educational games to meet individual learners' needs and interests. The higher occurrence of the term "genetics" suggests the possible use of educational games to make complex topics accessible.

Underused lemmas. The low use of "simulation", "project", and "computational thinking" shows that there is less interest in more traditional and structured or content-specific learning and computational strategies in this triennium. This might reflect a period of reevaluation or transition toward new methodologies or technologies that offer different opportunities for engaging students in STEM. The less frequent use of "mobile", "web", and "ICT" (information and communication technology) also suggests a nuanced shift in the focus on the use of technology in educational games, with increased interest in more immersive or novel technologies.

The underused terms "framework" and "game_construction" suggest a momentary lack of interest in structural design principles and in the process of educational game development. The decreased use of the lemmas "student_engagement" and "creativity" might be associated with a reduced exploration of these topics during this timeframe.

The underuse of STEM-specific content-related terms such as "energy", "green_chemistry", and "robot" points to a selective focus within STEM education; the lower frequency of the lemma "Game_Based_Learning" confirms a trend also observed in the previous period (2013–2016), suggesting that discussions directed at GBL were likely secondary to investigations addressed toward technological and pedagogical aspects.

The less frequent occurrence of "competition", "argumentation", and "peer" could indicate a change in focus toward individual learning experiences over competitive or collaborative learning frameworks within educational games. This shift might reflect a broader pedagogical trend or a response to emerging research highlighting the benefits of individualized learning paths.

(c) **Engagement and diverse learning modalities (sub-corpus 2020–2022)**

Overused lemmas. The increased use of "Student_engagement" and "Game_Base_Learning" in the last period highlights the research interest and effort toward game-centered solutions that actively and meaningfully engage students in the learning process. In addition, the lemmas "argumentation" and "inquiry-based" learning seem to reflect a greater emphasis on teaching strategies centered on critical thinking and problem solving. These strategies are probably viewed as tools that allow students to be engaged in thoughtful reflection and reasoned investigation, facilitating deeper understanding and knowledge construction.

Words such as "discipline", "competence", and "subject" suggest a broadening of the scope of research on educational games to encompass a wide range of academic disciplines and competencies. The significant presence of the lemmas "computational thinking" and "creativity" points to an effort to integrate 21st century essential skills into STEM education and educational games research. Indeed, they can be used to nurture a combination of logical problem-solving and creative-thinking abilities through a holistic approach to skill development.

The terms "art" and "STEAM" highlight an interdisciplinary approach, where the arts are integrated with science, technology, engineering, and mathematics. This reflects a growing appreciation for the value of combining artistic creativity with STEM disciplines, fostering innovative thinking and different learning experiences. The occurrence of words that refer to a variety of learning experiences, such as "web", "workshop", "classroom", and "laboratory" indicates a variety of applications of educational games across different educational settings and modalities.

Underused lemmas. The underuse of "Soil" and "genetic" suggests that certain specific scientific areas may not have been the primary focus within the broader scope of STEM education games in the last years. Moreover, the lower frequency of "robot" and "platform" could indicate a decreased research focus on integrating these technologies into educational games and reflect a broader diversification of technological tools or a shift toward new and emerging solutions.

The lower frequency of "learner", "center", and "learning effectiveness" suggests that direct discussions about the role of the learner and the effectiveness of GBL strategies may have received less attention in the more recent period. Notably, the evidence that "emotion", "self-efficacy, "social", "flow" and "mental" are less occurrent than in the past publications may indicate that the exploration of the emotional, psychological and relational dimensions of learning within game environments has become a less explored topic in the current research.

The underuse of "COVID_19" is particularly interesting, suggesting that the direct impacts of or responses to the pandemic may not have been a central theme in educational game research during this period. The less frequent mention of "disability" highlights a potential oversight or underemphasis on inclusivity and accessibility within game-based learning research.

Finally, the decreased use of "qualitative" and "theory" compared with the previous publications suggests a potential shift in the use of qualitative research methodologies toward quantitative inquiry approaches.

3.2. Mapping of Main Themes in the Last Three Years (RQ2)

Thematic Analysis of Elementary Contexts

To investigate the main research themes in the last few years, particularly from 2020 to 2023, this study used the "Thematic Analysis of Elementary Contexts" function. This analysis identified five key thematic clusters within the sub-corpus "years_three", which encompasses abstracts published during this latest period. The process involved a preliminary exploration of the lexical units and elementary contexts of each cluster; the clusters

were then named based on this early investigation of their characteristics. The detailed results are presented in Table 3.

Table 3. Overview of key thematic clusters identified in the sub-corpus "years_three".

Typical Lexical Units	Elementary Contexts (CE)
experience (77,65); topic (57,12); mental (43,42); DGBL (39,05); flow (32,94); measure (32,58); game (26, 24); motivation (23,98); feeling (22,31); frustration (22,3); intention_to_play (22,3); outcome_expectancy (22,3); post_test (22,19); knowledge (21,95); pre_test (21,6)	Flow experience and in-game performance significantly impacted students' post test scores (…) We measured their science self-efficacy, science outcome-expectancy beliefs, flow experience, feelings of frustration, and conceptual_understanding before and after playing_the_game (…) This study examined the effects of reality-based interaction and VR on measures of student motivation and mental workload, in a mental arithmetic game (…)
application (36,2); methodology (29,36); COVID-19 (28,55); pandemic (20,17); usability (20,17); active (18,1); disability (17,8); teaching_and_learning (16,89); strategy (16,65); efficiently (14,48); KAHOOT (14,24); Augmented_reality (14,18); traditional (12,54)	This phenomenological research aims to explore physics teacher strategies in conducting traditional game_based_learning in senior_high_schools during the COVID-19 pandemic (…). The proposed application has used the techniques in augmented_reality and game_based_learning (…). (…) studying with KAHOOT is believed to improve the outcomes of teaching-learning processes for instructors and students. In this study, a mobile_application was presented (…) for learners_with_intellectual disabilities by applying augmented_reality. (…) Wordwall is rarely used in learning media because there has not been socialization and application in the teaching_and_learning process for teachers.
model (80,26); theory (57,6); validity (56,25); inquiry (44,71); validation (28,77); control_group (25,61); combined_with_ edutainment (23,01); traditional_games (22,99); experimental_group (22,53); expert (17,67); achievement (17,51); learning_effectiveness (14,43)	This study_examined (…) by exploring the connections between the expectancy-value theory of achievement motivation and flow theory. Three experts in the field assessed the validity of the kit. Also, the achievements of the students from the experimental_group are compared with achievements of students (…). Based on the result, the guided inquiry_learning_model combined_with_edutainment affects increasing student learning interest compared to guided inquiry and conventional model. Some studies that have used a hybrid pedagogical model are recorded, combining gamification with other pedagogical models.
Emotion (51,23); educational (48,85); game (38,8); achievers (38,44); digital (36,48); opportunity (29,36); exercise (28,79); design (27,83); practice (25,43); link (18,08); scenario (17,93); collaborative (16,28); inclusive (15,36); positive_emotion (15,36); help_students (14,42)	This study showed that conventional exercises were detrimental to middle and high achievers' learning emotions, although their concepts improved (…). Science teachers may try innovative activities such as collaborative games to maintain students' positive emotions (…) (…) high achievers decreased their positive emotion, and middle to high achievers increased their negative emotion. This study explores how players engage in problem solving during a cross-platform collaborative learning game about cellular biology (…)

programme (73,91); program (65,38); class (60,89); questionnaire (41,58); sample (30,15); student (25,76); achievement (24,25); survey (23,83); interest (21,73); personality (20,02); Scratch (18,81); schools (18,11); learning_process (14,05); participation (11,59); playful (11,59); digital games (11,26)	This paper describes research introducing_students to programming concepts using a Scratch programming language (…) Students' learning interest questionnaire contains statements done by students before and after the learning_process. There are many programming environments and teaching approaches that address the learning needs of students (…) Results show different gender preferences for the three programming tools and, in some cases, different personalities (…) Moreover, all programming environments had different emotional effects on the students.

In the first thematic cluster, labeled "**Experience**", analysis revealed a focus on experimental research in game-based learning. This is evident from the presence of lemmas such as "pre-test", "post-test", and "measure", which point to empirical studies that measure the impact of gaming experiences. Other key lemmas, such as "experience" and "flow", suggest a direct interest in player involvement in games. In addition, this cluster includes terms referring to variables that can influence the effectiveness of games in STEM education ("motivation", "mental", and "self-efficacy").

The second cluster, "**Application**", is characterized by a set of words that collectively suggest a focus on the practical implementation of games, including the application of strategies, methodologies, and technological tools (e.g., "augmented_reality", "KA-HOOT") to promote active learning and move beyond traditional educational methods. The presence of lemmas such as "handicaps" suggest a potential growing research interest in inclusive education, particularly for students with disabilities. This group also reflects efforts to adapt educational games to emerging challenges related to the impact of the COVID-19 pandemic on education.

Within the "**Validation**" cluster, the focus is on attempting to validate current models and theories of gaming in educational settings. This is suggested by lemmas such as "validation", "model", "theory", and "expert", with a notable focus on experimental methodologies ("experimental_group", "control_group"). An interest in the integration of education and entertainment ("edutainment") also emerged.

The fourth cluster, labeled "**Emotion**", suggests a shift in the research focus toward the emotional aspects of GBL. In particular, the analysis reveals a trend of exploring how emotions affect academic achievement and motivation, as evidenced by lemmas such as "emotion", "positive_emotion", and "achievers". The cluster lemmas also highlight the presence of studies on emotional factors and collaborative or game-based instructional strategies.

Finally, the "**Programming**" cluster reveals a specific interest in teaching programming language in educational settings, (lemmas such as "program", "Scratch", "classroom", and "school"). This cluster also indicates that recent research is exploring the impact of programming on students' learning processes and their interest in STEM fields, as suggested by the presence of the words "learning_process" and "interest".

4. Discussion

The current study presents an exploratory analysis of game-based instructional approaches and technological solutions within secondary school STEM education, as investigated by the research community from 2013 to 2022. This analysis seeks to identify the principal themes and evolutionary trends within this domain, providing a comprehensive overview of how these approaches have been integrated and developed over time. In the following sections, the advantages of the methodology employed in this research and the outcomes will be discussed in detail, emphasizing their implications for further research and practice in the field.

4.1. Validating the Application of Co-Word Analysis as a Bibliometric Technique for Tracking Research Trends

This study builds upon the principles of bibliometric research, which seek to delineate the evolution and interconnections among pivotal topics within a scientific domain. As delineated in the "Methodology" section, the employment of quantitative textual analysis of titles and abstracts from academic publications over a specified period facilitated the identification and examination of trends and patterns within the academic landscape, thereby fostering a comprehensive grasp of the subject matter. Indeed, co-word analysis proved exceptionally adept at capturing the dynamic nature of research trends [57,58]. Moreover, this method enabled a more profound comprehension of the interrelationships among various research themes, offering a detailed depiction of the evolution of GBL in STEM education for secondary schools during the observed timeframe.

The analysis underscored the complexity characterizing the field of GBL, which stems from the interplay between learning theories, pedagogical methods, the design of educational games, and the features of the technological devices employed for their implementation. Through this approach, our study reinforces the validity of utilizing bibliometric analyses to monitor trends in educational research and highlights its potential to contribute strategically to the broader fields of educational innovation.

4.2. Main Research Trends over the Past Decade

Research on GBL within STEM education has experienced considerable development over the past decade, as demonstrated by the comprehensive results of the "Specificity Analysis" conducted in this study. The findings indicate that integrating games into secondary STEM education represents a promising and growing area of inquiry. The principal outcomes reveal a dynamic landscape in which the adoption and refinement of a game-centered approach have progressively increased. Overall, this study was marked by a widespread trend toward the implementation and exploration of more interactive and engaging strategies that incorporate elements of play in STEM education. This shift is likely associated with a broader movement away from conventional teaching methodologies in these fields. The following section elaborates on these trends in detail, citing specific research articles included in our dataset [71].

The past decade has witnessed a significant shift in the adoption and refinement of GBL within STEM education. Earlier literature frequently underscored the transformative potential of GBL in educational settings, a promise that recent studies have substantiated through nuanced applications and measurable benefits in real educational contexts. This research trend closely aligns with the theoretical premises of our study, particularly with the need for pedagogical practices that not only engage students but also provide substantive education [1,2].

Initially, scholarly research primarily concentrated on understanding specific game technologies, such as educational robotics and competitive gaming environments, likely due to their potential to enhance student engagement and motivation. For instance, [73] discussed how robotics, especially when combined with competitions, not only generates interest among students but also serves as an effective introduction to programming. This effort is consistent with the broader educational objective of integrating GBL into the STEM curriculum to provide students with practical applications of theoretical knowledge. Moreover, the focus on competition in early publications aligns with evidence suggesting that competitive elements in educational games and activities can enhance learning outcomes; students in competitive learning settings may exhibit higher engagement and improved performance [74].

Over time, research attention has significantly broadened, with recent studies focusing on how GBL can be effectively integrated into educational programs to enhance student engagement. This is consistent with evidence on the crucial role of motivation in the academic engagement and success of college freshmen in STEM subjects. Thus, GBL can

support the transition from high school to higher education by making learning more engaging and contextually relevant [75].

Additionally, the integration of GBL in educational settings has been investigated not only for its effectiveness in supporting engagement but also for its potential to sustain comprehension of complex scientific concepts. For example, [76] reported significant improvements in students' understanding of chemistry through the design and use of an educational board game, illustrating how such tools can foster a holistic understanding of scientific knowledge and enhance creative problem-solving skills.

A notable trend in the recent literature is the growing focus on the cognitive and emotional components of learning through GBL. While earlier studies highlighted GBL's potential to reduce cognitive overload and enhance enjoyment and motivation through interactive learning experiences, current research builds on this foundation by providing empirical evidence on how well-designed game elements can facilitate complex learning processes by balancing cognitive load and engaging students emotionally and intellectually. For instance, [77] investigated the impact of serious games on learning programming and revealed that cognitive style significantly affects learning effectiveness. This supports the notion that GBL should be tailored to individual cognitive profiles to maximize educational outcomes. Similarly, [78] explored the emotional impacts of cooperative games, finding that these games significantly enhanced positive emotions and reduced negative emotions among learners, correlating with improved engagement and learning outcomes.

Moreover, the relationship between engagement, cognitive load, and play experience has emerged as a particularly crucial area of research interest. In fact, our results suggest a recent focus on the importance of maintaining a balance between engaging narrative elements and the cognitive demands of educational tasks. This interest might be reflected in the adoption of some cognitive theories, such as Cognitive Load Theory [49,50], as the background of studies.

Other shifts in the research trends concern the technological solutions adopted and their integration into the curriculum. The advent of innovative technological solutions, such as immersive tools, has expanded the research field with new research questions. For example, in recent years, the study by [79] elaborated on the use of mixed reality systems in science centers, which foster flow and engagement through narrative game-based learning, underlining the potential of sophisticated design in GBL to effectively merge real and virtual elements.

Concerning the integration into the curriculum, over the past decade, research in GBL has increased its interest in understanding how to align the adoption of game solutions with curricular goals and standards. Initially, games were primarily used as supplementary tools, somewhat peripheral to the main curriculum. However, recent research indicates a trend toward directly integrating games into the curriculum to ensure they meet educational standards and directly contribute to learning outcomes. Current trends in the research show a growing emphasis on designing games with curricular integration in mind. This development not only aids in achieving the required educational outcomes but also bolsters the legitimacy and effectiveness of GBL as a pedagogical strategy. This attention to the integration of innovative technologies into the curriculum is reflected in some of the most recent evidence. For example, the use of augmented reality and gamification during lessons has been found to significantly boost student interest in subjects like physics and English, suggesting that these technologies can effectively bridge the gap between game-based learning and curriculum requirements [80].

4.3. Mapping of Main Themes of the Last Three Years

The detailed mapping of the principal themes from the past three years of scholarly output not only builds upon earlier educational theories and practices but also highlights a growing interest in the dynamic progression of STEM education through gamified approaches. The thematic clusters identified in recent publications offer a more comprehensive understanding of the current state of GBL strategies in STEM education. These

clusters—"Experience", "Application", "Validation", "Emotion", and "Programming"—each provide unique insights into the pedagogical applications and effectiveness of GBL strategies. The focus on these areas over the last three years indicates a shift toward enhancing the experiential and emotional components of learning, aligning with contemporary educational priorities that emphasize the importance of implementing interactive learning environments.

The impact of digital and emerging technologies, such as augmented reality (refer to Table 3), has significantly shaped current GBL strategies. These technologies afford immersive experiences that can support the learning process by simulating real-world environments, which is particularly relevant in STEM education, where the practical application of theoretical knowledge is crucial.

The results of our three-year thematic mapping largely confirm the theoretical premises outlined in the "Introduction". Indeed, the use of advanced technologies, the emphasis on emotional and experiential learning, and the focus on empirical validation reflect the prevailing themes in recent investigations into the general application of games in education. However, a deeper analysis of the recent trend toward more comprehensive applications of these technologies and strategies introduces novel elements, suggesting an evolution toward a more integrated and holistic approach to GBL. This indicates that the field continues to adapt and respond to the emerging challenges and opportunities presented by digital advancements. In the subsequent paragraphs, we will discuss each of the five clusters in detail, one by one, to further elucidate these developments.

The "**Experience**" cluster highlights the broad application of GBL, focusing on experiential learning that supports an active, learner-centered approach in STEM education [4]. This approach has become increasingly influential, reflecting a shift toward more engaging learning strategies. For example, a study by [74] investigated how an educational board game could enhance students' creative problem-solving skills and understanding of scientific concepts in chemistry. The integration of game-based elements into STEM curricula not only deepened students' comprehension but also boosted their engagement and application of scientific knowledge.

Additionally, the use of mobile technology to enhance science inquiry and game design elements is part of this trend. A study by [81] demonstrated how gamified science inquiry activities, facilitated by mobile devices connected via Bluetooth, could improve students' science process skills and engagement. In this study, students designed and manipulated a smartphone-controlled paper airplane, highlighting how mobile and gamification technologies can be effectively integrated to enhance engagement and deepen understanding of scientific principles among students. This experience highlights how mobile technologies such as smartphones and tablets are opening up new frontiers of GBL precisely because of the possibilities of "capturing" information from the environment, through sensors, and integrating it into the dynamics of the game, in a transparent way for the user, who is engaged in a playful experience of authentic and situated learning.

The "**Application**" cluster reflects a significant trend in GBL research within STEM education, focusing on the practical implementation of educational games. This shift highlights the need for games that not only actively engage students but also effectively contribute to educational curricula, meeting both academic standards and diverse student needs.

This trend toward applying GBL strategies in STEM teaching is aimed at enhancing active learning and moving beyond traditional educational methods. The use of augmented reality (AR) and tools like Kahoot has been particularly noteworthy. These technologies have been effective in boosting student engagement and facilitating the practical application of theoretical knowledge, which is crucial in STEM education [82].

Furthermore, the inclusion of GBL approaches has shown significant potential to enhance inclusivity in education. Recent studies have focused on developing educational games that accommodate students with disabilities, reflecting a broader commitment to inclusive education. The design of educational actions centered on appropriately designed

games (especially digital games) can, therefore, support both the Universal Design for Learning (UDL) guidelines in relation to all three principles of this approach: offering multiple options for perception, offering multiple options for action and expression, and finally, offering multiple options for engagement. There is, however, a need to investigate and insist on the accessibility, both sensory and cognitive, of digital artefacts and the devices necessary for their use [83]. This aspect of GBL research has become especially relevant in response to the challenges posed by the COVID-19 pandemic, which has necessitated more versatile and accessible educational solutions [84].

The "**Validation**" cluster highlights an increasing emphasis on the necessity of rigorous empirical studies to evaluate the effectiveness of GBL strategies. This focus corresponds with recent calls in the literature [64] for validated educational practices supported by solid empirical evidence. While the potential of GBL is widely acknowledged, there is a crucial need for systematic research that can provide conclusive data to affirm its effectiveness across various educational settings.

For instance, [75] discusses the critical role of motivation in engaging students, particularly during their transition from high school to college-level STEM courses. This study underscores the potential of GBL to support students effectively during this transition and calls for further research into the biological, cultural, and philosophical foundations that underpin the effectiveness of game-based learning as a pedagogical strategy.

Furthermore, the researchers in [85] report on a pilot study that evaluates data collection instruments in an epistemic game development competition, reflecting a growing focus on validating GBL approaches through rigorous methodologies. Although their findings provide early indications of achieving the desired learning outcomes, they also highlight the need for more comprehensive methods to substantiate these results, closely aligning with the need for systematic studies as emphasized in the validation cluster.

The "**Emotion**" cluster underscores the increasing emphasis on the affective dimensions of learning, where emotional engagement is closely associated with better retention and deeper understanding. This trend illustrates that educational games eliciting positive emotional responses can significantly boost student motivation and engagement [45].

A study by [78] examined the emotional impacts of cooperative games on science learning. The research found that students engaged in GBL reported higher levels of positive emotion and fewer negative emotions compared to their peers using traditional learning methods. This evidence is vital, demonstrating that integrating games into the curriculum can create an emotionally supportive learning environment, thus enhancing both engagement and understanding.

Additionally, the study by [86] introduced an Intelligent Pedagogic Agent (IPA) in the educational game "Gea 2: A New Earth". This agent is designed to detect and react to players' emotions during gameplay, supporting the game's educational objectives and boosting students' emotional engagement. This adaptive approach to students' emotions represents a sophisticated integration of emotional considerations into game design, aligning with the contemporary educational focus on emotionally engaging learning experiences.

The "**Programming**" cluster specifically emphasizes integrating computational thinking and coding into GBL. This focus aligns with discussions highlighted in the "Introduction" that underline the necessity of developing these skills to prepare students for a technologically advanced society [5]. Integrating coding into GBL not only boosts students' technical abilities but also fosters the development of problem-solving skills, logical thinking, and creativity—capabilities that are essential in today's digital age.

Recent studies have substantiated the benefits of integrating game-based learning with curricular objectives. For instance, research has shown that game-based environments significantly increase student engagement and learning outcomes in STEM subjects, making complex concepts more accessible and engaging through gamification and interactive elements [87].

Additionally, the creation of educational games that include programming and computational thinking has been proven to enhance cognitive skills and students' ability to apply these concepts in real-world scenarios [88]. These findings are pivotal as they demonstrate the evolving nature of educational technologies and their impact on learning modalities, reinforcing earlier discussions about the potential and effectiveness of GBL within contemporary educational frameworks.

5. Conclusions

This exploratory analysis mapped the trajectory of research into gamified approaches in secondary STEM education over the past decade, uncovering a pronounced interest in their integration into educational curricula. This direction is bolstered not only by the potential of GBL to enhance student engagement and interest but also by its significant role in improving academic achievement by rendering complex STEM concepts more accessible and enjoyable. Furthermore, the current study illustrates a transition from initial explorations of basic game mechanics to a sophisticated application of games that consider cognitive and emotional aspects of learning within well-defined theoretical and methodological frameworks.

Despite these promising developments, the field continues to confront challenges in addressing critical issues in STEM education. A primary concern, related to the broader application of GBL in educational settings, is maintaining educational efficacy alongside its intrinsic entertainment value. It is particularly challenging to balance the cognitive load without diminishing the entertainment factor in subjects that necessitate mastering complex content, which in turn demands considerable mental effort from students.

Moreover, the rapid advancement of technology perpetually reshapes the potential and application of GBL in education, requiring ongoing adaptation of GBL strategies and tools. This study underscores the scholarly community's capability to embrace these challenges, moving toward the exploration of instructional solutions tailored to new technological scenarios, such as immersive tools. By harnessing these advanced technologies, GBL can provide more dynamic and interactive environments, potentially transforming traditional educational settings into more effective and engaging learning spaces.

However, like any knowledge domain, this field necessitates continual reflection on the applicability and relevance of empirical findings in real-world educational contexts. STEM education still exhibits social disparities across different countries; thus, the sustainability of technological solutions, despite their effectiveness and innovation, remains a critical issue that researchers cannot ignore. This study also notes a prevailing preference for quantitative methodological approaches in the current research, despite recent critiques of GBL studies. Nonetheless, an exclusive reliance on quantitative methodologies, with rigorous experimental designs, might risk underestimating the importance of capturing the subjective experiences of students and teachers in actual educational environments.

Additionally, there is an ongoing need for researchers to reassess the most suitable frameworks for evaluating the multifaceted impacts of GBL and implementing effective gamified solutions. These frameworks should assess not only academic performance but also emotional and social skills, which are crucial for learning STEM subjects and which GBL can help develop. A deeper understanding of these broader impacts by the scientific community will facilitate the dissemination of effective GBL strategies among educators, supporting multifaceted, holistic educational objectives.

Overall, the results of the present study suggest that the scientific community is exploring different dimensions related to the use of GBL for teaching and learning STEM subjects in secondary schools. In addition to an unavoidable influence of technological evolution on the questions covered, it is possible to conclude that the field of inquiry is incorporating issues related to the broader topics of the effective use of games in education and the improvement of pedagogical approaches for STEM teaching, even considering the challenges that still remain.

One of the strengths of this investigation lies in the methodology adopted. Document analysis based on the co-occurrence of words is an effective and yet under-explored way to understand the conceptual framework of a scientific field. Starting with a systematic collection of publication titles and abstracts, our study was based on a representative body of research and used a tool specifically designed for textual analysis. Moreover, the combination of multiple types of analyses focusing on the co-occurrence of lemmas allowed us to explore different facets of studies on GBL applied to secondary education in STEM over the past decade, resulting in a broader and evolving view. However, the limitations should be mentioned. The results are based on abstracts from peer-reviewed and double-blinded journals, but publications and research on GBL are also published in various other formats. In addition, rapid technological development may be reflected in other new areas of current research not yet sufficiently represented in the body of literature considered in this study. Future research considering additional databases and centered on a systematic literature review is therefore needed and may provide a more comprehensive insight. Nevertheless, the results present an interesting, albeit tentative, picture that can be used as a useful basis for reflection by both scientific communities and educational policymakers.

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