IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 14 May 2024, accepted 2 June 2024, date of publication 7 June 2024, date of current version 18 June 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3411094

RESEARCH ARTICLE

Exploring the Evolution of Educational Serious Games Research: A Topic Modeling Perspective

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This work was supported by the Norwegian University of Science and Technology, Gjøvik, Norway.

ABSTRACT This study aims to reveal the dominant research interests and models in serious games research using topic modeling analysis. The dataset of this study covers a comprehensive collection of 2676 articles from the past to the end of 2022, indexed in the Scopus database. The study begins by presenting descriptive attributes of the articles, including their publication years, subject areas, and the journals in which they are published. Subsequently, employing topic modeling analysis, a form of unsupervised machine learning, the study identifies concealed themes, research interests, and tendencies within the literature. The findings indicate a notable surge in publications in this domain, particularly post-2009 and 2019. Furthermore, the study identifies eleven primary topics dominating the literature, with notable emphasis on ''Training of STEM-related fields,'' ''Programming learning,'' and ''Medical education''. To gauge the dynamics within these topics, the study calculates accelerations both within individual topics and in comparison to others over time. Remarkably, ''Child and adolescent health'' emerges as the topic with the highest self-acceleration, while ''Medical education'' stands out for its acceleration in comparison to other topics. In sum, the outcomes of this study, which provides a comprehensive overview of the serious games field, are anticipated to yield valuable insights for understanding the current landscape, guiding future research endeavors, and shaping the trajectory of this field.

INDEX TERMS Data science applications in education, research trend, serious games, topic modeling.

I. INTRODUCTION

In recent years, there has been a growing interest in developing innovative tools to enrich learning environments and support learning. Accordingly, the use of games for educational purposes has become increasingly widespread [1], [2], [3]. Games used in the education and training process—including simulation and video games—are considered serious games (SG) [3], [4], [5], [6]. With the acceptance and use of information and communication technologies (ICT), SGs have received and continue to attract great attention in recent years [7]. This interest is based on their potential to support learning [8], [9]. According to [10], well-designed SGs have the potential to turn learning into a challenge full of fun through the right mix of educational and entertaining elements. Similarly, [11] emphasizes that well-designed SGs can support effective learning. From this point of view, it can be said that SGs play an active role in encouraging learning because of their interesting and immersive features that increase the active participation of students in the learning process [12]. For this reason, educational SGs are seen by many researchers as a fun activity and are considered to support the development of knowledge, skills, and abilities through immersive experiences [13], [14].

SG is mostly regarded as an application-type of digital game-based education system. As a matter of fact, SG is a game that aims not only for entertainment but also for teaching purposes [15], [16]. While entertainment games are

The associate editor coordinating the review of this manuscript and approving it for publication was Mostafa M. Fouda.

primarily focused on entertainment and leisure activities, SGs are designed to serve a primary purpose beyond entertainment, such as education, training, or promoting social change [8], [12]. By using entertainment elements, SGs aim to increase players' motivation and interest while at the same time achieving specific learning objectives or supporting the development of specific skills. As such, SGs are hybrid in nature, combining entertainment and learning objectives [14]. SGs can also be thought of as games containing purposeful tasks aimed at improving the player's performance and cognitive skills [17], [18]. From this aspect, different from entertainment games, SGs are designed for an educational purpose [2], [19], [20]. With SG, the player also learns while playing [4]. An effective SG tries to put the player in a positive mood to continue the game, thereby increasing interest in the game. This manifests itself as better academic performance [18]. In this context, SGs have proven to be a powerful tool in education in terms of attracting students' attention, motivating them, and helping them learn [21], [22]. While there were mostly positive opinions about the effects of SGs on learning, negative results were reported in a number of studies, albeit in a limited number. At the top of these disadvantages, it has been shown that SGs negatively affect the relationship between mental workload and learning effect and increase mental workload [23], [24].

A. EXAMPLES OF THE INTEGRATION OF SGs INTO LEARNING ENVIRONMENTS

Studies analyzing learning through SGs and their effects on learning have gained importance in recent years [25]. Because SGs include both formal and informal environments and can appeal to target audiences from almost every age group [6]. For this reason, SGs are integrated into learning environments in a wide range and at different levels, from theoretical and practical training to military training; from mathematics education to health education; from programming to engineering education; from safety training to rehabilitation [6], [26], [27], [28], [29], [30]. Some of these studies can be detailed as follows: [10] aimed to measure the effectiveness of SG in training students in safe design thinking in the construction and maintenance of facilities. In the research, three interventions were developed and implemented to measure pedagogical values: a computer-based serious game, a paper-based game (the paper version of the serious game), and a traditional lecture. The results of the study revealed that the serious game is more effective than the traditional lecture, and the paper-based game cannot motivate the students as much as the SG. Reference [21] conducted a study on an SG application developed for first aid techniques. In the study, they proposed a combination of game learning analytics and data mining techniques to predict changes in knowledge level based on student interactions within SG. The results of the study showed that SGs can be used not only for teaching but also for measuring knowledge acquisition after playing. Reference [31] investigated the effects of a multiple intelligence-based SG on attention deficit hyperactivity disorder and specific learning disorder, and they found significant differences in attention performance measures between experimental and control groups in the posttest. Reference [25] developed a SG for learning arithmetic operations on polynomials, which they named Tempoly. The aim of the study is to measure the reactions of students to SG and to examine the effect of SG use on students' learning. The results of the study revealed that the students enjoyed playing the game, the game helped them learn polynomial operations, and the students who played the game synchronously with the lesson were statistically more successful than those who did not. Reference [22] compared the effects of teaching programming to secondary school students with SG and traditional teaching approaches. According to the results, although students who learned with SG were more successful, there was no statistically significant difference. In addition, perceived ease of use, usefulness, and attitude towards SG use were quite high. Reference [32] implemented an SG for learning the concepts of ''Thermotechnics'' in his study conducted with engineering students. The results of the study revealed a statistical effect of SG on academic achievement. On the other hand, most of the students expressed the opinion that SG increases motivation and that they find it easy and fun to use. Reference [33] examined the effect and effectiveness of SG on science learning and concluded that students understood the relevant scientific concepts in a holistic way, academic performance increased significantly in the case of SG playing, and the effect of learning was preserved in the long term. Reference [34] developed a SG for the sexual health education of adolescent students and conducted an experimental study. The results of the study revealed positive results in terms of both academic success and the effectiveness of SG. Reference [35] developed and implemented a SG for medical decision-making education, which they named GeriatriX, by weighing the patient preferences of medical students with the relevance and costs of medical care. The results of the study showed that there was a large increase in weighing patient preferences, appropriateness, and cost of medical care in the SG-trained group.

The examples provided showcase the diverse applications of SGs in education, ranging from STEM fields to programming, medical and health sciences, child and adolescent health, rehabilitation, cultural heritage education, and safety education. These examples provide a very comprehensive perspective on the widespread use of SGs across different educational disciplines and levels.

B. RELATED WORKS AND IMPORTANCE OF THE PRESENT STUDY

The increasing popularity of SGs in recent years has resulted in their integration into learning environments at almost all levels and in different fields. In this context, a number of bibliometric, scientometric, meta-analysis, and systematic review analyses have been carried out to describe the current

situation of SG research both in general and in a specific field and to offer a holistic perspective on the field. Some studies in this field can be listed as follows: bibliometric analysis with 376 articles in the field of simulation and SG used in educating for sustainability published between 1997-2019 [26], meta-analysis with 39 articles published between 2009-2018 [18], a literature review on 26 articles on the possible role of the narrative in the experience of the student participating in SG games [20], a systematic review study conducted with 48 studies to determine the trends of SGs in the field of health care training [36], bibliometric analysis conducted with a total of 1431 publications on SG published between 2007-2017 [37], review and bibliometric analysis with 795 articles to determine the health care trend in SG [38], systematic scoping with 21 articles including SGs used for health promotion with adolescents (SGs used for health promotion with adolescents) review [39], a systematic review study conducted with 53 empirical SGs in science education published between 2002 and 2013 [6], and a systematic review study conducted with 30 SGs used in health professions education [40], a systematic review study conducted with 7 SG articles in nursing education [41], the effectiveness of SGs in alleviating depression a systematic review and meta-analysis study [42] with 16 articles on effectiveness of SGs in easing the depression, systematic review study conducted with 12 articles on SG design and clinical improvements in physical rehabilitation between 2010-2021 an article [43]. The contribution of such studies to the field, describing the studies conducted in different fields with SG, cannot be ignored. However, both bibliometric studies focusing on specific indicators and systematic review studies with relatively little documentation and manual analysis may have limitations due to these characteristics. These limitations make it difficult to look at the field from a wider perspective and increase the risk of missing semantic information in the extraction of hidden semantic patterns [44], [45]. At this point, topic modeling studies based on data/text mining, which is an unsupervised machine learning technique, provide important outputs. Bano et al. demonstrated how BERT and BiGRU can be combined for summative text summarization, revealing how unsupervised learning algorithms can effectively extract key information from long and complex scientific articles. This work is an example of how the power of unsupervised learning can be harnessed to find meaningful patterns and relationships in large amounts of text data, just like topic modeling [83].

Topic modeling is an innovative computational technique that has revolutionized the analysis of large volumes of unstructured text data [44], [46], [47]. This innovative approach enables researchers to uncover hidden semantic structures, or ''topics,'' within document collections, providing a deeper understanding of the underlying themes and concepts present in the data [44], [48]. By using advanced algorithms and statistical methods, topic modeling can reveal patterns and relationships that may not be immediately apparent through traditional methods of analysis. One of the key innovations of topic modeling, particularly exemplified by Latent Dirichlet Allocation (LDA), is its ability to automatically identify topics without the need for pre-defined categories or labels [50], [51]. This unsupervised nature of topic modeling is particularly valuable in exploratory data analysis, where researchers seek to gain insights from data without prior assumptions about its structure [53]. This approach allows for a more flexible and adaptable analysis, as the topics identified by the model can evolve based on the content of the documents being analyzed [44], [45], [50].

LDA, a foundational model in topic modeling, is a probabilistic generative model that posits each document as a mixture of topics and each topic as a distribution over words [50], [54], [55]. The model assumes a three-level hierarchical Bayesian structure, wherein documents are represented as random mixtures of topics, which are in turn characterized by distributions over words. Through iterative application of the Dirichlet distribution, LDA estimates the posterior distribution of topics in each document and the distribution of words in each topic. This iterative process allows LDA to capture the underlying thematic structure of the document collection, enabling researchers to uncover hidden patterns and semantic relationships [45], [50], [52]. LDA-based topic modeling offers a methodologically sound approach to analyzing textual data. While topic modeling analysis is used to reveal hidden structures in text data, bibliometric analysis is more commonly used to examine the content, publication frequency, and interactions of publications in academic literature [44]. The advantage of topic modeling analysis over bibliometric analysis is that it allows a deeper understanding of the data by revealing hidden structures in text data [45], [46]. In recent years, many studies based on topic modeling have been mentioned, thereby identifying interests and trends in various fields [44], [47], [48], [51], [53], [81].

The current study aims to reveal the big picture in articles about SG from the past to the present. Additionally, it aims to reveal the research interests and trends of articles in the field of SG and their hidden semantic patterns through topic modeling analysis. This study provides a comprehensive analysis of the field of SG with a total of 2676 articles, providing the opportunity to look at this field from the broadest perspective. In addition, the fact that it was conducted with an innovative method based on unsupervised machine learning-based topic modeling is an important study. In this direction, answers to the following research questions were sought in the study:

RQ_1: What is the distribution of articles on SG by years?
RQ_2: What are the prominent subject areas and journals in articles about SG?
RQ_3: What are the prominent topics in SG-related articles?
RQ_4: What is the trend of the topics emerging in the articles with SG?

These research questions are critical to better understanding the role of SGs in education, guiding future research, and shaping developments in the field. By answering these questions, the current study will be able to understand the current state of SG research, identify which topics are at the forefront, and reveal potential research gaps in the field. In this context, the study will make a significant contribution to the literature by providing a broad perspective on the field of SG and by using an advanced analysis technique such as topic modeling.

II. METHODS

This study relies on two bases. The first of these is to reveal the descriptive characteristics of the articles in the field of SG (to answer the first two research questions), and the second is the topic modeling analysis of these articles (to answer the third and fourth research questions). Descriptive analysis was primarily used to reveal common characteristics of articles in the field of SG. Descriptive analysis is an accepted method for extracting specific indicators and summary information from studies, such as publication years, subject areas, and journals [49]. While this approach provides an overview of the field, it may not capture complex relationships and nuances in texts. Therefore, we examined key trends and focal points in SG research more comprehensively using topic modeling analysis for more in-depth semantic analysis [50]. With topic modeling analysis, it becomes possible to extract semantic information from large text stacks that are difficult to handle manually. For this reason, topic modeling analysis has been a preferred approach in recent years for determining research interests and trends in literature reviews [44], [45], [51], [52], [53]. In this study, the Latent Dirichlet Allocation (LDA) algorithm [50], which is accepted and frequently used in the topic modeling analysis process, was used. LDA is a probabilistic generative method used in topic modeling [54], [55]. The LDA algorithm is a probabilistic topic modeling technique used to extract hidden semantic patterns from text data [50], [82]. LDA assumes that each document is a mixture of topics, and each topic has a distribution over words. By estimating the probability distributions of topics in documents and words in topics, the algorithm reveals the underlying thematic structures in the text collection. In this way, semantic patterns in large text datasets can be automatically identified without human intervention. The flow diagram of the study is summarized in Figure 1.

According to Figure 1, the study starts with the creation of a comprehensive dataset of articles in the field of SG from the Scopus database. The collected data is then subjected to cleaning and preprocessing stages to make it suitable for topic modeling analysis. These stages include removing numerical expressions, punctuation marks, and symbols from the text data, lowercase conversion, the removal of stop words, and lemmatization. The cleaned data is then subjected to two different types of analysis: descriptive analysis and topic modeling analysis. Descriptive analysis aims to reveal the basic characteristics of the articles, such as publication years, subject areas, and journals. Topic modeling analysis, on the other hand, uses the LDA algorithm to identify hidden semantic patterns in the texts, i.e., topics. Finally, the findings from both analyses are combined and interpreted, and the main conclusions of the study are presented.

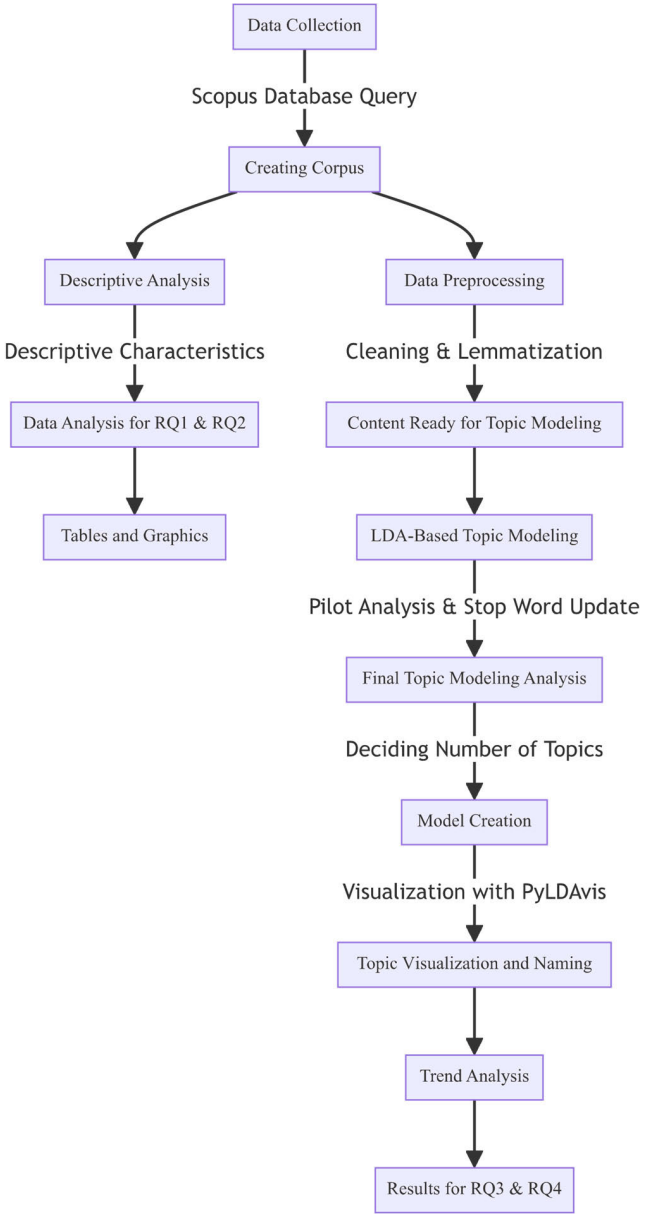

FIGURE 1. Flow diagram of the whole study.

A. DATA COLLECTING AND CREATING THE CORPUS

The first and most important step in the literature review is the creation of the largest corpus in the studied area. Accordingly, the Scopus database was chosen to create the most transitional corpus in the SG area. The Scopus database stands out as the most comprehensive database that brings together more than 7000 publishers worldwide, including Elsevier (Web of Science), Emerald, IEEE, Sage, Springer, Taylor & Francis, and Wiley Blackwell, and also includes more than 240 disciplines

[56], [57]. Thanks to this inclusive and wide network, the Scopus database is accepted and frequently preferred in such studies [45]. In this context, the terms that will best cover the SG field on the Scopus database were searched with the support of the literature, and the title, abstract, and keywords were searched in order to cover the article. The following final query was created as a result of the investigations carried out with the researcher and two field experts:

TITLE-ABS-KEY ("serious game" AND ("educ*" OR "learn*" OR "teach*" OR "train*" OR "instruct*")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (EXCLUDE (PUBYEAR, 2023))*

When selecting the dataset from the Scopus database with the above query, specific criteria were used to cover serious game studies with an educational focus. All articles and reviews that included the term ''serious game*'' and at least one of the terms ''educ*'', ''learn*'', ''teach*'', ''train*'' or ''instruct*'' were included in the dataset. This selection aimed to identify research that focused on the use of serious games in an educational context. The use of these criteria ensured that studies examining serious games in fields other than education were excluded from the dataset. This query was run on February 8, 2023, and a total of 2676 articles (2437 articles and 239 reviews) were obtained as a result of the query. In this way, all journal articles published in the field of SG from the past to the present (as of the end of 2022) have been reached. Descriptive analyes were conducted with these articles. The title, abstract, and author keywords of the articles were combined and stored in .csv format, and a corpus was created ready for topic modeling.

B. DATA ANALYSIS AND IMPLEMENTATION OF TOPIC MODELING

In this study, constructed on two bases, firstly, a descriptive analysis was conducted. With these analyses, the descriptive characteristics of the studies in the field of SG were revealed. The numerical, frequency, and proportional data obtained for answering the first two research questions (RQ1 and RQ2) were converted into tables and graphics. In the second stage, the LDA-based topic modeling stage was carried out to answer the third and fourth research questions (RQ3 and RQ4). The topic modeling phase requires a number of sequential processes. These stages, also known as data cleaning and preprocessing stages, are of great importance in terms of making the corpus ready for analysis [45], [58]. Firstly, numerical expressions, punctuation marks, and symbols in the data set were removed from the texts, and words were converted to lowercase. Then, a list of stop words (generic words such as a, an, the, and etc. that do not make sense for the text) was created and removed from the text. Finally, the lemmatization process was applied to express the words as unique. With this process, the stems of the words are obtained. All these preprocessing steps are fulfilled with the Python language and related libraries of this language. As a result of these processes, content ready for topic modeling analysis was created.

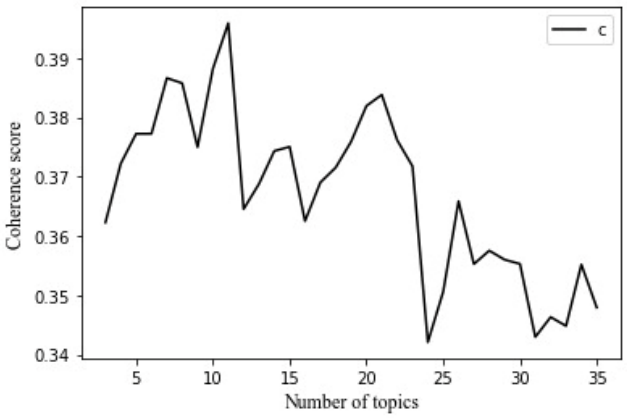

FIGURE 2. Topic number – c_v coherence graph.

LDA-based topic modeling analysis was performed on the data set, which was preprocessed and cleaned. A pilot analysis was conducted using the Python language Gensim library [59], and distributions of topics were observed. As a result of the pilot analysis, the stop word list was updated, and since the terms ''serious'' and ''game'' were seen in almost every topic, it was decided to add these words to the stop word list. As a matter of fact, these terms are terms that belong to the topic studied, and it does not make any sense to mention them. After this stage, the final analysis was made and a model was created for each topic between K = [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35] topics. In order to decide on the ideal number of topics, the c_v coherence value is one of the coherence values used for the decision [44], [60]. Ideally, the c_v consistency value is expected to be 0.7, and in real practice, the closest value is accepted [50]. As a result of the analysis, it was seen that the model with 11 topics with the highest c_v value (c_v = 0.3958) was the ideal number of topics. In Figure 2, the graph of the number of topics (c_v coherence value) is given.

As seen in Figure 2, there is a relationship between the number of topics and the c_v consistency value. As a result of the analysis, the highest c_v consistency value (0.3958) was obtained for 11 topics. Since this value is closest to the ideal c_v consistency value (0.7) accepted in the literature, the number of 11 topics was determined as the ideal number of topics in this study.

After deciding on the number of topics, the topics were visualized with the PyLDAvis library and named with the help of this visualization. PyLDAvis is a library built on LDAvis [61] that provides web-based interactive and dynamic visualization of topics [62]. The importance of the words that make up the topics for that topic can be seen with the help of the lambda parameter. As this parameter,

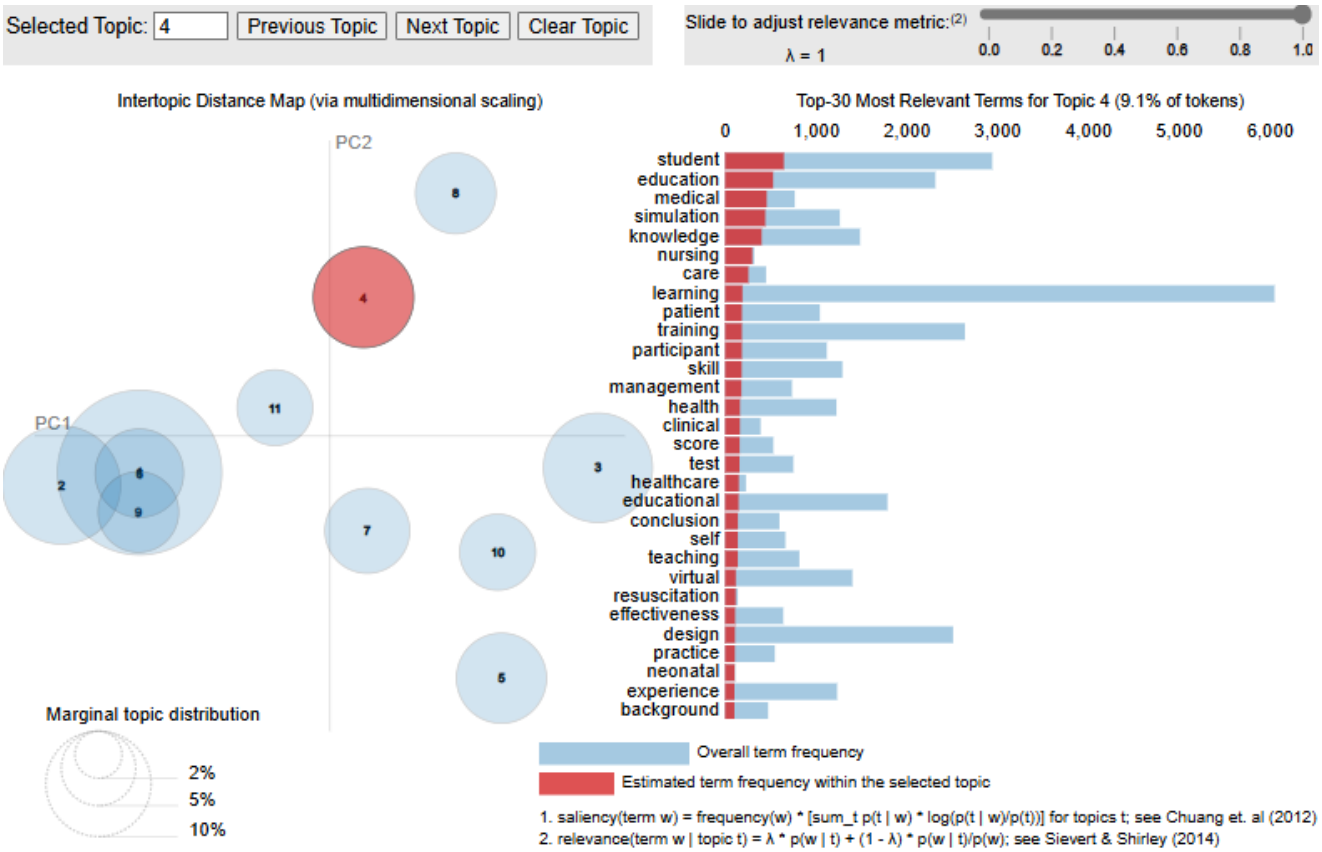

FIGURE 3. Screenshot pyLDAvis.

which is 1.0 by default, is decreased, the important words that stand out for the relevant topic are moved up. For better predictions on the topics, the optimum value of the lambda parameter was adjusted to 0.6 as suggested in the literature [53], [61]. A screenshot of PyLDAvis is given in Figure 3. The terms constituting the topics were examined by two educational technologists besides the researcher, and the topics were named together. In addition, trend analyses were made, showing the ratio of each topic among all topics and the change of topics over time. As shown in Figure 3, the topic model resulting from the LDA analysis consists of 11 topics. This interactive visualization, obtained using the pyLDAvis tool, was used to examine the relative importance of the terms characterizing each topic and possible overlaps between topics. PyLDAvis is a powerful tool that facilitates the understanding and interpretation of the topic model.

III. FINDINGS

In this section, the findings obtained from the study, which aims to look at the field of SG from the widest perspective, are presented with two titles to answer the research questions. The first title is "Findings on Descriptive Analysis," in which the findings obtained for the first two research questions (RQ1 and RQ2) are presented, and the second title is "Topic Modeling Analysis Findings," where the findings for the third and fourth research questions (RQ3 and RQ4) are presented.

A. FINDINGS ON DESCRIPTIVE ANALYSIS

In order to reveal the descriptive characteristics of the SG field, firstly, the distribution of the number of publications in this field by year was examined. In Figure 4, the number-year graph of the publications in the field (n = 2676), which first started with a publication in 2005, and its slope are given (for answering RQ1). The slope of the graph of the number of publications by year was obtained as 17,774.

As seen in Figure 4, although there has been a linear increase in the number of publications in general, this increase has become more evident, especially after 2009 and 2019. Findings related to subject areas and journals that stand out in publications in the field of SG (for answering RQ2) are given in Figure 5 and Table 1, respectively.

In Figure 5, the top ten subject areas of the articles on SG are listed in order. 27 different subject areas were obtained individually. Since some of the 2676 articles in total are tagged in more than one subject area, the total number of subject areas is greater than the number of articles. In other words, some studies are labeled under more than one subject area because they are interdisciplinary. This situation should not go unnoticed. As seen in Figure 5, the computer science

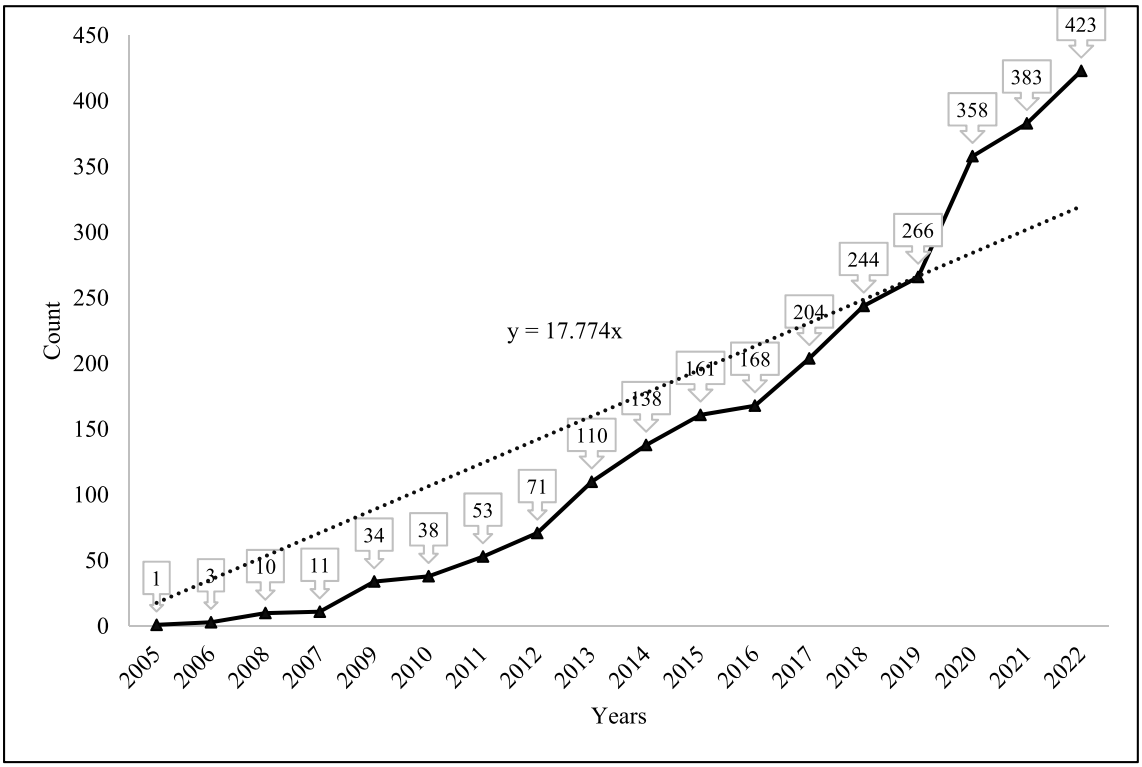

FIGURE 4. Number of publications by year and slope graph.

TABLE 1. The top ten journals with the highest number of publication and number of publications.

Journal	Count
Jmir Serious Games	128
Simulation and Gaming	70
Computers and Education	54
Entertainment Computing	46
International Journal of Game Based Learning	45
Games for Health Journal	40
Sustainability Switzerland	39
Computers in Human Behavior	37
International Journal of Emerging Technologies in Learning	35
International Journal of Serious Games	33

subject area (n = 1209; f = 45.18%) came to the fore the most in publications. This is followed by the subject areas of ''Social Science'' and ''Engineering'', respectively. Finally, the findings regarding the journals with the most publications in the field of SG are given in Table 1.

In Table 1, the first ten journals and the number of publications in these journals are given. It can be said that the number of publications (n = 527) in the top ten journals with the highest number of publications is approximately equal to one-fifth of the total number of publications (n = 2676). Looking

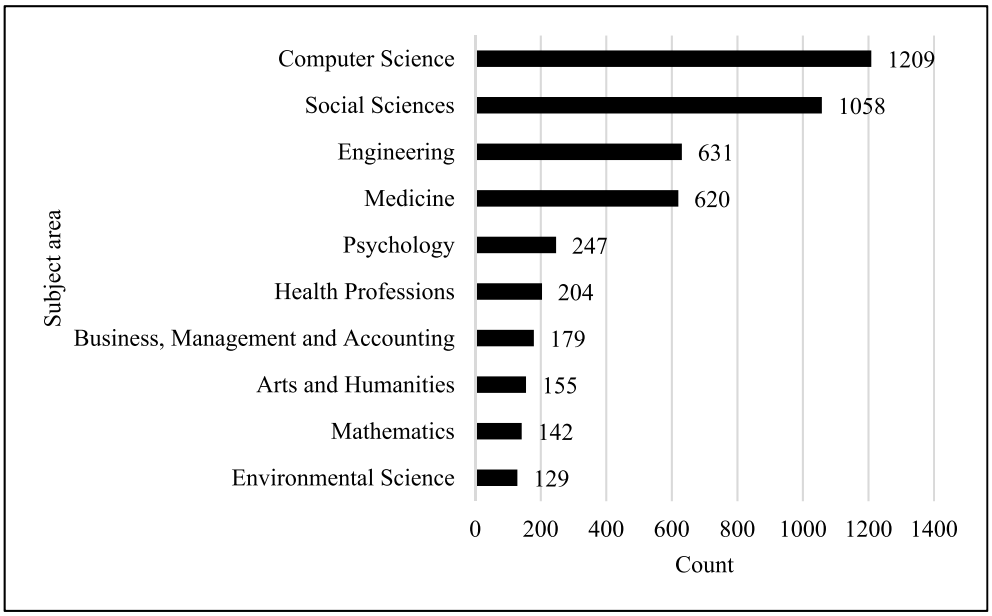

FIGURE 5. The top ten subject areas with the highest number of publications and number of publication.

at the journals, it is possible to say that there are publications in different disciplines, as the subject areas reveal. As a matter of fact, it has been revealed that journals directly related to games, educational technology journals, and journals in the fields of entertainment, health care, and medicine are among the top ten most published journals.

B. FINDINGS RELATED TO THE TOPIC MODELLING ANALYSIS

First, the topics for answering the third research question (RQ3) were examined. Findings from the LDA-based topic modeling analysis revealed that the SG domain was represented by 11 topics. Topics are coded as T1,…,T11. The topics obtained as a result of the analysis, the terms that make up these topics, and the proportional distribution of the topics are given in Appendix-A; the matrix of the number of publications by topic-years and the acceleration of each topic are given in Appendix-B (both in an order according to the volume of the topic). In Figure 6, the topics are given according to the rank of volume (a) and rank of acceleration (b).

As seen in Figure 6, "T1: Training of STEM-related fields" is the most studied topic in SG (f = 44.84%). This is followed by "T2: Programming learning" and "T3: Medical education", respectively (f = 21.49% and f = 8.33%). Similarly, the top four topics that have been studied the most—with the highest acceleration rate—are also the top four most studied topics over time. Comparing Figures 6.a and 6.b, in general, the ranks for the most studied topics and the topics with the highest acceleration are largely the same. Only "T5: Dental Education" breaks the ranking and accelerates slower than the topics "T6: Child and adolescent health", and "T7: Training of cognitive function in adults and the elderly".

TABLE 2. The volume percentage and acceleration of each topic in periods.

	2005-2010	2011-2016	2017-2022	Acc
	f			
T6	0.98%	13.73%	85.29%	0.42
T8	1.09%	17.39%	81.52%	0.40
T7	3.09%	16.49%	80.41%	0.39
T3	1.35%	20.63%	78.03%	0.38
T10	3.33%	20.00%	76.67%	0.37
T11	8.00%	16.00%	76.00%	0.34
T5	3.42%	25.64%	70.94%	0.34
T9	4.17%	25.00%	70.83%	0.33
T2	4.52%	26.78%	68.70%	0.32
T4	4.79%	26.95%	68.26%	0.32
T1	3.83%	29.83%	66.33%	0.31

To answer the fourth research question (RQ_4), the years 2005–2022 were divided into three six-year periods in order to determine the trend of topics in SG articles. This method was used to see the changes in the topics over time. The volume ratio of each topic in the periods (how many percent of the articles on each topic were conducted in the relevant period) and the acceleration of this ratio are given in Table 2 in order according to the acceleration.

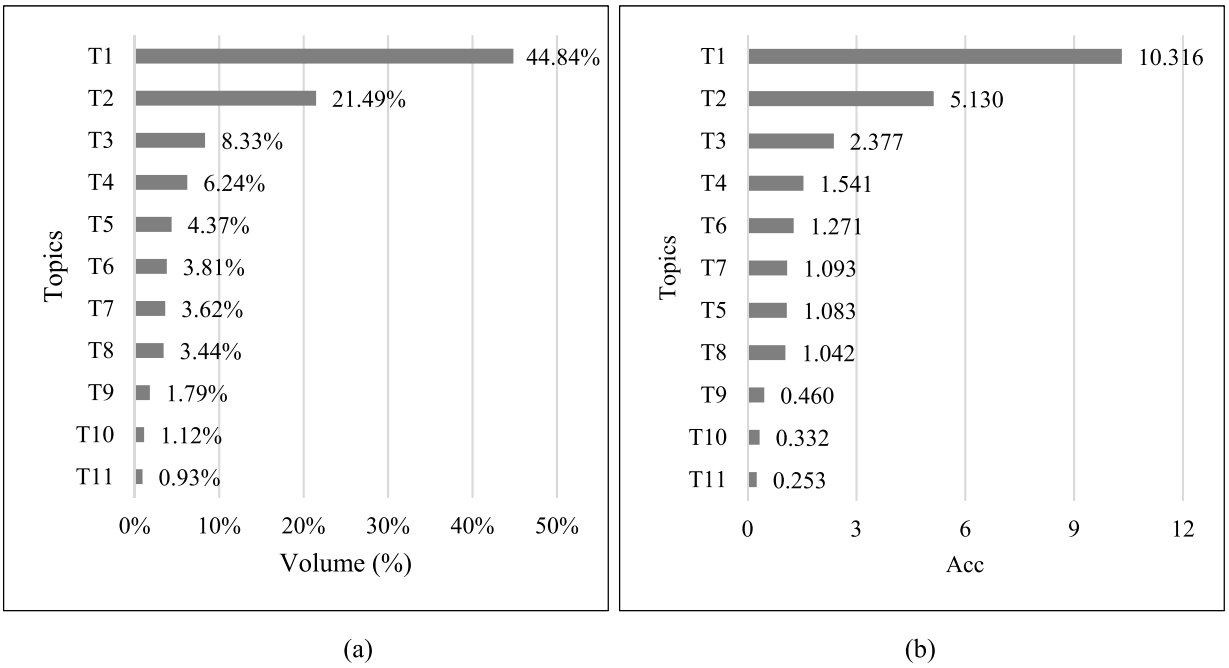

FIGURE 6. Ranks of the topics according to their ratio of volume (a) and acceleration rate (b).

As it can be seen in Table 2, all topics' percentage of being studied increases over time. Table 2 should be read on the basis of rows, and it should be understood that each row represents the volume percentage of the relevant topic in that period. However, the top three topics whose intensity of study increased the fastest in time were "T6: Child and adolescent health" (Acc = 0.42), "T8: Rehabilitation training" (Acc = 0.40), and "T7: Training of cognitive function in adults and the elderly" (Acc=0.39).

Finally, the percentages of the topics in the field of SG compared to other topics in the periods were calculated. In this way, considering the volume ratios of all topics in each period, the status of each topic compared to other topics was determined. In other words, the percentage of each topic in each period was determined. In this way, the acceleration of each topic over time compared to other topics was calculated. Thus, the intensity of the study regarding each topic compared to the other topic was determined. In Table 3, the percentage rate and acceleration of each topic compared to other topics in periods are given.

Table 3 should be read on a column-by-column basis, and it should be understood that each value in the column represents a percentage of the publishing volume of the related topic in that period. As seen in Table 3, the top three topics whose intensity of study increased most over time compared to other topics are "T3: Medical education", "T6: Child and adolescent health", and "T8: Rehabilitation training", respectively. Similarly, "T4: Cyber security and military education", "T1: Training of STEM-related fields" and "T2: Programming learning" are three topics whose frequency of study has decreased over time compared to other topics. In light of the findings given in Table 2 and Table 3, both the changes within the topics over time (a) and the changes compared to other topics (b) are given together in Figure 7.

TABLE 3. Volume percentage and acceleration rate of each topic compared to other topics in periods.

	2005-2010	2011-2016	2017-2022	Acc
	f			
T3	3.09%	6.56%	9.27%	0.031
T6	1.03%	2.00%	4.63%	0.018
T8	1.03%	2.28%	3.99%	0.015
T7	3.09%	2.28%	4.15%	0.005
T5	4.12%	4.28%	4.42%	0.001
T10	1.03%	0.86%	1.22%	0.001
T9	2.06%	1.71%	1.81%	-0.001
T11	2.06%	0.57%	1.01%	-0.005
T4	8.25%	6.42%	6.07%	-0.011
T1	47.42%	51.07%	42.39%	-0.025
T2	26.80%	21.97%	21.03%	-0.029

As can be seen in Figure 7.a, all topics increase their value within themselves. Additionally, the first three topics, whose frequency of study increased the most over time, emerged as

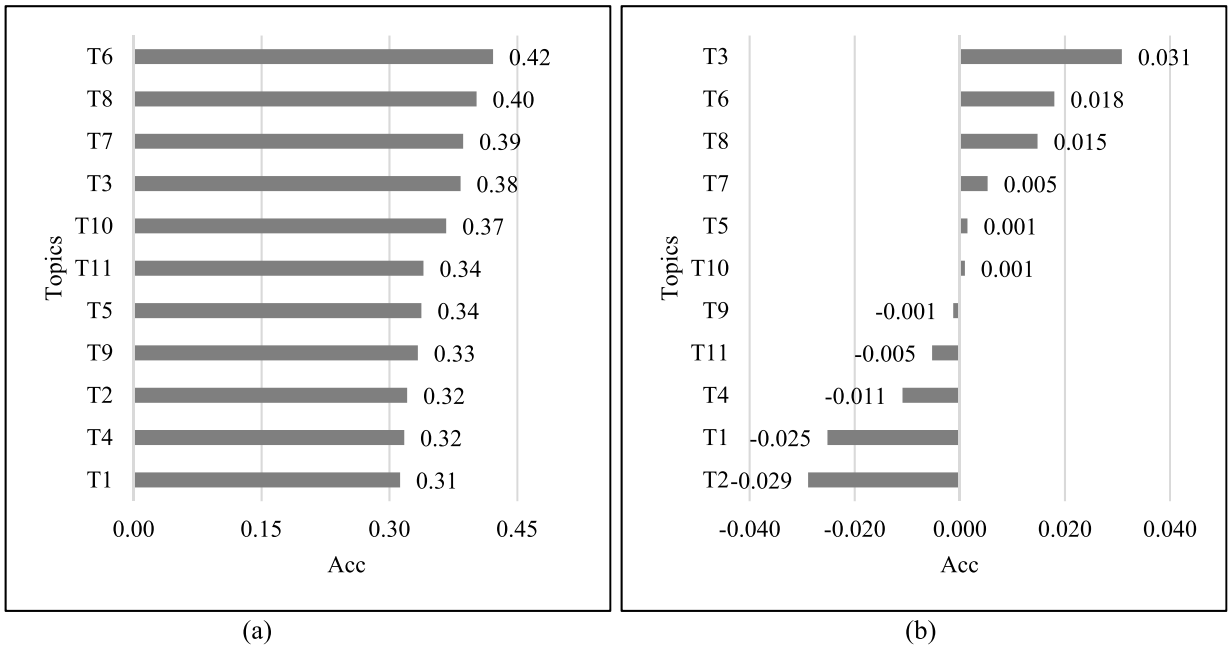

FIGURE 7. Acceleration of topics within themselves (a) and compared to other topics (b) over time.

T6, T8, and T7, respectively. In Figure 7.b, 6 of the topics (T3, T6, T8, T7, T5, and T10 topics, respectively) started to be studied more than the others over time, while 5 of them (T9, T11, T4, T1, and T2, respectively) started to be studied less than other topics over time.

IV. DISCUSSION AND CONCLUSION

In this section, the results obtained from the study are given, and the possible reasons for these results are discussed within the framework of the current literature. It can be said that the number of publications about the integration of SG into the education environment has increased regularly, which has been studied since the 2005s. In addition, the increase, especially in 2009 and 2019, is remarkable. Reference [26] mentions a significant increase since 2010, while there were a limited number of studies before the 2010s. In recent years, it can be thought that the positive effects of SGs on learning have encouraged studies in this area.

When the subject areas and journals of SG studies in the field of education are analyzed, it supports that this field is an interdisciplinary field and studies are carried out in a different range. Different subject areas, such as ''Social science'', ''Engineering'', ''Medicine'', ''Psychology'', and ''Health Professions'', especially ''Computer science'', emphasize the diversity of studies related to SG. This is a stable and well-known situation in the literature and supports studies that emphasize the interdisciplinary nature of the field [6], [18], [36]. On the other hand, the journals with the highest number of publications in this field also confirm these results. Indeed, there are journals from different fields, such as both pure game journals (such as Jmir Serious, Simulation and Gaming), educational technologies (Computers and Education, International Journal of Game Based Learning), and health care and medical (Games for Health Journal). In the studies in the literature, it is known that almost the same journals are at the top of the list of journals with the most publications in this field [37].

The topic modeling analysis made with the articles published in the field of education related to SG revealed 11 topic models. When these topics are examined, the three most studied are ''Training of STEM-related fields'' (n = 1200; f = 44.80%), ''Programming learning'' (n = 575; f = 21.50%), and ''Medical education'' (n = 223; f = 8.30%). It is not surprising that this topic, called STEM-related, is the most voluminous, since the most voluminous topic is the collection of articles on science, engineering, and mathematics learning. Indeed, it is emphasized in the literature that scientific concepts in science and mathematics education are mostly abstract and complex, which makes learning difficult and causes loss of interest in learning, and at this point, SGs bring important opportunities [6], [25], [63]. On the other hand, when considering engineering education specifically, the fact that SG offers the opportunity to experience a simulated environment representing concrete and realistic engineering problems at appropriate levels of detail [32], [64] may have induced studies in this field. The second most studied topic has emerged as ''Programming learning.'' Many studies can be mentioned in the literature emphasizing the importance of SG in the field of programming learning. Encouraging active learning in general and providing support for learning cognitively challenging topics such as programming [7], [22], [65] may have resulted in SG's solidifying its place in programming learning.

The third most studied topic was ''Medical education'', and we think that this topic should be examined specifically. Namely, apart from this topic, the topics of ''Dental

education'', ''Child and adolescent health'', ''Training of cognitive function in adults and the elderly'', ''Rehabilitation training'' and ''Cognitive health training'' are directly or indirectly related to healthcare and medicine. In this context, it is possible to say that the field of healthcare and medicine and other fields related to healthcare and medicine are important application areas for SG. Creating an interactive and active learning environment [36], [66], showing effectiveness in improving various health outcomes [67], [68], and being able to be offered to people with mental illness due to their entertaining approach and ability to motivate users [69] as a possible educational strategy that can contribute to the transformation of health professions education [40] may have led to an increase in studies in these areas.

Apart from these topics, topics such as ''Cyber security and military education'', ''Training of environmental and cultural elements'', and ''Safety training in hazardous environments'' attract attention as areas where SG finds educational applications. The fact that SGs provide an entertaining environment where learners learn and apply cyber security concepts through games and help them complete computer-based security education [70], [71] may have pioneered studies in the fields of cyber security and military education. On the other hand, the fact that the virtual environment and SGs are seen as having the potential to complement the existing tools and practices based on concrete foundations such as museums, exhibitions, books, and visual content and enable the extensive masses to experience cultural heritage [72], [73], [74] may lay under the basis of the topic of ''Training of environmental and cultural elements'', which includes elements regarding cultural heritage and environmental elements. Finally, the topic of ''Safety training in hazardous environments'' is another application area of this field. When evaluated in the context of safety education, we come across a wide range of evacuation and safety concepts, from fire to earthquake, healthcare to mining. In this context, studies on this topic, which is called safety regarding hazardous environments, stand out, and in these studies, SGs are blended together with virtual reality [75], [76], [77]. The realization and experience of especially dangerous environments through immersive virtual reality and games [78], [79] has enabled SGs to be used for safety training and become widespread. Considering the general acceleration of the topics, it was seen that all of them were positive—the frequency of study increased over time. When the volume-acceleration ranks of the topics were compared, a great deal of similarity emerged. As a matter of fact, the most voluminous topics have emerged as the most accelerated topics at the same time. Only ''Dental education'' deteriorated the ranking, accelerated more slowly than the topics of ''Child and adolescent health'', and ''Training of cognitive function in adults and the elderly''.

Periods were created in order to determine the trend of the topics over time. Since the publications in this field were made over an eighteen-year period, three periods of six years have been established. The acceleration of the topics in these periods and their acceleration compared to other topics were examined. First, when we look at the acceleration values that determine the topics' frequency of being studied over time, the top five topics that accelerated the most were T6, T8, T7, T3, and T10, respectively (''Child and adolescent health'', ''Training of cognitive function in adults and the elderly'', ''Rehabilitation training'', ''Medical education'', and ''Cognitive health training''). These topics, which are generally related to health, health care, and medical sciences, are the ones that increase the rate of being studied within the periods the most. In addition, when the topics' frequency of being studied compared to other topics is examined, it is seen that six topics (T3, T6, T8, T7, T5, and T10, respectively) accelerated positively—the frequency of being studied increased compared to other topics—and five topics (T9, T11, T4, T1, and T2, respectively) also accelerated negatively—the frequency of being studied decreased compared to other topics. It is seen that the top five topics that increase the frequency of being studied within themselves the most over time and the top five topics that increase the frequency of being studied compared to other topics are the same (T5 and T10 have the same rate, therefore T5 and T10 can both be considered the fifth). This situation can be considered an indication that studies in different fields of healthcare and medicine have come to the fore. However, in terms of the frequency of being studied, a decrease over time compared to other topics is observed for the most voluminous topics, T1 and T2 (''Training of STEM-related fields'' and ''''Programming learning''). Particularly, the rapid increase in the intensity of studies in different fields of healthcare and medicine [36], [80] has shown itself as a relatively slowdown of the acceleration in these topics, although they maintain their volume.

A. INSIGHTS INTO FUTURE SERIOUS GAMES TRENDS

Trend analyses are vital to understanding how serious gaming (SG) research has evolved over time. These analyses help identify shifts in the research community's interests and emerging research focuses. In our study, we obtained some important insights by analyzing the ratio of each topic determined by topic modeling in total publications and the temporal changes of these ratios. These insights can be listed as follows:

Shifting Focus from STEM and Programming to Health and Medicine: The topics of ''Education of STEM-Related Fields'' and ''Programming Learning'' have long been dominant topics in SG research. However, our analysis shows that these issues have relatively lost momentum in recent years. On the other hand, topics related to health and medicine such as ''Medical Education'', ''Child and Adolescent Health'', and ''Rehabilitation Education'' are attracting rapidly increasing attention both within themselves and compared to other topics.

The Rise of Serious Games in Healthcare: This shift may reflect a growing interest in the applications of SGs in healthcare. COs can be used in a variety of healthcare

TABLE 4.

Topics	Topic terms	Volume rate
T1	learning, student, education, gamification, design, science, engagement, learner, engineering, mathematic, teacher, problem, digital, teaching, motivation	44.80%
T2	programming, learning, student, tool, computer, intellectual, fidelity, intelligent, accessibility, project, cybersecurity, disability, concept, system, environment, teaching, people	21.50%
T3	medical, nursing, student, simulation, education, care, knowledge, healthcare, neonatal, resuscitation, nurse, clinical, diabetes, pharmacy, score, management	8.30%
T4	security, training, gaming, cyber, military, player, risk, decision, bias, scenario, conflict, mitigation, experience, moral, attack	6.20%
T5	dental, evaluation, learning, educational, design, covid, development, hearing, skill, framework, social, model, application, virtual, reality	4.40%
T6	child, adolescent, health, intervention, parent, autism, nutrition, behavior, emotion, cancer, food, healthy, anxiety, asthma, mental	3.80%
T7	cognitive, dementia, impairment, memory, older, adult, elderly, alzheimer, function, people, cognition, decline, assessment, analysis, training	3.60%
T8	rehabilitation, patient, stroke, training, motor, movement, treatment, performance, system, attention, task, therapy, exercise, disorder	3.40%
T9	cultural, heritage, climate, sustainable, planning, collaborative, sustainability, escape, development, design, environmental, policy, water, urban, museum	1.80%
T10	health, cognitive, training, construction, design, leadership, machine, skill, stress, safety, assessment, performance, detection, vision, behavior	1.10%
T11	training, safety, virtual, patient, surgical, fire, evacuation, surgery, medical, reality, emergency, laparoscopic, resident, earthquake, immersive	0.90%

T1: Training of STEM-related fields
T2: Programming learning
T3: Medical education
T4: Cyber security and military education
T5: Dental education
T6: Child and adolescent health
T7: Training of cognitive function in adults and the elderly
T8: Rehabilitation training
T9: Training of environmental and cultural elements
T10: Cognitive health training
T11: Safety training in hazardous environments

areas, such as training healthcare professionals, treating and rehabilitating patients, promoting healthy lifestyle changes, and preventing disease.

Impact of Technological Advances: This increase in SG research in health and medicine may be due in part to advances in technologies such as virtual reality (VR) and augmented reality (AR). VR and AR technologies have the potential to increase the impact of SGs in healthcare by providing more immersive and realistic learning experiences.

Future-Forwarding Insights: Trend analyses also play an important role in guiding future SG research. By focusing on topics in rapidly developing fields, researchers can contribute to more current and needed areas. For example, investigating more thoroughly the effectiveness and usage areas of SGs in healthcare could provide significant contributions to the body of knowledge in this field.

The evolution of VR research in education can be effectively understood using trend analyses. Our findings suggest that the research community's interests are shifting from STEM and programming to health and medicine. This trend reflects the increasing potential for the use of SGs in healthcare and the impact of technological developments in this field. It is anticipated that future VR research will make significant contributions to the field by focusing on these rapidly developing areas and leveraging insights from trend analyses.

V. IMPLICATIONS FOR FUTURE AND STAKEHOLDERS

Integration of SGs into educational environments has accelerated in recent years. Many practices have been implemented to enrich the learning experience at different levels and branches, and their effects on learning have been investigated. While the most voluminous topics are ''Training of STEM-related fields'', ''Programming learning'', and ''Medical education'', the topics that have been studied the most within themselves and compared to other topics are in different fields of medical and healthcare sciences. In particular, the topic of ''Medical education'' stands out both in terms of the volume rate and as the most studied topic both within itself and in comparison to other topics. In addition, topics related to healthcare and medicine, such as ''T6: Child and adolescent health'', ''T8: Rehabilitation training'', and ''T7: Training of cognitive function in adults and the elderly'', which are among the topics that are more frequently studied compared to other topics, are noteworthy. The trends that emerged in this study are important in terms of providing a perspective on future studies in this field. In this context, changes in these topics can be observed in the future.

According to the findings of the study, stakeholders in the serious gaming field, including researchers, educators, developers, and policymakers, can observe that the significant acceleration in health and medical education research indicates a growing awareness of the potential of serious games in these fields. This suggests that serious gaming can offer solutions to a variety of challenges in healthcare. Stakeholders should prioritize the funding, development, and implementation of serious games designed to address various health challenges, including patient education, medical education, rehabilitation, and mental health support. They should also encourage interdisciplinary research projects and knowledge sharing, leveraging the collective expertise of different disciplines and fostering innovation in serious game design and implementation.

VI. LIMITATIONS AND FUTURE WORKS

With this study, research interests and trends in the integration of SG into educational environments from the past to

TABLE 5.

	Years																			
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022		
Topics	n																		Total	Acc
T1	1	2	4	6	17	16	33	40	71	64	76	74	97	110	118	136	155	180	1200	10.32
T2	0	1	3	2	11	9	14	16	20	33	34	37	45	38	67	93	80	72	575	5.13
T3	0	0	1	1	1	0	2	3	3	10	13	15	16	24	20	43	40	31	223	2.38
T4	0	0	3	0	2	3	1	2	6	9	15	12	9	15	15	27	28	20	167	1.54
T5	0	0	0	0	0	4	3	4	3	7	7	6	8	14	11	19	14	17	117	1.08
T6	0	0	0	0	1	0	0	1	1	2	4	6	6	9	10	11	21	30	102	1.27
T7	0	0	0	0	0	3	0	0	1	3	4	8	8	12	6	14	16	22	97	1.09
T8	0	0	0	0	1	0	0	1	1	3	7	4	5	13	14	7	15	21	92	1.04
T9	0	0	0	1	0	1	0	1	2	4	1	4	4	8	1	3	7	11	48	0.46
T10	0	0	0	0	1	0	0	3	1	1	0	1	3	0	2	2	3	13	30	0.33
T11	0	0	0	0	0	2	0	0	1	2	0	1	3	1	2	3	4	6	25	0.25
Total	1	3	11	10	34	38	53	71	110	138	161	168	204	244	266	358	383	423	2676	

Acc: Acceleration

the present were determined. This is a comprehensive and innovative study that best describes the overall picture of the field. The study, which stands out with these features, also has some limitations. The data set of the study is limited to the Scopus database, which is the largest database, even though it is accepted in such studies. Another limitation is that SG is limited to educational studies. In future studies, different dimensions can be researched by considering the entire SG corpus. With this study, a complete view of the area was obtained, and more detailed studies could be carried out in the future. These studies will provide an opportunity to make a comparison among the existing studies and to understand how topics have evolved over time. In this way, the general trends of SG and the changes in the studies related to its integration into education will be followed.

APPENDIX A
TOPICS, THE FIRST FIFTEEN TERMS REPRESENTING TOPICS, AND THE VOLUME RATES

See Table 4.

APPENDIX B
DISTRIBUTION OF THE NUMBER OF PUBLICATIONS OF THE TOPICS BY YEARS AND THE ACCELERATION VALUES OF EACH TOPIC

See Table 5.

REFERENCES

[1] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A systematic literature review of empirical evidence on computer games and serious games," *Comput. Educ.*, vol. 59, no. 2, pp. 661–686, Sep. 2012, doi: 10.1016/j.compedu.2012.03.004.

[2] A. De Gloria, F. Bellotti, and R. Berta, "Serious games for education and training," *Int. J. Serious Games*, vol. 1, no. 1, pp. 1–23, Feb. 2014, doi: 10.17083/ijsg.v1i1.11.

[3] M. S. Calabor, A. Mora, and S. Moya, "The future of 'serious games' in accounting education: A Delphi study," *J. Account. Educ.*, vol. 46, pp. 43–52, Mar. 2019.

[4] D. A. M. Darwesh, "Concepts of serious game in education," *Int. J. Eng. Comput. Sci.*, vol. 4, no. 12, pp. 15229–15232, Jan. 2016.

[5] M. Zyda, "From visual simulation to virtual reality to games," *Computer*, vol. 38, no. 9, pp. 25–32, Sep. 2005, doi: 10.1109/mc.2005.297.

[6] M.-T. Cheng, J.-H. Chen, S.-J. Chu, and S.-Y. Chen, "The use of serious games in science education: A review of selected empirical research from 2002 to 2013," *J. Comput. Educ.*, vol. 2, no. 3, pp. 353–375, Sep. 2015, doi: 10.1007/s40692-015-0039-9.

[7] S. Xinogalos and M. M. Tryfou, "Using greenfoot as a tool for serious games programming education and development," *Int. J. Serious Games*, vol. 8, no. 2, pp. 67–86, Jun. 2021, doi: 10.17083/ijsg.v8i2.425.

[8] D. Crookall, "Serious games, debriefing, and simulation/gaming as a discipline," *Simul. Gaming*, vol. 41, no. 6, pp. 898–920, Dec. 2010, doi: 10.1177/1046878110390784.

[9] S. M. Eftimova, A. M. Bogdanova, and V. Trajkovik, "Practical evaluation on serious games in education," *J. Emerg. Comput. Technol.*, vol. 1, no. 2, pp. 21–24, 2021.

[10] Z. U. Din and G. E. Gibson, "Serious games for learning prevention through design concepts: An experimental study," *Saf. Sci.*, vol. 115, pp. 176–187, Jun. 2019, doi: 10.1016/j.ssci.2019.02.005.

[11] S. Rosenthal and R. A. Ratan, "Balancing learning and enjoyment in serious games: Kerbal space program and the communication mediation model," *Comput. Educ.*, vol. 182, Jun. 2022, Art. no. 104480, doi: 10.1016/j.compedu.2022.104480.

[12] E. A. Boyle, T. M. Connolly, T. Hainey, and J. M. Boyle, "Engagement in digital entertainment games: A systematic review," *Comput. Hum. Behav.*, vol. 28, no. 3, pp. 771–780, May 2012, doi: 10.1016/j.chb.2011.11.020.

[13] F. Almeida and J. Simoes, "The role of serious games, gamification and Industry 4.0 tools in the Education 4.0 paradigm," *Contemp. Educ. Technol.*, vol. 10, no. 2, pp. 120–136, Apr. 2019, doi: 10.30935/cet.554469.

[14] K. Bernecker and M. Ninaus, "No pain, no gain? Investigating motivational mechanisms of game elements in cognitive tasks," *Comput. Hum. Behav.*, vol. 114, Jan. 2021, Art. no. 106542, doi: 10.1016/j.chb.2020.106542.

[15] U. Ritterfeld, M. Cody, and P. Vorderer, *Serious Games: Mechanisms and Effects*. New York, NY, USA: Routledge, 2009.

[16] Y. Charrouf and M. Taha Janan, "The use of a serious game in entrepreneurship teaching," *Educ. Inf. Technol.*, vol. 24, no. 6, pp. 3841–3854, Nov. 2019, doi: 10.1007/s10639-019-09958-4.

[17] Y.-R. Shi and J.-L. Shih, "Game factors and game-based learning design model," *Int. J. Comput. Games Technol.*, vol. 2015, pp. 1–11, Aug. 2015, doi: 10.1155/2015/549684.

[18] Y. Zhonggen, "A meta-analysis of use of serious games in education over a decade," *Int. J. Comput. Games Technol.*, vol. 2019, pp. 1–8, Feb. 2019, doi: 10.1155/2019/4797032.

[19] N. N. M. Nazry and D. M. Romano, "Mood and learning in navigation-based serious games," *Comput. Hum. Behav.*, vol. 73, pp. 596–604, Aug. 2017, doi: 10.1016/j.chb.2017.03.040.

[20] E. Naul and M. Liu, "Why story matters: A review of narrative in serious games," *J. Educ. Comput. Res.*, vol. 58, no. 3, pp. 687–707, Jun. 2020, doi: 10.1177/0735633119859904.

[21] C. Alonso-Fernández, I. Martínez-Ortiz, R. Caballero, M. Freire, and B. Fernández-Manjón, "Predicting students' knowledge after playing a serious game based on learning analytics data: A case study," *J. Comput. Assist. Learn.*, vol. 36, no. 3, pp. 350–358, Jun. 2020, doi: 10.1111/jcal.12405.

[22] C. Kroustalli and S. Xinogalos, "Studying the effects of teaching programming to lower secondary school students with a serious game: A case study with Python and CodeCombat," *Educ. Inf. Technol.*, vol. 26, no. 5, pp. 6069–6095, Sep. 2021, doi: 10.1007/s10639-021-10596-y.

[23] B. Cowley, N. Ravaja, and T. Heikura, "Cardiovascular physiology predicts learning effects in a serious game activity," *Comput. Educ.*, vol. 60, no. 1, pp. 299–309, Jan. 2013, doi: 10.1016/j.compedu.2012.07.014.

[24] B. Cowley, M. Fantato, C. Jennett, M. Ruskov, and N. Ravaja, "Learning when serious: Psychophysiological evaluation of a technology-enhanced learning game," *Educ. Technol. Soc.*, vol. 17, no. 1, pp. 3–16, 2013.

[25] C. Barros, A. A. Carvalho, and A. Salgueiro, "The effect of the serious game tempoly on learning arithmetic polynomial operations," *Educ. Inf. Technol.*, vol. 25, no. 3, pp. 1497–1509, May 2020, doi: 10.1007/s10639-019-09990-4.

[26] P. Hallinger, R. Wang, C. Chatpinyakoop, V.-T. Nguyen, and U.-P. Nguyen, "A bibliometric review of research on simulations and serious games used in educating for sustainability, 1997–2019," *J. Cleaner Prod.*, vol. 256, May 2020, Art. no. 120358, doi: 10.1016/j.jclepro.2020.120358.

[27] T. H. Laine and R. S. N. Lindberg, "Designing engaging games for education: A systematic literature review on game motivators and design principles," *IEEE Trans. Learn. Technol.*, vol. 13, no. 4, pp. 804–821, Dec. 2020, doi: 10.1109/TLT.2020.3018503.

[28] C. Tanner, D. Schmocker, J. Katsarov, and M. Christen, "Educating moral sensitivity in business: An experimental study to evaluate the effectiveness of a serious moral game," *Comput. Educ.*, vol. 178, Mar. 2022, Art. no. 104381, doi: 10.1016/j.compedu.2021.104381.

[29] Y. Zhonggen, "Differences in serious game-aided and traditional English vocabulary acquisition," *Comput. Educ.*, vol. 127, pp. 214–232, Dec. 2018, doi: 10.1016/j.compedu.2018.07.014.

[30] L. S. Ferro, F. Sapio, A. Terracina, M. Temperini, and M. Mecella, "Gea2: A serious game for technology-enhanced learning in STEM," *IEEE Trans. Learn. Technol.*, vol. 14, no. 6, pp. 723–739, Dec. 2021, doi: 10.1109/TLT.2022.3143519.

[31] P. García-Redondo, T. García, D. Areces, J. C. Núñez, and C. Rodríguez, "Serious games and their effect improving attention in students with learning disabilities," *Int. J. Environ. Res. Public Health*, vol. 16, no. 14, p. 2480, Jul. 2019, doi: 10.3390/ijerph16142480.

[32] L. R. Rodríguez, "Engaging future engineers: The case study of a serious game implementation," *Educ. Inf. Technol.*, vol. 28, no. 3, pp. 2909–2939, Mar. 2023, doi: 10.1007/s10639-022-11279-y.

[33] M. Cheng, Y. Lin, H. She, and P. Kuo, "Is immersion of any value? Whether, and to what extent, game immersion experience during serious gaming affects science learning," *Brit. J. Educ. Technol.*, vol. 48, no. 2, pp. 246–263, Mar. 2017, doi: 10.1111/bjet.12386.

[34] H. Haruna, Z. Zainuddin, R. R. Mellecker, S. K. W. Chu, and X. Hu, "An iterative process for developing digital gamified sexual health education for adolescent students in low-tech settings," *Inf. Learn. Sci.*, vol. 120, nos. 11–12, pp. 723–742, Nov. 2019, doi: 10.1108/ils-07-2019-0066.

[35] J. Lagro, M. H. J. van de Pol, A. Laan, F. J. Huijbregts-Verheyden, L. C. R. Fluit, and M. G. M. Olde Rikkert, "A randomized controlled trial on teaching geriatric medical decision making and cost consciousness with the serious game GeriatriX," *J. Amer. Med. Directors Assoc.*, vol. 15, no. 12, p. 957e, Dec. 2014, doi: 10.1016/j.jamda.2014.04.011.

[36] R. Wang, S. DeMaria, A. Goldberg, and D. Katz, "A systematic review of serious games in training health care professionals," *Simul. Healthcare, J. Soc. Simul. Healthcare*, vol. 11, no. 1, pp. 41–51, Feb. 2016.

[37] S. Çiftci, "Trends of serious games research from 2007 to 2017: A bibliometric analysis," *J. Educ. Training Stud.*, vol. 6, no. 2, p. 18, Jan. 2018, doi: 10.11114/jets.v6i2.2840.

[38] Y. Wang, Z. Wang, G. Liu, Z. Wang, Q. Wang, Y. Yan, J. Wang, Y. Zhu, W. Gao, X. Kan, Z. Zhang, L. Jia, and X. Pang, "Application of serious games in health care: Scoping review and bibliometric analysis," *Frontiers Public Health*, vol. 10, pp. 1–12, Jun. 2022, Art. no. 896974, doi: 10.3389/fpubh.2022.896974.

[39] L. Andrew, D. Barwood, J. Boston, M. Masek, L. Bloomfield, and A. Devine, "Serious games for health promotion in adolescents—A systematic scoping review," *Educ. Inf. Technol.*, vol. 28, no. 5, pp. 5519–5550, May 2023, doi: 10.1007/s10639-022-11414-9.

[40] S. V. Gentry, A. Gauthier, B. L'Estrade Ehrstrom, D. Wortley, A. Lilienthal, L. Tudor Car, S. Dauwels-Okutsu, C. K. Nikolaou, N. Zary, J. Campbell, and J. Car, "Serious gaming and gamification education in health professions: Systematic review," *J. Med. Internet Res.*, vol. 21, no. 3, Mar. 2019, Art. no. e12994, doi: 10.2196/12994.

[41] A. Min, H. Min, and S. Kim, "Effectiveness of serious games in nurse education: A systematic review," *Nurse Educ. Today*, vol. 108, Jan. 2022, Art. no. 105178, doi: 10.1016/j.nedt.2021.105178.

[42] A. Abd-Alrazaq, E. Al-Jafar, M. Alajlani, C. Toro, D. Alhuwail, A. Ahmed, S. M. Reagu, N. Al-Shorbaji, and M. Househ, "The effectiveness of serious games for alleviating depression: Systematic review and meta-analysis," *JMIR Serious Games*, vol. 10, no. 1, Jan. 2022, Art. no. e32331, doi: 10.2196/32331.

[43] C. Vieira, C. Ferreira da Silva Pais-Vieira, J. Novais, and A. Perrotta, "Serious game design and clinical improvement in physical rehabilitation: Systematic review," *JMIR Serious Games*, vol. 9, no. 3, Sep. 2021, Art. no. e20066, doi: 10.2196/20066.

[44] O. Ozyurt and A. Ayaz, "Twenty-five years of education and information technologies: Insights from a topic modeling based bibliometric analysis," *Educ. Inf. Technol.*, vol. 27, no. 8, pp. 11025–11054, Sep. 2022.

[45] O. Ozyurt, H. Ozyurt, and D. Mishra, "Uncovering the educational data mining landscape and future perspective: A comprehensive analysis," *IEEE Access*, vol. 11, pp. 120192–120208, 2023, doi: 10.1109/ACCESS.2023.3327624.

[46] J. Kang, S. Kim, and S. Roh, "A topic modeling analysis for online news article comments on nurses' workplace bullying," *J. Korean Acad. Nursing*, vol. 49, no. 6, p. 736, 2019, doi: 10.4040/jkan.2019.49.6.736.

[47] X. Chen, D. Zou, G. Cheng, and H. Xie, "Detecting latent topics and trends in educational technologies over four decades using structural topic modeling: A retrospective of all volumes of computers & education," *Comput. Educ.*, vol. 151, Jul. 2020, Art. no. 103855, doi: 10.1016/j.compedu.2020.103855.

[48] C. C. Ekin, E. Polat, and S. Hopcan, "Drawing the big picture of games in education: A topic modeling-based review of past 55 years," *Comput. Educ.*, vol. 194, Mar. 2023, Art. no. 104700, doi: 10.1016/j.compedu.2022.104700.

[49] Ş. Büyüköztürk, E. Kilic, Ö. E. Akgün, and Ş. Karadeniz, "Bilimsel araştırma yöntemleri," Pegem Akademi, Ankara, 2017.

[50] D. M. Blei, A. Y. Ng, and M. I. Jordan, "Latent Dirichlet allocation," *J. Mach. Learn. Res.*, vol. 3, pp. 993–1022, Jan. 2003.

[51] C. B. Asmussen and C. Møller, "Smart literature review: A practical topic modelling approach to exploratory literature review," *J. Big Data*, vol. 6, no. 1, pp. 1–13, Dec. 2019, doi: 10.1186/s40537-019-0255-7.

[52] G. Liu, J. H. Nzige, and K. Li, "Trending topics and themes in offsite construction(OSC) research: The application of topic modelling," *Construct. Innov.*, vol. 19, no. 3, pp. 343–366, Jul. 2019, doi: 10.1108/ci-03-2018-0013.

[53] B. Yin and C.-H. Yuan, "Detecting latent topics and trends in blended learning using LDA topic modeling," *Educ. Inf. Technol.*, vol. 27, no. 9, pp. 12689–12712, Nov. 2022, doi: 10.1007/s10639-022-11118-0.

[54] D. Blei, L. Carin, and D. Dunson, "Probabilistic topic models," *IEEE Signal Process. Mag.*, vol. 27, no. 6, pp. 55–65, Nov. 2010.

[55] A. De Mauro, M. Greco, M. Grimaldi, and P. Ritala, "Human resources for big data professions: A systematic classification of job roles and required skill sets," *Inf. Process. Manage.*, vol. 54, no. 5, pp. 807–817, Sep. 2018, doi: 10.1016/j.ipm.2017.05.004.

[56] Scopus. (2022). *Content Coverage*. [Online]. Available: https://www.elsevier.com/solutions/scopus/how-scopus-works/content?dgcid=RN_AGCM_Sourced_300005030

[57] R. Yung and C. Khoo-Lattimore, "New realities: A systematic literature review on virtual reality and augmented reality in tourism research," *Current Issues Tourism*, vol. 22, no. 17, pp. 2056–2081, Oct. 2019, doi: 10.1080/13683500.2017.1417359.

[58] C. C. Aggarwal and C. X. Zhai, *Mining Text Data*. Cham, Switzerland: Springer, 2013.

[59] S. Prabhakaran, "Topic modeling with gensim (Python)". Accessed: Dec. 12, 2023. [Online]. Available: https://www.machinelearningplus.com/nlp/topic-modeling-gensim-python/

[60] H. Özköse, O. Ozyurt, and A. Ayaz, "Management information systems research: A topic modeling based bibliometric analysis," *J. Comput. Inf. Syst.*, vol. 63, no. 5, pp. 1166–1182, Sep. 2023, doi: 10.1080/08874417.2022.2132429.

[61] C. Sievert and K. Shirley, "LDAvis: A method for visualizing and interpreting topics," in *Proc. Workshop Interact. Lang. Learn. Vis., Interfaces*, 2015, pp. 63–70.

[62] B. Mabey. (2018). *PyLDAvis Documentation*. [Online]. Available: https://pyldavis.readthedocs.io/_/downloads/en/stable/pdf/

[63] D. B. Clark, B. Nelson, P. Sengupta, and C. M. D'Angelo, "Rethinking science learning through digital games and simulations: Genres, examples, and evidence," in *Proc. Nat. Academies Sci. Learn. Sci.: Comput. Games, Simulations, Educ. Conf.* Washington, DC, New York, NY, USA: Routledge, 2009.

[64] M. Urgo, W. Terkaj, M. Mondellini, and G. Colombo, "Design of serious games in engineering education: An application to the configuration and analysis of manufacturing systems," *CIRP J. Manuf. Sci. Technol.*, vol. 36, pp. 172–184, Jan. 2022, doi: 10.1016/j.cirpj.2021.11.006.

[65] M. A. Miljanovic and J. S. Bradbury, "A review of serious games for programming," in *Serious Games*. Cham, Switzerland: Springer, 2018, pp. 204–216.

[66] M. Graafland, J. M. Schraagen, and M. P. Schijven, "Systematic review of serious games for medical education and surgical skills training," *Brit. J. Surgery*, vol. 99, no. 10, pp. 1322–1330, Sep. 2012, doi: 10.1002/bjs.8819.

[67] N. Sharifzadeh, H. Kharrazi, E. Nazari, H. Tabesh, M. Edalati Khodabandeh, S. Heidari, and M. Tara, "Health education serious games targeting health care providers, patients, and public health users: Scoping review," *JMIR Serious Games*, vol. 8, no. 1, Mar. 2020, Art. no. e13459, doi: 10.2196/13459.

[68] B. E. Holtz, K. Murray, and T. Park, "Serious games for children with chronic diseases: A systematic review," *Games Health J.*, vol. 7, no. 5, pp. 291–301, Oct. 2018, doi: 10.1089/g4h.2018.0024.

[69] Y. Francillette, E. Boucher, B. Bouchard, K. Bouchard, and S. Gaboury, "Serious games for people with mental disorders: State of the art of practices to maintain engagement and accessibility," *Entertainment Comput.*, vol. 37, Mar. 2021, Art. no. 100396, doi: 10.1016/j.entcom.2020.100396.

[70] A. Yasin, L. Liu, T. Li, R. Fatima, and W. Jianmin, "Improving software security awareness using a serious game," *IET Softw.*, vol. 13, no. 2, pp. 159–169, Apr. 2019, doi: 10.1049/iet-sen.2018.5095.

[71] S. Hart, A. Margheri, F. Paci, and V. Sassone, "Riskio: A serious game for cyber security awareness and education," *Comput. Secur.*, vol. 95, Aug. 2020, Art. no. 101827, doi: 10.1016/j.cose.2020.101827.

[72] M. Mortara, C. E. Catalano, F. Bellotti, G. Fiucci, M. Houry-Panchetti, and P. Petridis, "Learning cultural heritage by serious games," *J. Cultural Heritage*, vol. 15, no. 3, pp. 318–325, May 2014, doi: 10.1016/j.culher.2013.04.004.

[73] F. Liarokapis, P. Petridis, D. Andrews, and S. de Freitas, "Multimodal serious games technologies for cultural heritage," in *Mixed Reality Gamification for Cultural Heritage*. Cham, Switzerland: Springer, 2017, pp. 371–392.

[74] A. Coghlan and L. Carter, "Serious games as interpretive tools in complex natural tourist attractions," *J. Hospitality Tourism Manage.*, vol. 42, pp. 258–265, Mar. 2020, doi: 10.1016/j.jhtm.2020.01.010.

[75] Z. Liang, K. Zhou, and K. Gao, "Development of virtual reality serious game for underground rock-related hazards safety training," *IEEE Access*, vol. 7, pp. 118639–118649, 2019, doi: 10.1109/ACCESS.2019.2934990.

[76] A. Rahouti, R. Lovreglio, S. Datoussaïd, and T. Descamps, "Prototyping and validating a non-immersive virtual reality serious game for healthcare fire safety training," *Fire Technol.*, vol. 57, no. 6, pp. 3041–3078, Nov. 2021, doi: 10.1007/s10694-021-01098-x.

[77] Z. Feng, V. A. González, C. Mutch, R. Amor, A. Rahouti, A. Baghouz, N. Li, and G. Cabrera-Guerrero, "Towards a customizable immersive virtual reality serious game for Earthquake emergency training," *Adv. Eng. Informat.*, vol. 46, Oct. 2020, Art. no. 101134, doi: 10.1016/j.aei.2020.101134.

[78] Z. Feng, V. A. González, C. Mutch, R. Amor, and G. Cabrera-Guerrero, "Instructional mechanisms in immersive virtual reality serious games: Earthquake emergency training for children," *J. Comput. Assist. Learn.*, vol. 37, no. 2, pp. 542–556, Apr. 2021, doi: 10.1111/jcal.12507.

[79] R. Lovreglio, V. Gonzalez, Z. Feng, R. Amor, M. Spearpoint, J. Thomas, M. Trotter, and R. Sacks, "Prototyping virtual reality serious games for building Earthquake preparedness: The Auckland city hospital case study," *Adv. Eng. Informat.*, vol. 38, pp. 670–682, Oct. 2018, doi: 10.1016/j.aei.2018.08.018.

[80] O. Abraham, S. LeMay, S. Bittner, T. Thakur, H. Stafford, and R. Brown, "Investigating serious games that incorporate medication use for patients: Systematic literature review," *JMIR Serious Games*, vol. 8, no. 2, Apr. 2020, Art. no. e16096, doi: 10.2196/16096.

[81] A. Ayaz, O. Ozyurt, W. Mugahed Al-Rahmi, S. A. Salloum, A. Shutaleva, F. Alblehai, and M. Habes, "Exploring gamification research trends using topic modeling," *IEEE Access*, vol. 11, pp. 119676–119692, 2023, doi: 10.1109/ACCESS.2023.3326444.

[82] S. Khalid, S. Wu, A. Wahid, A. Alam, and I. Ullah, "An effective scholarly search by combining inverted indices and structured search with citation networks analysis," *IEEE Access*, vol. 9, pp. 120210–120226, 2021, doi: 10.1109/ACCESS.2021.3107939.

[83] S. Bano, S. Khalid, N. M. Tairan, H. Shah, and H. A. Khattak, "Summarization of scholarly articles using BERT and BiGRU: Deep learning-based extractive approach," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 35, no. 9, Oct. 2023, Art. no. 101739.

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