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Review Article

A Systematic Review of Virtual Reality-Based Education Research Using Latent Dirichlet Allocation: Focus on Topic Modeling Technique

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Using virtual reality in the context of education is becoming important since this technology enhances learners' motivation and performance with transfer of learning, problem-solving skills, educational equity, and multisensory learning. Along with the 4th Industrial Revolution and COVID-19, the attention on virtual reality has been increased again. Some studies reviewed the trends of research on virtual reality-based education, mostly focusing on specific subject matters or areas. The purpose of the study is to investigate the change of research trends in the virtual reality-based education field by implementing the topic modeling analysis based on latent Dirichlet allocation (LDA) technique with 6,755 articles published in the last 30 years (between 1992 and 2022). As a result of this study, it was revealed that the research on virtual reality-based education was clearly divided into the following four periods; 1992–2011, 2012–2016, 2017–2019, and 2020–2022. The main topics for each period were suggested. Here are three major findings of this study. First, it is identified that the weight of "virtual reality for learning and teaching" has increased in recent years. Second, conversely, it is identified that the proportion of "virtual reality in medical education" has decreased relatively recently. It means it is possible to interpret that the proportion of other topics has relatively increased. Third, the topics of "virtual reality education platform" and "virtual reality-based education in rehabilitation" continue to maintain a certain weight. Limitations of this study and further research suggestions are provided based on the results of the study.

1. Introduction

In recent years, virtual reality has received significant attention as a next generation's platform even though this is not a recent new technology. Along with the increasing interest on virtual reality, cases using it as well as research studies are rapidly expanding [1–11]. Technical developments such as head-mounted display (HMD), controllers, and motion tracking systems as well as content development that apply virtual reality to games, movies, advertisements, exhibitions in museums, and education are rapidly growing in various areas.

Virtual reality refers to a real world like a simulated environment artificially created by computer technology [1]. Virtual reality targets to create immersive and interactive experiences based on a highly realistic visual and auditory stimuli along with diverse feedback by tracking the user's position, movements, and choices.

Virtual reality-based education has the potential for great impact on the enhancement of learners' motivation, engagement, satisfaction, and transfer of learning [1–6, 12–14]. A number of recent research efforts have provided invaluable insights on understanding and applying virtual reality from a multidisciplinary point of view. In recent years, virtual reality-based education is being expanded in various areas such as medical education, special education, and K-12 or higher education [8, 15–18]. There are four major benefits of virtual reality-based education as follows.

First, transfer of learning has been regarded as one of the important issues to solve in education, specifically where performance improvement is critical as the results of

education programs. Virtual reality can be one of the learning aids to create authentic learning environments that facilitate the transfer of learning [1]. Reality, interaction, and immersion are key aspects of virtual reality, which enhance the sense of presence for learners. Sense of presence is the feeling of being in the virtual environment with immersion [12, 13]. Sense of presence is a status that a learner feels he or she is in a virtual environment with virtual objects as a part of that environment even though his or her body is physically in a separate environment [2]. Previous studies suggested positive relationships between immersion and sense of presence [2, 12, 13]. In addition, the higher reality of graphics/audio information and natural/immediate interaction with virtual objects can create a better sense of presence in the virtual environment.

Second, with the socio-economic changes such as the 4th Industrial Revolution, aging population, and digital natives, the needs for advanced formats of education become stronger. Active problem solvers are important in current and upcoming societies, and creativity, critical thinking, communication, and collaboration are the major competencies that these problem solvers must have. To support learners to have these competencies, education programs that help learners experience various problems/situations by themselves and engage in problem solving assisted by constructive feedback are necessary. Virtual reality-based education allows trying and error without a feeling of shame or helplessness, so learners can learn from experience, engagement, and feedback.

Third, virtual reality-based education can contribute to provide equal educational opportunities for everybody. For learners who live in small islands, visiting museums or learning second languages with foreign teachers is not easy due to distance and cost-related issues. Specifically, learners who need special education have difficulties to receive individualized education based on their weaknesses, preferences, or other characteristics. Even though special education teachers and counselors are doing their best to provide good education to these learners, it is not easy with limited numbers of teachers and counselors specialized in this education. Virtual reality is suggested as one of the teaching/leaning aids for special education that offer a safe, repeatable, interesting, interactive learning experiences for learners [3, 4, 14].

Fourth, virtual reality-based education can provide multisensory experiences to learners including visual, auditory, and haptic feedback [5, 6]. Stimuli with multi-senses help learners immerse into the virtual learning environment and learn better.

Due to the various benefits of virtual reality on learning, this technology has been applied to many areas of education. Therefore, understanding the main stream of research on applying virtual reality to education is becoming important to researchers and practitioners. The beginnings of research about virtual reality-based education go back to the early 1900s, and the number of studies in this area has significantly increased recently. It would be beneficial to understand the change of research trends in this area by analyzing related papers using a rigorous analysis frame. There are attempts to analyze the previous studies which applied virtual reality to educational purposes in various areas. These studies reviewed the previous articles to answer specific research questions for understanding important keywords or topics of the field.

Some review papers focused on the trends of virtual reality-based education research related to specific fields as shown in Table 1, such as Earth science engineering education [7], medical education [8, 19], STEM education [20], math education [21], computer science education [22], higher education [23–25], heritage education [26], rehabilitation management of breast cancer survivors [27], virtual reality-based training for daily living in patients with chronic stroke [28], PSTD treatments [29], foreign language learning gamification using virtual reality [30, 31], K-12 and higher education [15, 17], surgical training [32], industrial skills training [31], virtual reality cognitive training in individuals with mild cognitive impairment [16, 18], science education [33, 34], sensorimotor learning [35], dental education [36], virtual reality-based emotional response and symptom provocation in patients with OCD (obsessive compulsive disorder) [37], nursing education [38, 39], virtual reality therapy for social anxiety disorder [40], evacuation training [41], virtual reality-assisted neuromuscular therapy [42], home-based virtual reality rehabilitation for individuals with Parkinson disease [43], virtual reality-based physiology and anatomy learning [44], social work education [45], and marketing higher education [46].

There were several studies which reviewed virtual reality-based education research focusing on specific target learners such as training professionals [9], soft skills training of employees [10], students with learning disabilities [47], children with social skills deficits [48], individuals with autism spectrum disorder [49], patients with dementia [50], and patients with paranoia [51].

Due to the importance of technical aspects of virtual reality-based education, some of the previous studies reviewed research focusing on specific virtual reality application such as oculus [52], HMD-based virtual reality systems in engineering education [53], educational 360-degree videos in virtual reality [54], HMD in education and training [55], educational virtual reality games [56], and virtual laboratories [57] as shown in Table 2.

Previous review papers in virtual reality-based education mostly used systematic literature review [58–60], co-citation network analysis [61], meta-analysis [62], and knowledge mapping analysis [63] as an analytical method.

There are a limited number of review studies which provide an overview of research trends on virtual reality-based education in general. Kavanagh et al. conducted a systematic review on 99 virtual realities in education articles and found health and medicine were the major fields and higher education was the major institution in terms of using virtual reality-based education [11]. Kurniawan et al. also conducted a systematic literature review on 32 virtual realities for learning and found four purposes of applying virtual reality for learning including engagement, motivation, learning experience, and achievement [58]. Cheng et al. conducted a co-citation network analysis on 49 virtual

Table 1: Summary of previous VR education review studies based on the field of interest.

Field of interest among VR education	Related research
Earth science engineering education	Özyurt, Ö., Cagiltay, N. E., Özyurt, H., and Akgun, A. (2021)
Medical education	Tang, Y. M., Chau, K. Y., Kwok, A. P. K., Zhu, T., and Ma, X. (2021)
STEM education	Pellas, N., Dengel, A., and Christopoulos, A. (2020)
Math education	Lai, J. W., and Cheong, K. H. (2022)
Computer science education	Agbo, F. J., Sanusi, I. T., Oyelere, S. S., and Suhonen, J. (2021)
Higher education	Mystakidis, S., Berki, E., and Valtanen, J. P. (2021) Rashid, S., Khattak, A., Ashiq, M., Ur Rehman, S., and Rashid Rasool, M. (2021) Nesenbergs, K., Abolins, V., Ormanis, J., and Mednis, A. (2020)
Heritage education	Arteaga, J. V., Gravini-Donado, M. L., and Zanello Riva, L. D. (2021)
Rehabilitation management of breast cancer survivors	Bu, X., Ng, P. H., Chen, Q., Cheng, A. S., Xu, W., Tong, Y., and Liu, X. (2022)
Daily living in patients with chronic stroke	Gao, Y., Ma, L., Lin, C., Zhu, S., Yao, L., Fan, H., and Wang, T. (2021)
PSTD treatments	Eshuis, L. V., van Gelderen, M. J., van Zuiden, M., Nijdam, M. J., Vermetten, E., Olff, M., and Bakker, A. (2021)
Foreign language learning	Pinto, R. D., Peixoto, B., Melo, M., Cabral, L., and Bessa, M. (2021) Peixoto, B., Pinto, R., Melo, M., Cabral, L., and Bessa, M. (2021)
K-12 and higher education	Di Natale, A. F., Repetto, C., Riva, G., and Villani, D. (2020) Pellas, N., Mystakidis, S., and Kazanidis, I. (2021)
Surgical training	Mao, R. Q., Lan, L., Kay, J., Lohre, R., Ayeni, O. R., and Goel, D. P. (2021)
Industrial skills training	Peixoto, B., Pinto, R., Melo, M., Cabral, L., and Bessa, M. (2021)
Cognitive training in individuals with mild cognitive impairment	Zhong, D., Chen, L., Feng, Y., Song, R., Huang, L., Liu, J., and Zhang, L. (2021) Dehghan, B., Saeidimehr, S., Sayyah, M., and Rahim, F. (2021)
Science education	Arici, F., Yildirim, P., Caliklar, Ş., and Yilmaz, R. M. (2019) Durukan, A., Artun, H., and Temur, A. (2020)
Sensorimotor learning	Ratcliffe, J., and Tokarchuk, L. (2021, November)
Dental education	Imran, E., Adanir, N., and Khurshid, Z. (2021)
Emotional response and symptom provocation in patients with OCD (obsessive compulsive disorder)	Dehghan, B., Saeidimehr, S., Sayyah, M., and Rahim, F. (2021) Jallad, S. T., and Işık, B. (2021)
Nursing education	Plotzky, C., Lindwedel, U., Sorber, M., Loessl, B., König, P., Kunze, C., and Meng, M. (2021)
Virtual reality therapy for social anxiety disorder	Caponnetto, P., Triscari, S., Maglia, M., and Quattropani, M. C. (2021)
Evacuation training	Feng, Z., González, V. A., Amor, R., Lovreglio, R., and Cabrera-Guerrero, G. (2018)
Neuromuscular therapy	Baur, K., Schättin, A., de Bruin, E. D., Riener, R., Duarte, J. E., and Wolf, P. (2018)
Rehabilitation for individuals with Parkinson disease	Truijen, S., Abdullahi, A., Bijsterbosch, D., van Zoest, E., Conijn, M., Wang, Y., and Saeys, W. (2022)
Physiology and anatomy learning	Moro, C., Birt, J., Stromberga, Z., Phelps, C., Clark, J., Glasziou, P., and Scott, A. M. (2021)
Social work education	Huttar, C. M., and BrintzenhofeSzoc, K. (2020)
Marketing higher education	Loureiro, S. M. C., Bilro, R. G., and de Aires Angelino, F. J. (2020)

Table 2: Summary of previous VR education review studies based on the VR application.

VR application	Related research
Oculus	Smutny, P., Babiuch, M., and Foltynek, P. (2019, May)
HMD-based virtual reality systems in engineering education	Huang, W., and Roscoe, R. D. (2021).
Educational 360-degree videos in virtual reality	Snelson, C., and Hsu, Y. C. (2020)
HMD in education and training	Jensen, L., and Konradsen, F. (2018)
Educational virtual reality games	Oyelere, S. S., Bouali, N., Kaliisa, R., Obaido, G., Yunusa, A. A., and Jimoh, E. R. (2020)
Virtual laboratories	Roda-Segarra, J. (2021)

reality education articles and found the main stream as the interaction between learners' cognition and affection in virtual reality-based learning [61]. A recent study conducted a systematic review on 139 virtual realities in K-12 and higher education articles published between 2000 and 2019 and found that virtual reality was used more in higher education than K-12 and science, social science, health, and medicine were the most popular fields using virtual reality [62].

Previous review studies on virtual reality-based learning are valuable for understanding some aspects of this field. However, these studies have limitations including a focus on specific fields, a small number of articles, and analytical methods. It is necessary to analyze a large-scale article to understand the overview of research trends. Topic modeling analysis is one of the analytical methods being used to get a deeper understanding on specific domain or field [64]. Accordingly, this paper aimed to provide a wider perspective on virtual reality-based education research by analyzing 6,755 journal articles and reviews published between 1992 and 2022 using the latent Dirichlet allocation (LDA) [65].

The purpose of this paper is to analyze the trends of journal articles related to virtual reality-based education. Here are the research questions of this study.

RQ1: What have been the bibliometric characteristics of virtual reality-based education research during the period between 1992 and 2022?

RQ2: What have been the emerging topics in the virtual reality-based education field in the period between 1992 and 2022?

RQ3: How have the topics of interest in virtual reality-based education research changed between 1992 and 2022?

2. Methods

This study considered only peer-reviewed journal articles. More specifically, only virtual reality in education-oriented journal articles published in English in the last 30 years (between 1992 and 2022) was included in this study. Strict validation process was followed to determine the search string. First, wide literature reviews were carried out to determine the synonym of virtual reality. Then, the opinions of field experts and researchers were obtained regarding the extracted terms. The final keywords were determined after the evaluation of field experts and researchers.

The search queries that met the search string and other criteria determined as the result of these processes were as follows: TITLE(TI) = ("virtual reality" OR "augmented reality" OR "mixed reality" OR "extended reality" OR "metaverse") AND TI = ("education" OR "training" OR "learning" OR "teaching" OR "school" OR "college" OR "university") OR ABSTRACT(AB) = ("virtual reality" OR "augmented reality" OR "mixed reality" OR "extended reality" OR "metaverse") AND AB = ("education" OR "training" OR "learning" OR "teaching" OR "school" OR "college" OR "university") OR AUTHOR KEYWORDS(AK) = ("virtual reality" OR "augmented reality" OR "mixed reality" OR "extended reality" OR "metaverse") AND AK = ("education" OR "training" OR "learning" OR "teaching" OR "school" OR "college" OR "university")

Web of Science (WoS) of the database was used to obtain articles related to the search queries since it covers wide publishers worldwide. Searching the queries above was run in February 2022 to obtain the relevant articles from the WoS database. The first search brought up a total of 8,926 articles (only included research articles, and review articles were excluded). Afterward, a rigorous selection process was gone through under the examination of the field experts and researchers to exclude irrelevant papers. Finally, 6,755 research articles were selected.

LDA was used to obtain latent topics from abstracts in this study. LDA is a generative approach used to discover hidden topics in a large, relatively unstructured document corpus [66]. LDA is a probabilistic model that estimates the probability of occurrence of latent topics in a document based on a document term matrix [65, 67]. Documents contain hidden topics, and each of these topics is defined by a probability distribution over a fixed set of words [65]. The LDA model is frequently used in content analysis based on topic modeling [65, 67]. For these reasons, the LDA model was employed for topic modeling analysis in this study. In this study, LDA analysis was performed using LDAvis and lda library in R.

3. Results

The results of the study are first descriptive analysis, which include the number of yearly publications, and the top research areas and journals. Furthermore, a detailed topic modeling analysis is presented to provide an overall picture of virtual reality studies.

3.1. Descriptive Analysis. Figure 1 shows the yearly publication distribution. It is largely divided into the following four periods. 1992–2011 (236, 3.49% (percentile based on 6755)), 2012–2016 (1281, 18.96%), 2017–2019 (2036, 30.14%), and 2020–2022 (2868, 42.46%).

Figure 2 shows the top 13 research areas addressed by the highest number of articles. The majority of the articles were published in the field of education and educational research ($n = 1103$, 16.33%), computer science ($n = 499$, 7.39%), surgery ($n = 279$, 4.13%), psychology ($n = 273$, 4.03%), etc.

Figure 3 shows the top 10 journals with the highest number of published articles. The virtual reality journal published the highest number of articles ($(n) = 113$), followed by the Applied Sciences-Basel ($n = 106$) and the Interactive Learning Environments ($n = 100$).

3.2. LDA Analysis. To reveal the emerging topics related to the use of virtual reality in education, LDA analysis was performed on the abstracts of articles. LDA analysis was performed by dividing the period from 1992 to 2002 into four periods, because the four periods are clearly distinguished (see Figure 1).

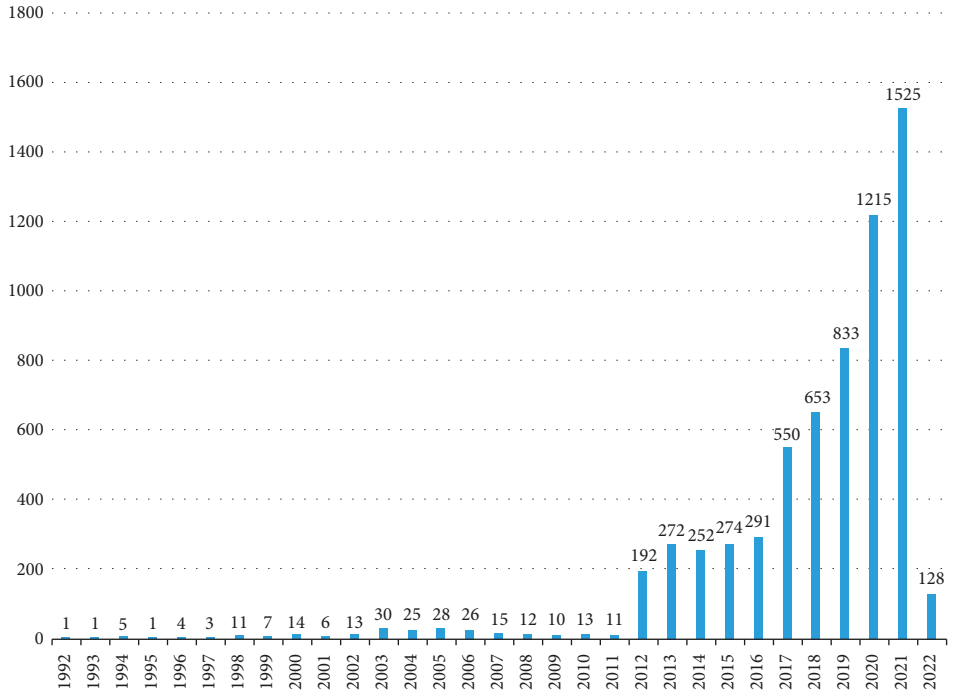

Figure 1: Yearly distribution of the articles.

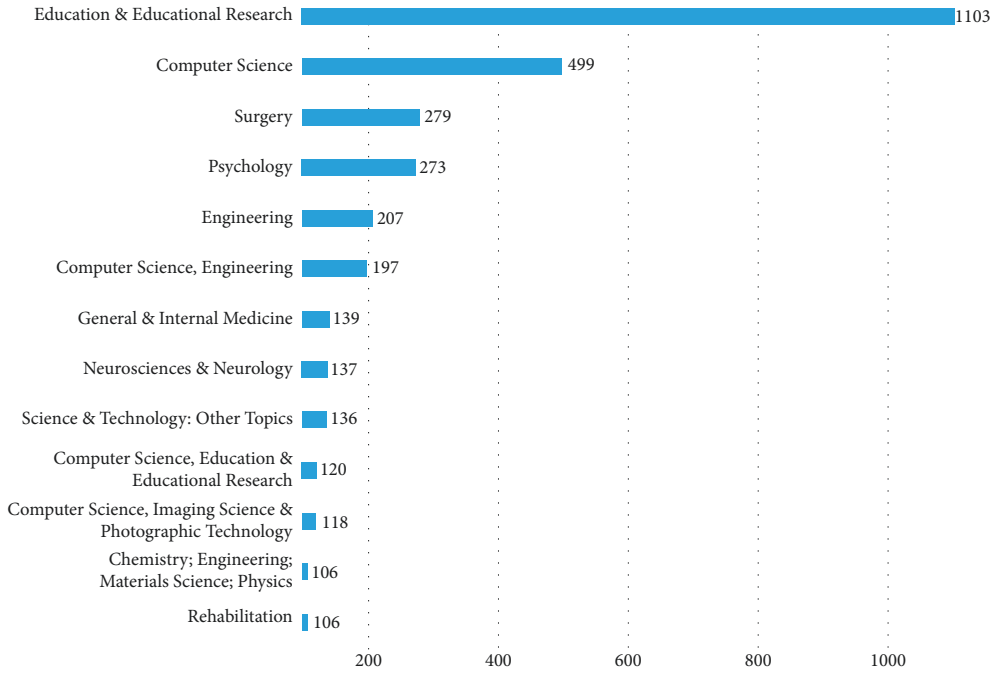

Figure 2: Top 13 research areas with most published articles.

3.2.1. Period 1: 1992–2011. A total of 236 articles were published during this period (3.49% of the total), and as a result of LDAvis analysis, 5 topics were clearly identified (see Figure 4).

The keywords (top 20 most relevant terms) of topic 1 are as follows (see Figure 5). The keywords of topic 1 are composed of system, environment, training, learning, application, etc., and these terms make up 47.1% of the total tokens of the abstracts of the articles in period 1, so topic 1 was named "virtual reality for training and learning."

The keywords (top 20 most relevant terms) of topic 2 are as follows (see Figure 6). The keywords of topic 2 are composed of training, simulator, skill, performance, laparoscopic, etc., and these terms make up 26.8% of the total tokens of the abstracts of the articles in period 1, so topic 2 was named "virtual reality in medical education."

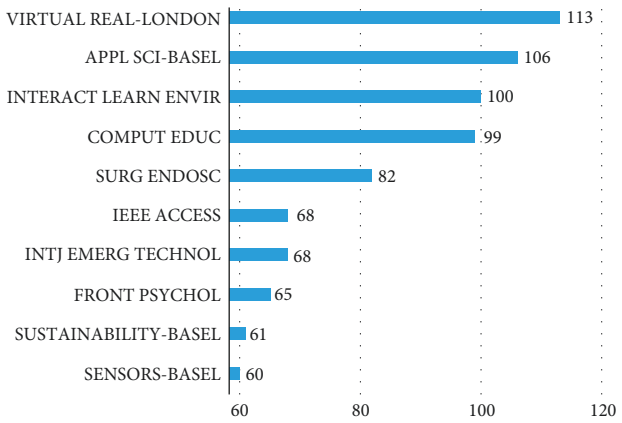

Figure 3: Top 10 journals with most published articles.

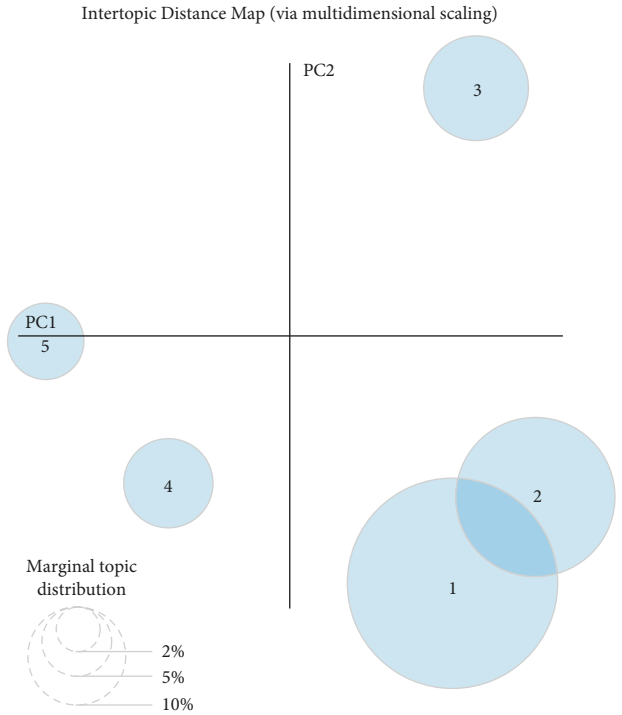

Figure 4: 5 topics of period 1 (1992–2011).

The keywords (top 20 most relevant terms) of topic 3 are as follows (see Figure 7). The keywords of topic 3 are composed of model, image, motion, haptic, surgical, etc., and these terms make up 11.5% of the total tokens of the abstracts of the articles in period 1, so topic 3 was named "virtual reality education platform."

The keywords (top 20 most relevant terms) of topic 4 are as follows (see Figure 8). The keywords of topic 4 are composed of rehabilitation, motor, patient, hand, cognitive, etc., and these terms make up 8.4% of the total tokens of the abstracts of the articles in period 1, so topic 4 was named "virtual reality-based education in rehabilitation."

The keywords (top 20 most relevant terms) of topic 5 are as follows (see Figure 9). The keywords of topic 5 are composed of patient, health, medical care, ultrasound, etc.,

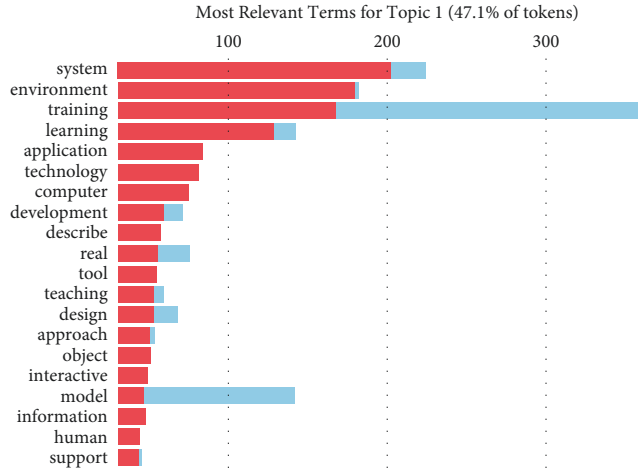

Figure 5: Top 20 most relevant terms for topic 1.

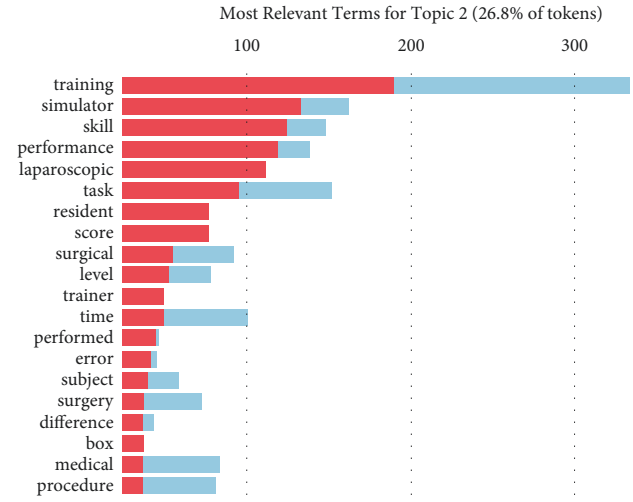

Figure 6: Top 20 most relevant terms for topic 2.

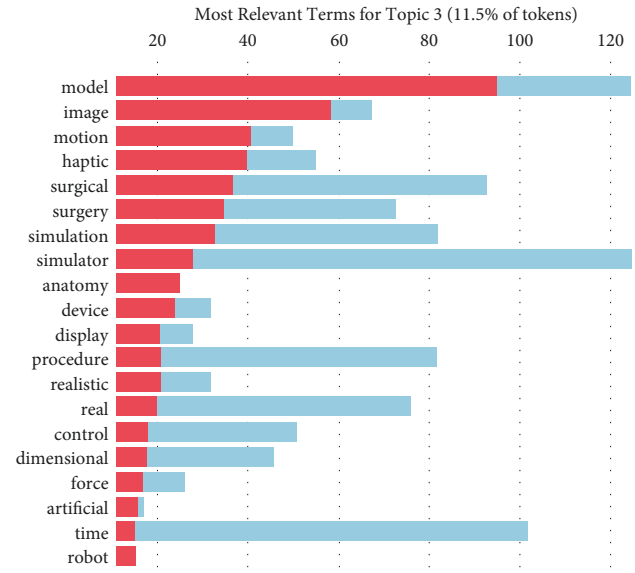

Figure 7: Top 20 most relevant terms for topic 3.

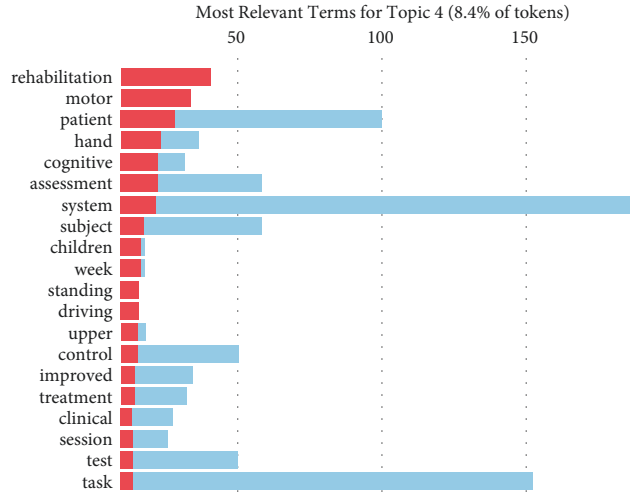

Figure 8: Top 20 most relevant terms for topic 4.

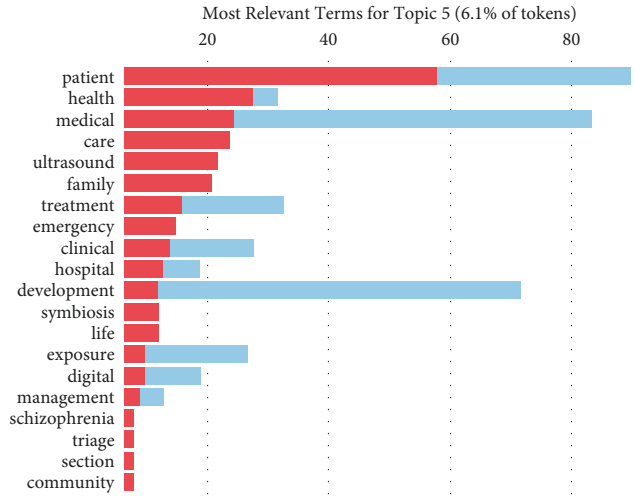

Figure 9: Top 20 most relevant terms for topic 5.

and these terms make up 6.1% of the total tokens of the abstracts of the articles in period 1, so topic 5 was named "virtual reality training and treatment in health care."

3.2.2. Period 2: 2012–2016. A total of 1281 articles were published during this period (18.96% of the total), and as a result of LDAvis analysis, 5 topics were clearly identified (see Figure 10).

The keywords (top 20 most relevant terms) of topic 1 are as follows (see Figure 11). The keywords of topic 1 are composed of learning, technology, environment, system, design, etc., and these terms make up 29.6% of the total tokens of the abstracts of the articles in period 2, so topic 1 was named "virtual reality for learning and teaching."

The keywords (top 20 most relevant terms) of topic 2 are as follows (see Figure 12). The keywords of topic 2 are composed of training, simulator, skill, performance, surgical, etc., and these terms make up 25.8% of the total tokens of the abstracts of the articles in period 2, so topic 2 was named "virtual reality in medical education."

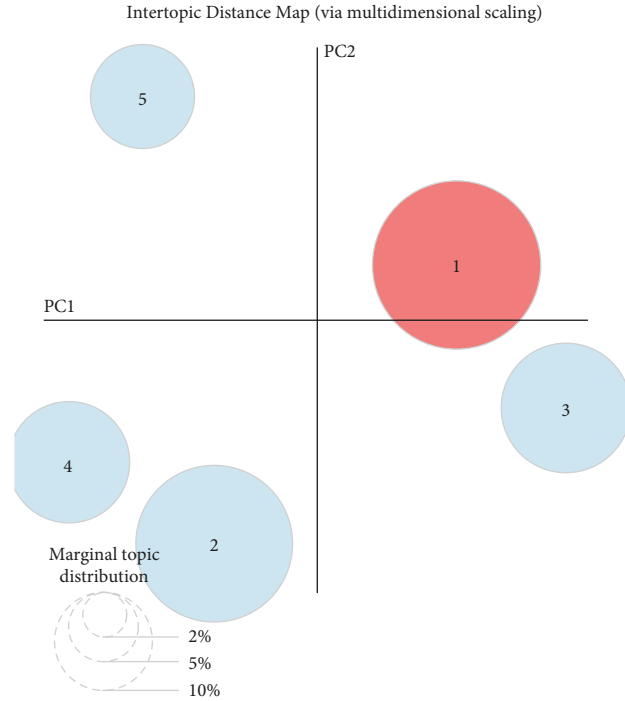

Figure 10: 5 topics of period 2 (2012–2016).

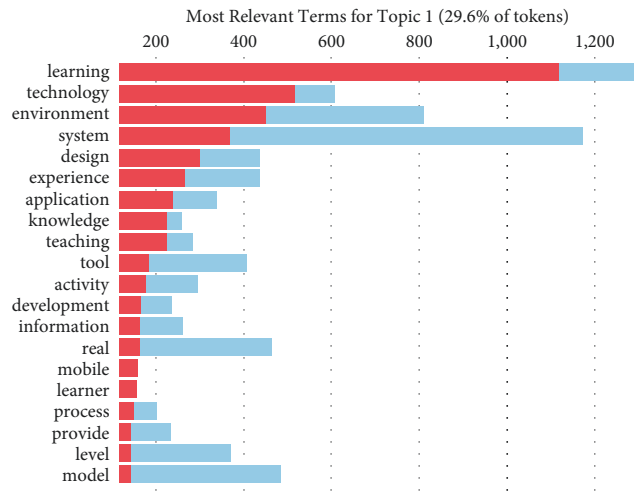

Figure 11: Top 20 most relevant terms for topic 1.

The keywords (top 20 most relevant terms) of topic 3 are as follows (see Figure 13). The keywords of topic 3 are composed of system, training, real, environment, feedback, etc., and these terms make up 17.7% of the total tokens of the abstracts of the articles in period 2, so topic 3 was named "virtual reality education platform."

The keywords (top 20 most relevant terms) of topic 4 are as follows (see Figure 14). The keywords of topic 4 are composed of training, patient, balance, motor, rehabilitation, etc., and these terms make up 15.3% of the total tokens of the abstracts of the articles in period 2, so topic 4 was named "virtual reality-based education in rehabilitation."

The keywords (top 20 most relevant terms) of topic 5 are as follows (see Figure 15). The keywords of topic 5 are

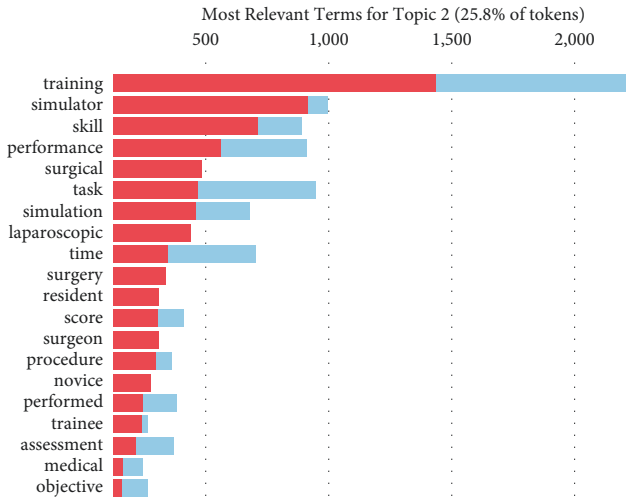

Figure 12: Top 20 most relevant terms for topic 2.

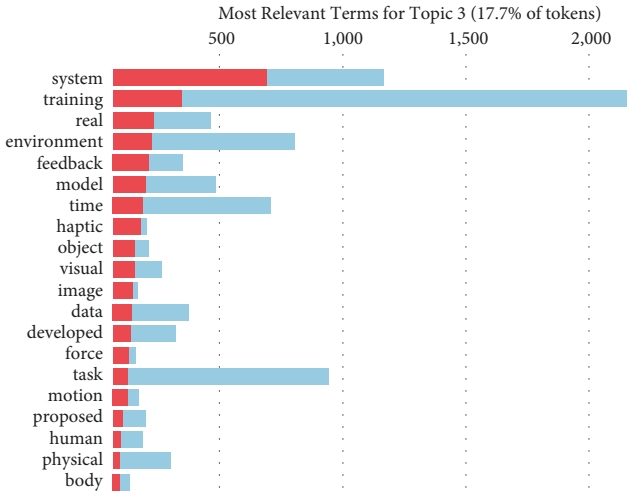

Figure 13: Top 20 most relevant terms for topic 3.

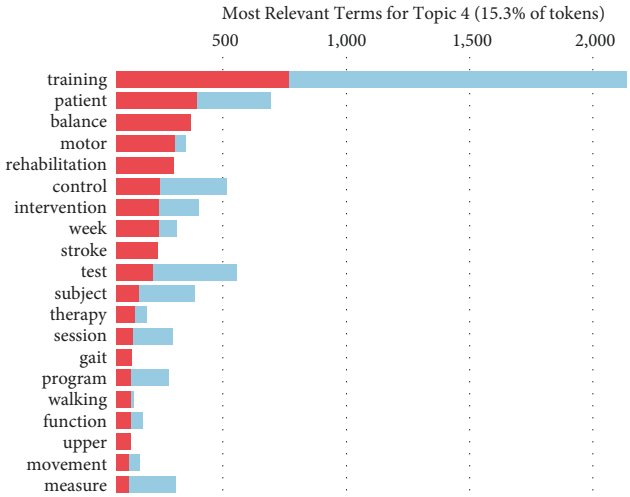

Figure 14: Top 20 most relevant terms for topic 4.

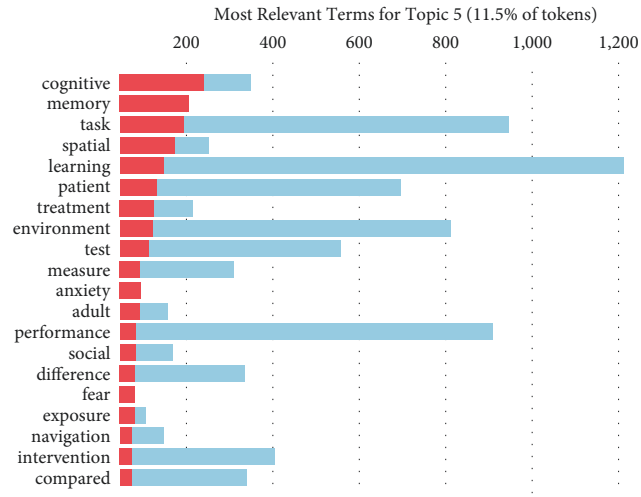

Figure 15: Top 20 most relevant terms for topic 5.

composed of cognitive, memory, task, spatial learning, etc., and these terms make up 11.5% of the total tokens of the abstracts of the articles in period 2, so topic 5 was named "effects of virtual reality for cognitive and affective domain."

3.2.3. Period 3: 2017–2019. A total of 2036 articles were published during this period (30.14% of the total), and as a result of LDAvis analysis, 4 topics were clearly identified (see Figure 16).

The keywords (top 20 most relevant terms) of topic 1 are as follows (see Figure 17). The keywords of topic 1 are composed of learning, technology, experience, application, teaching, etc., and these terms make up 43.8% of the total tokens of the abstracts of the articles in period 3, so topic 1 was named "virtual reality for learning and teaching."

The keywords (top 20 most relevant terms) of topic 2 are as follows (see Figure 18). The keywords of topic 2 are composed of training, patient, intervention, rehabilitation, motor, etc., and these terms make up 21.7% of the total tokens of the abstracts of the articles in period 3, so topic 2 was named "virtual reality-based education in rehabilitation."

The keywords (top 20 most relevant terms) of topic 3 are as follows (see Figure 19). The keywords of topic 3 are composed of system, training, environment, real, visual, etc., and these terms make up 18.6% of the total tokens of the abstracts of the articles in period 3, so topic 3 was named "virtual reality education platform."

The keywords (top 20 most relevant terms) of topic 4 are as follows (see Figure 20). The keywords of topic 4 are composed of training, simulator, simulation, skills, surgical, etc., and these terms make up 15.9% of the total tokens of the abstracts of the articles in period 3, so topic 4 was named "virtual reality in medical education."

3.2.4. Period 4: 2020–2022. A total of 2868 articles were published during this period (42.46% of the total), and as a result of LDAvis analysis, 7 topics were clearly identified (see Figure 21).

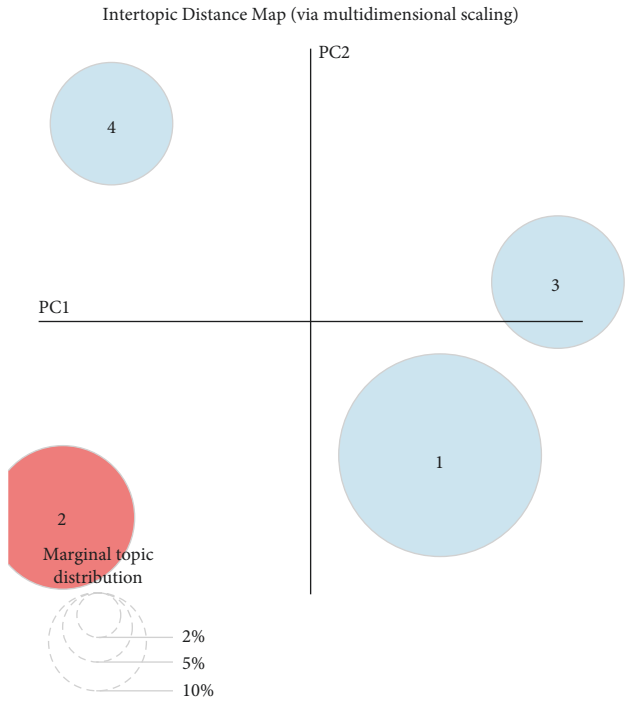

Figure 16: 4 topics of period 3 (2017–2019).

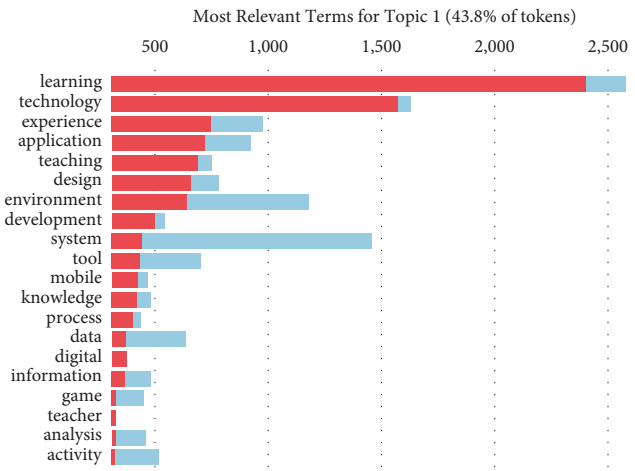

Figure 17: Top 20 most relevant terms for topic 1.

The keywords (top 20 most relevant terms) of topic 1 are as follows (see Figure 22). The keywords of topic 1 are composed of technology, learning, experience, teaching, application, etc., and these terms make up 29.6% of the total tokens of the abstracts of the articles in period 4, so topic 1 was named "virtual reality for learning and teaching."

The keywords (top 20 most relevant terms) of topic 2 are as follows (see Figure 23). The keywords of topic 2 are composed of training, patient, intervention, cognitive, rehabilitation, etc., and these terms make up 13.7% of the total tokens of the abstracts of the articles in period 4, so topic 2 was named "virtual reality-based education in rehabilitation."

The keywords (top 20 most relevant terms) of topic 3 are as follows (see Figure 24). The keywords of topic 3 are composed of training, simulation, surgical, simulator, skill,

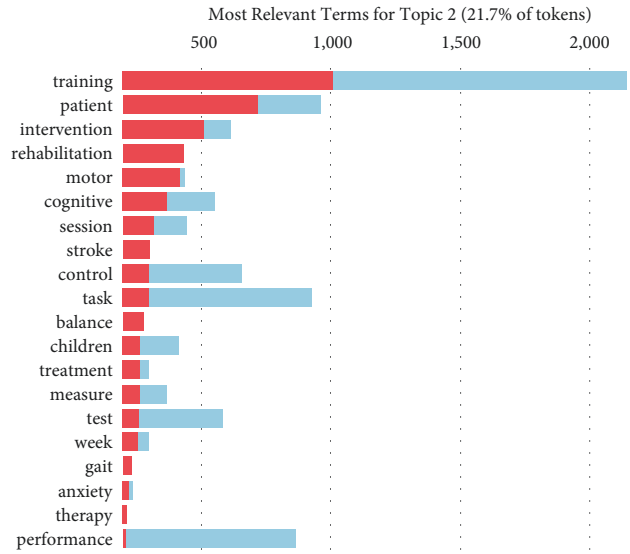

Figure 18: Top 20 most relevant terms for topic 2.

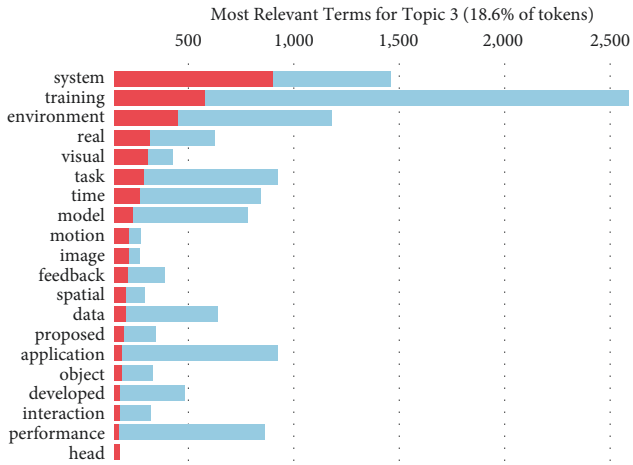

Figure 19: Top 20 most relevant terms for topic 3.

etc., and these terms make up 13.5% of the total tokens of the abstracts of the articles in period 4, so topic 3 was named "virtual reality in medical education."

The keywords (top 20 most relevant terms) of topic 4 are as follows (see Figure 25). The keywords of topic 4 are composed of task, system, performance, visual, environment, etc., and these terms make up 11.8% of the total tokens of the abstracts of the articles in period 4, so topic 4 was named "virtual reality education platform."

The keywords (top 20 most relevant terms) of topic 5 are as follows (see Figure 26). The keywords of topic 5 are composed of training system, application, environment, model, etc., and these terms make up 11.6% of the total tokens of the abstracts of the articles in period 4, so topic 5 was named "virtual reality for training."

The keywords (top 20 most relevant terms) of topic 6 are as follows (see Figure 27). The keywords of topic 6 are composed of learning, teaching, experimental, learner, application, etc., and these terms make up 10.1% of the total

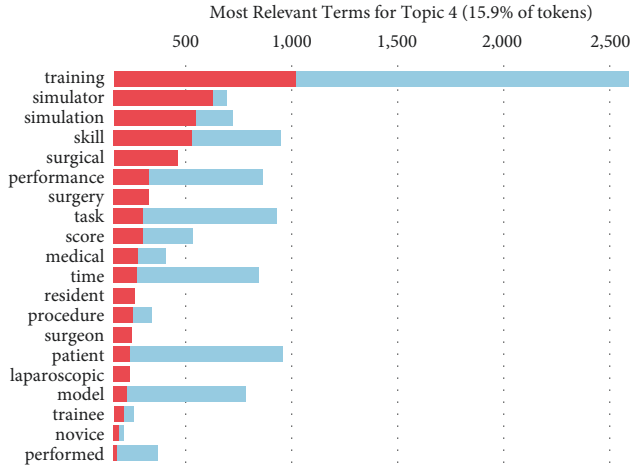

Figure 20: Top 20 most relevant terms for topic 4.

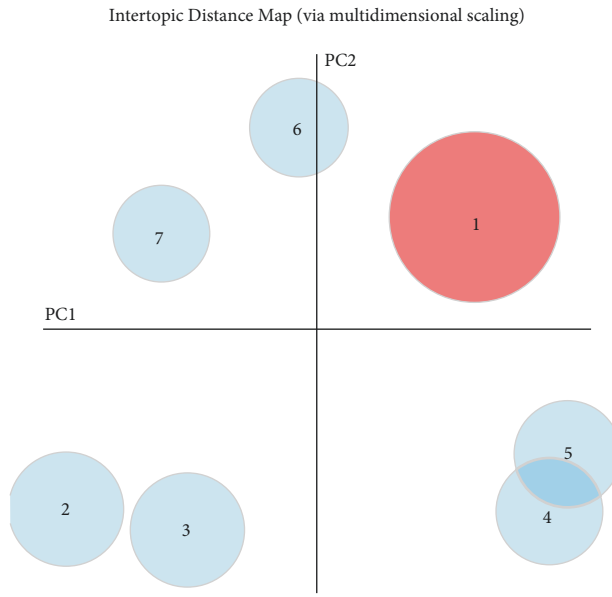

Figure 21: 7 topics of period 4 (2020–2022).

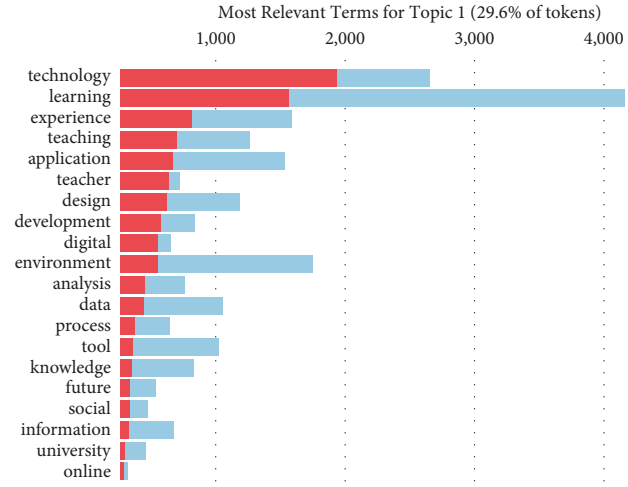

Figure 22: Top 20 most relevant terms for topic 1.

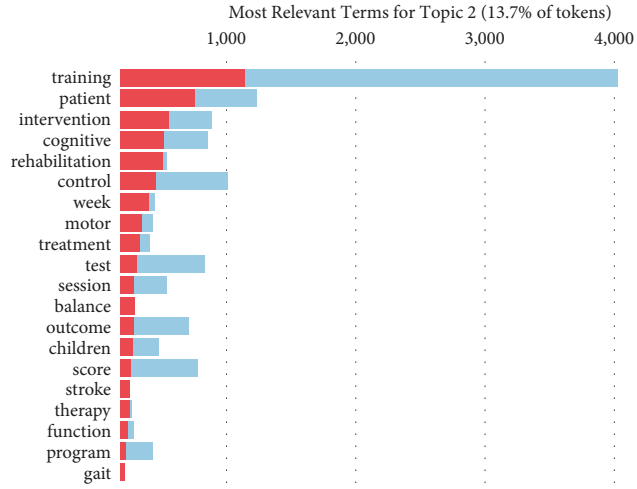

Figure 23: Top 20 most relevant terms for topic 2.

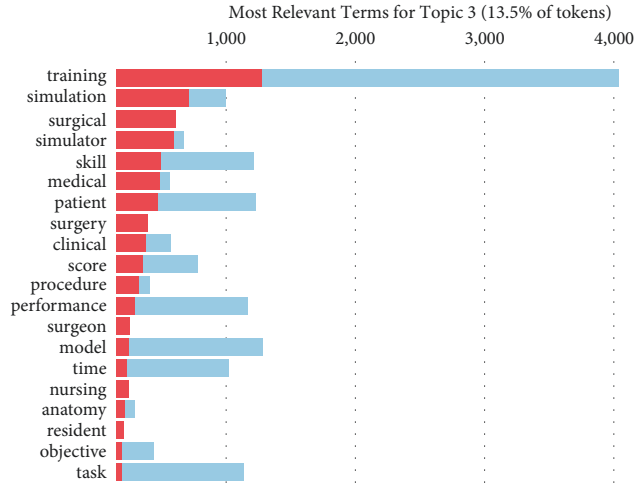

Figure 24: Top 20 most relevant terms for topic 3.

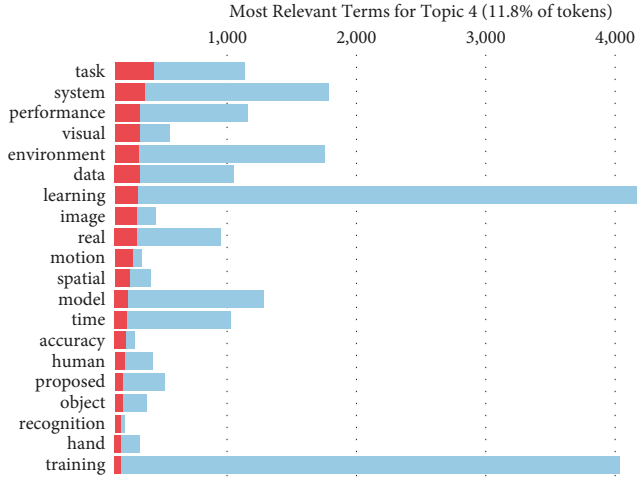

Figure 25: Top 20 most relevant terms for topic 4.

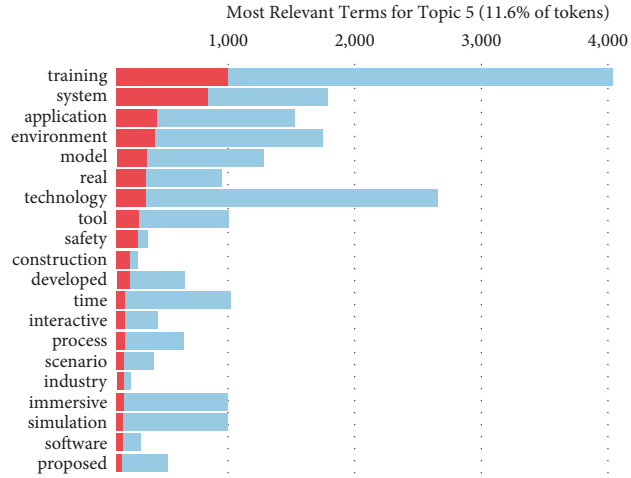

Figure 26: Top 20 most relevant terms for topic 5.

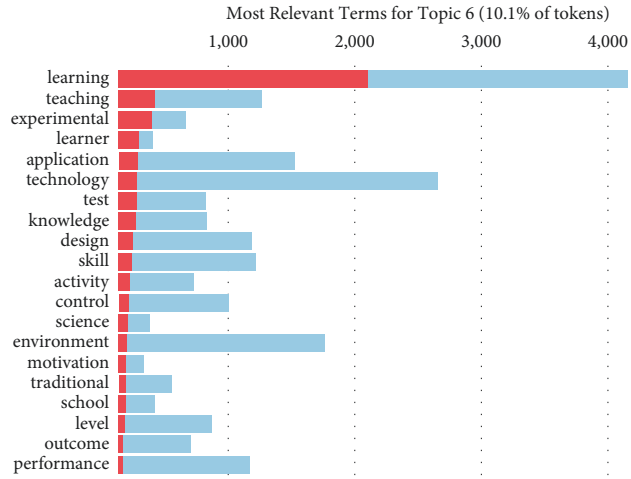

Figure 27: Top 20 most relevant terms for topic 6.

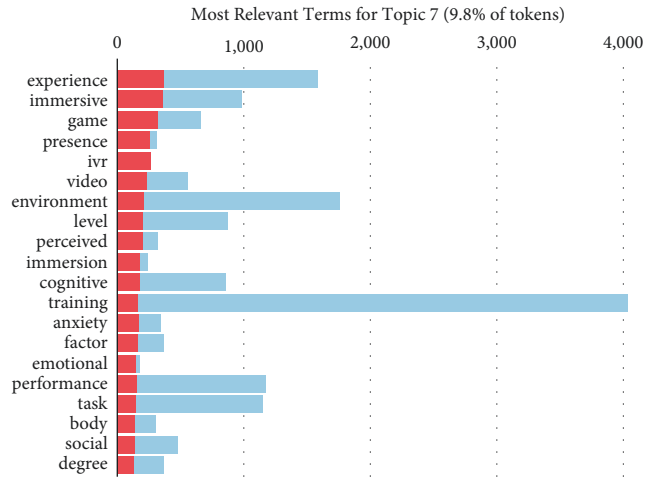

Figure 28: Top 20 most relevant terms for topic 7.

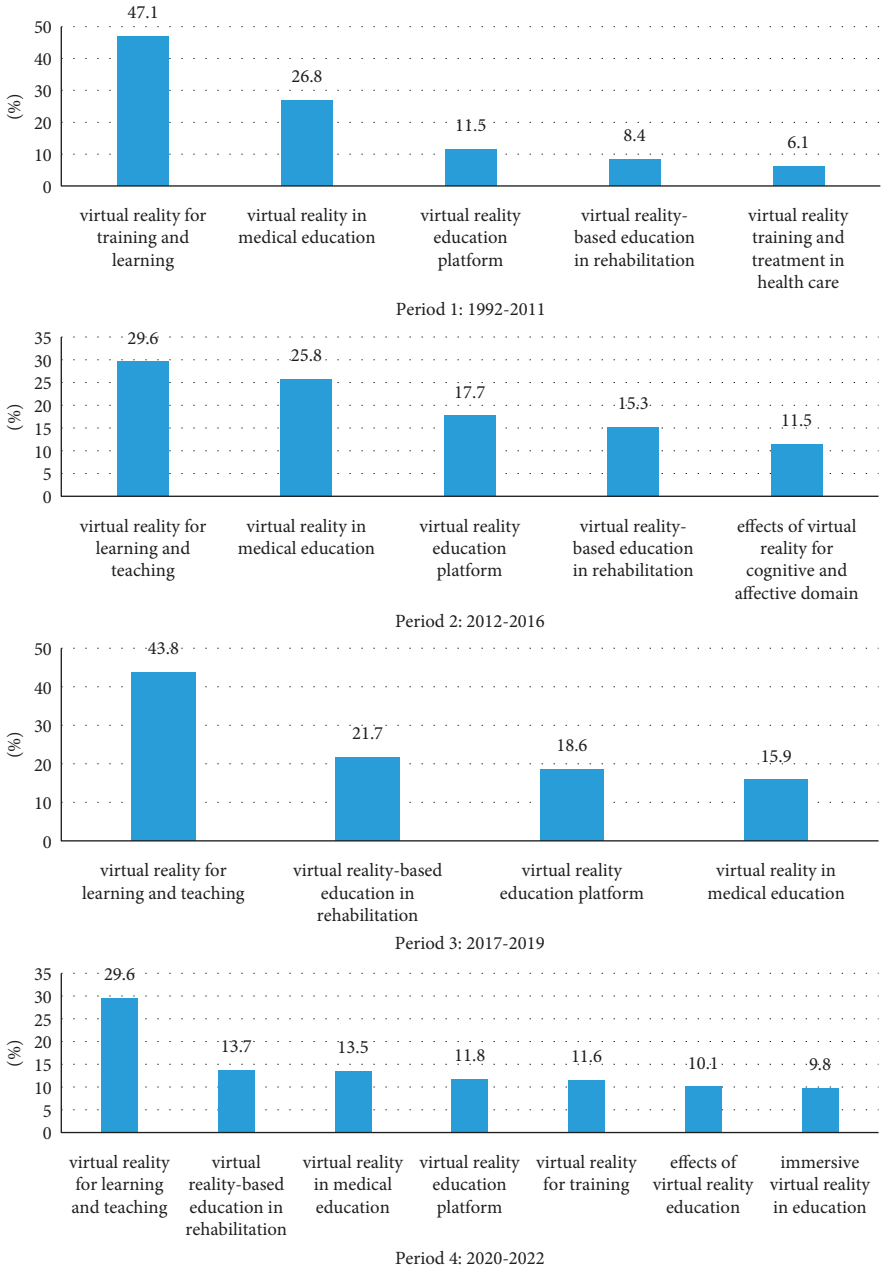

Figure 29: Topics by period.

tokens of the abstracts of the articles in period 4, so topic 6 was named "effects of virtual reality education."

The keywords (top 20 most relevant terms) of topic 7 are as follows (see Figure 28). The keywords of topic 7 are composed of experience, immersive, game, presence, IVR, etc., and these terms make up 9.8% of the total tokens of the abstracts of the articles in Period 4, so topic 7 was named "immersive virtual reality in education."

Figure 29 shows the topics by each period. "Virtual reality for training and learning" was the most salient topic in period 1: 1992–2011 followed by "virtual reality in medical education" (26.8%). In period 2: 2012–2016, the gap of proportion of research about "virtual reality for learning and teaching" (29.6%) and "virtual reality in medical education" (25.8%) has been decreased. And a new topic called "effects of virtual reality for cognitive and affective domain" was emerged in period 2. In period 3: 2017–2019, "virtual reality for learning and teaching" (43.8%) was the dominant topic again followed by "virtual reality-based education in rehabilitation" (21.7%). In period 4: 202–2022, the proportion of "virtual reality for learning and teaching" has decreased to 29.6% and new topics such as "virtual reality for training" and "immersive virtual reality in education" have emerged.

4. Conclusion

During the last 30 years (1992–2002), it was revealed that the research on virtual reality-based education was clearly divided

into the following four periods; 1992–2011, 2012–2016, 2017–2019, and 2020–2022. The main topics for each period were identified as follows. In period 1 (1992–2011), there were 5 topics including "virtual reality for training and learning," "virtual reality in medical education," "virtual reality education platform," "virtual reality-based education in rehabilitation," and "virtual reality training and treatment in health care." In period 2 (2012–2016), 5 topics were identified including "virtual reality for learning and teaching," "virtual reality in medical education," "virtual reality education platform," "virtual reality-based education in rehabilitation," and "effects of virtual reality for cognitive and affective domain." In period 3 (2017–2019), 4 topics were shown including "virtual reality for learning and teaching," "virtual reality-based education in rehabilitation," "virtual reality education platform," and "virtual reality in medical education." In period 4 (2020–2022), 7 topics were identified including "virtual reality for learning and teaching," "virtual reality-based education in rehabilitation," "virtual reality in medical education," "virtual reality education platform," "virtual reality for training," "effects of virtual reality education," and "immersive virtual reality in education."

Here are major findings of this study. First, virtual reality-based education research could be largely divided into the following four periods including 1992–2011 (3.49%), 2012–2016 (18.96%), 2017–2019 (30.14%), and 2020–2022 (42.46%). And research in this area had been rapidly increased in quantity from 2012. Second, education and educational research (16.33%), computer science (7.39%), surgery (4.13%), and psychology (4.03%) was the mostly published research area for virtual reality-based education. Third, "Virtual Reality," "Applied Science-Basel," and "Interactive Learning Environments" were the mostly published journals for virtual reality-based education research. Fourth, since the topics of "virtual reality for training" and "effects of virtual reality education" in period 4 could be included in the topic of "virtual reality for learning and teaching" in the wider point of view, it is identified that the weight of "virtual reality for learning and teaching" has increased in recent years again. Fifth, conversely, it is identified that the proportion of "virtual reality in medical education" has decreased relatively recently. However, this does not mean that research in "virtual reality in medical education" has decreased. Instead, it is possible to interpret that the proportion of other topics has relatively increased. Sixth, it has identified that the topics of "virtual reality education platform" and "virtual reality-based education in rehabilitation" continue to maintain a certain weight. Seventh, with the rapid growth of number of research in this field from 2012, new topics including "effects of virtual reality for cognitive and affective domain" in period 2: 2012–2016, and "virtual reality for training" and "immersive virtual reality in education" in period 4: 2020–2022 had emerged. New research topics along with development of VR technology and expansion of VR education in various fields in different purposes would be continuously emerged.

Further research on analyzing the change of trends in detail for each research topic is suggested based on the results of this study.

There is a limitation of this study in terms of analytical methods. In this study, LDA-based topic modeling technique was implemented on 6,755 journal articles. Even though this technique provides an opportunity to analyze large data sets, currently, it is not possible to conduct deeper analyses like systematic reviews through LDA [68]. It is expected that more detailed and precise analysis needs to be performed on the improvement of the LDA algorithm in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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