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Systematic Review

Potentials in Using VR for Facilitating Geography Teaching in Classrooms: A Systematic Review

Klára Czimre [1,2,*], Károly Teperics [1,2], Ernő Molnár [1,2], János Kapusi [1,2], Ikram Saidi [1], Deddy Gusman [3] and Györgyi Bujdosó [2,4]

[1] Department of Social Geography and Regional Development Planning, Institute of Geosciences, Faculty of Science and Technology, University of Debrecen, 4010 Debrecen, Hungary; teperics.karoly@science.unideb.hu (K.T.); molnar.erno@science.unideb.hu (E.M.); geo.bethlen@gmail.com (J.K.); ikram@mailbox.unideb.hu (I.S.)
[2] MTA-SZTE Research Group on Geography Teaching and Learning, University of Szeged, 6722 Szeged, Hungary; bujdoso.gyongyi@inf.unideb.hu
[3] Doctoral School of Informatics, Faculty of Informatics, University of Debrecen, 4010 Debrecen, Hungary; deddy.gusman@inf.unideb.hu
[4] Department of Computer Science and Library and Information Science, Faculty of Informatics, University of Debrecen, 4010 Debrecen, Hungary
* Correspondence: czimre.klara@science.unideb.hu

Abstract: The application of virtual reality (VR) in geography education is regarded as a progressive and proactive method that has still not gained sufficient attention in the educational policy in Hungary. The aim of our review is to find the ways and means to make it happen. We selected 47 works that are closely linked to geography teaching and analyzed their bibliometric (authorship and journal characteristics, types of works and applied methods, keywords, referencing, and co-citation networks) and contextual characteristics (research objectives, demographic, gender and social background, hardware and software specifications, advantages and disadvantages, conclusions, and predictions) which we expected to help us to understand the slow implementation and undeserved marginalization of VR in the curricular geography education. We used a mixed-method research analysis combining elements of quantitative and qualitative analysis using inductive reasoning. Our preliminary assumption that the application of VR technology is an effective and useful way of teaching geography was proved by our findings. The methods used by the authors of the reviewed empirical works, together with the recommended future research topics and strategies, can be applied to future empirical research on the use of VR in geography education.

Keywords: virtual reality; geography teaching; public education; educational effectiveness; educational technology; research methods; learning and teaching; networking

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1. Introduction

The understanding and reputation of geography have undergone considerable changes during history, facing ups and downs. Nevertheless, there were many centuries when it was regarded as one of the most essential subjects in education. By all means, it is one of the most richly illustrated and picturesque school subjects, with all the maps, diagrams, flowcharts, and photographs that help students understand the world around them. In spite of that, we often experience that "geography education still suffers from neglect, lack of structure and little attention" [1]. Reversing this trend requires a progressive approach to education while giving more space for technology in the classrooms to retain attention and interest [2].

One of the latest technologies, although not yet sufficiently applied, is the use of virtual reality (VR) in various ways to convey information and knowledge. In the modern world, widely accessible devices for the use of VR enable an increasingly stable place for the application of this technology not only in cinemas [3], museums [4], or tourist attractions [5,6] but also in education [7]. Research findings on the effects of VR computer games on primary school students' achievement and motivation in geography learning show the impact of the innovation and the need to harness it in education "as understanding geography becomes more and more crucial in our daily lives" [8] (p. 76).

The focus of geography teaching has gradually shifted towards a more practical application of geographical knowledge and skills, which involves the widespread application of digital solutions, ICT devices, and methodological innovations [9]. The spirit of technological disruption, including digital contents and methods, is now penetrating the entire spectrum of geography education, appearing in curriculum development, study materials, classroom activities, and expected learning outcomes in accordance with the guidelines set by the International Charter on Geographical Education [10]. Due to the steady rate of development of the technological environment of teaching, new directions in pedagogy have emerged with the purpose of integrating a more tech-based approach within geography lessons, harnessing the subject's interdisciplinary nature and the digital transformation of the world surrounding it [11].

However, the prestige of geographic knowledge and geography as a subject within Hungarian public education has slowly disappeared over the last two decades. Conceptual changes in the national curricula (revised twice in 15 years), the low number of subject lessons (1-2-2-1 per week from Grades 7 to 10), and the drop in optional final (school-leaving) intermediate-level exam numbers have consolidated the status of geography as a less relevant subject [12–14]. Empirical studies revealed that while students seem to be generally interested in geography and even tend to like geography, they do not really consider it important or useful enough, making it difficult for students to realize the relevance of geographic knowledge or find motivation in studying it [14]. The only positive change is the rise in advanced-level final exams because of their inclusion within the application process of higher education courses specialized in agricultural and economic studies.

The renewal of geography education requires a methodological change with digital skills development at its core. Online textbook developments and various e-learning materials have already been around in geography education in Hungary for a while now, reflecting a general openness towards the incorporation of technology into daily teaching practice. A number of international studies, pilot projects, publications, and good practices have justified the widespread use of modern ICT devices and platforms in geography education, including the application of VR, which aims to provide new opportunities for the simultaneous development of students' geographical and IT skills in a quite exciting learning environment. Creating more interactive lessons and classrooms with VR could significantly enhance students' learning experience and promote geographical thinking among the younger generations. We hope that the development of new innovations in both VR technology and its use in education will provide new opportunities and solutions for geography teaching [1].

VR technology was not originally designed for educational purposes. Curcio, Dipace, and Norlund provide a detailed history of the development of VR hardware and software technologies, mentioning the 'feelies' [15], the View-Master (1939), the first experimental VR Head Mounted Display (HMD) of 1968 [16] and other experimental VRs in limited environments and functions [17]. In fact, the history of VR dates back as early as 1838, when Sir Charles Wheatstone was the first to construct a stereoscope [18]. Extensive technological development and progress happened only during the second half of the twentieth century, and the first interactive VR platform was created in 1975 (Krueger's VIDEOPLACE). The first company to sell VR goggles and gloves was founded in 1985 and started developing VR equipment [18]. From that year onward, VR has become more and more popular with researchers and companies offering a widening range of equipment—including the involvement of NASA scientists as well. In the nineties, a shift started from research facility to practical application. As Pantelidis worded it in 1993, "Now is the time to consider uses in the classroom" [19] (p. 24). By 1995, VR had also become a means of entertainment in the form of video games and consoles with headsets made accessible for homes. The year 2007 is regarded as the most important milestone in modern technological developments, and it was also marked by the introduction of Google Street View. This resulted in the expansion of VR technology in all fields of life and the appearance of competitive structures with the chief inventors, including Facebook, Google, and Samsung. In 2014, Facebook bought the Oculus VR company, and VR became almost indispensable equipment for high-tech games and applications. Hundreds of companies started developing VR products in 2016. However, as Han notes, "Despite the potential for and expectation of increasing presence and learning, empirical research on the use of immersive VR is scarce [20] (p. 423)." This statement encouraged us to find out more about the state of VR in education, more specifically in teaching geography in elementary and high schools.

The aim of our systematic review is to find answers to the following questions inter alia:

1. What do these works have in common in terms of their bibliometric indicators (type of research, journal, ranking, number of reads, and citations)?
2. Are the works on the use of VR in geography education-related (bibliographic coupling, co-citation)?
3. How do the objectives of the reviewed works correlate?
4. What kind of hardware and software specifications are discussed in the reviewed works? In which areas of geography can they be used?
5. What are the advantages/pros and disadvantages/contras of using VR in geography education?
6. When teaching geography to twenty-first-century students, how relevant and effective can the use of methods using VR technologies be?

2. Materials and Methods

Records were selected using the search engine of the Library of the University of Debrecen (Debrecen, Hungary), ProQuest Summon^{TM} (unideb.summon.serialsolutions.com), which includes 153 databases (such as ProQuest, ERIC, PubMed Central, ScienceDirect, Springer, Taylor & Francis, Elsevier, etc.). First, we ran three searches (S1, S2, S3), including three sets of keywords in all categories to find the relevant works, and collected them all in a Zotero folder. Then, we aggregated the keywords (S4), added the new search results to our Zotero folder, and thus finally obtained a total of 913 works where our keywords appeared in 'All fields' (Table 1). We searched for all works published before July 2024. The keywords selected were narrowed down from a broad list of topics relevant to the research, and five keywords were finally used with the aim of being specifically focused on the application of VR technology in geography teaching/education in schools.

Table 1. Selection criteria settings for our systematic review on the application of VR in geography teaching.

	S1 (Virtual Reality) AND (Geography) AND (Teaching)	**S2 (Virtual Reality) AND (Geography) AND (Education)**	**S3 (Virtual Reality) AND (Geography) AND (School)**	**S4 (Virtual Reality) AND (Geography) AND (Teaching) OR (Education) OR (School)**
journal article	245	531	172	**626**
conference proceeding	12	23	10	**30**
book/e-book	22	45	12	**54**
dissertation/thesis	6	10	6	**18**
book chapter	14	25	10	**21**
book review	-	4	-	**4**
newsletter	*9*	*97*	*10*	***98***
magazine article	*3*	*16*	*6*	***19***

Table 1. *Cont.*

	S1 (Virtual Reality) AND (Geography) AND (Teaching)	S2 (Virtual Reality) AND (Geography) AND (Education)	S3 (Virtual Reality) AND (Geography) AND (School)	S4 (Virtual Reality) AND (Geography) AND (Teaching) OR (Education) OR (School)
newspaper article	2	25	24	**32**
publication	1	1	1	**1**
trade publication article	1	8	-	**8**
web resource	1	1	1	**1**
streaming video	-	1	-	**1**
total number of results	316	787	252	**913**
number of databases	36	61	43	**63**

Three types of works were selected for the systematic review: journal articles and conference proceedings were selected as peer-reviewed works, and in addition to them, the dissertation/thesis category was also added as they also undergo a thorough filter when corrected and commented on by at least two opponents. The S4 results showed a great variety of works, which also allowed for preliminary observations that revealed interdisciplinary connections and highlighted specific subject terms. The search engine assigned the findings into 53 disciplinary categories, and each work was assigned to more than one discipline. Most of the records were listed under the disciplines of geography (46%) and education (37%), and the disciplines of environmental sciences, economics, and computer sciences each had a share of more than 20%. The wide variety and high proportion of disciplines imply that the topic under investigation requires a multidisciplinary approach (Figure 1).

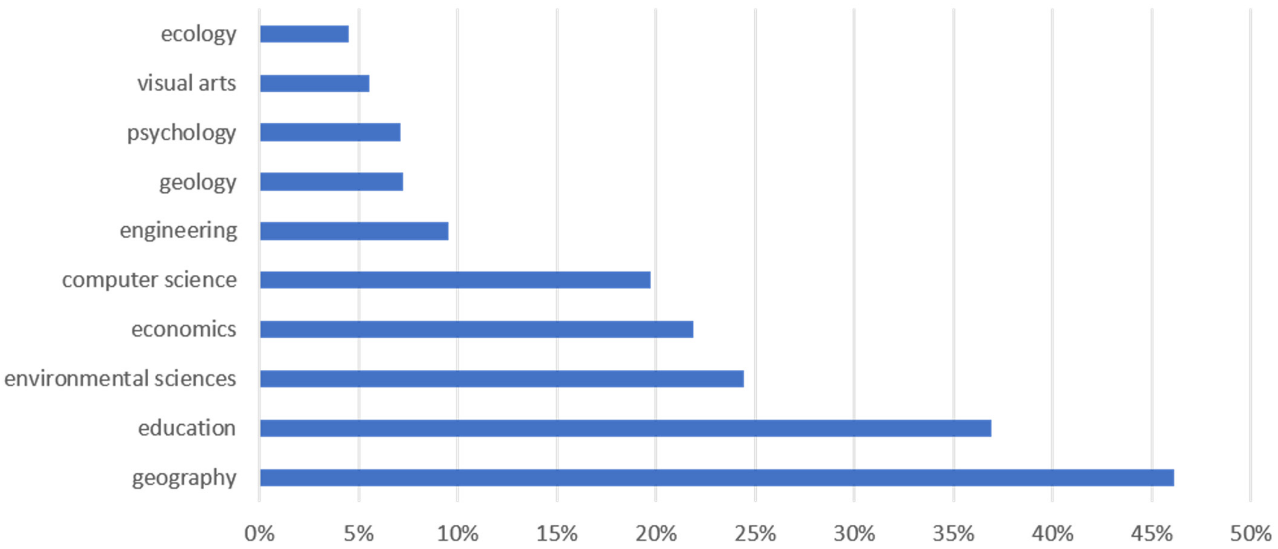


Figure 1. Relative frequency of mentions of the total number of works in S4 by disciplines (%).

We also looked at the subject terms in the 913 works and found that most often they included the following: virtual reality (571), science and technology (344), education (281), geography (268), social sciences (245), life sciences and biomedicine (228), environmental sciences (212), and environmental sciences and ecology (211). The top three subject terms supported our presupposition that the above works are closely related to our research objectives. At this point, we started the screening and refining stages of our search.

The refining strategy for our systematic review consisted of the following steps (Figure 2):

1. We narrowed down the research to the discipline of geography—421 results
2. We selected only three types of works: peer-reviewed journal articles, peer-reviewed conference proceedings, and dissertations/thesis (the dissertation/thesis type of documents were kept for two basic reasons: the dissertations/thesis all had useful case studies and had bibliographies that were worth to consider for our analysis of references)—284 results
3. Retrieved works were assessed for eligibility—171 results
4. Works were excluded for a variety of reasons after reading (not relevant age group, does not refer to geography as a school subject, and other reasons)—125 results
5. After screening, we finally included 47 works that were considered relevant and accessible.

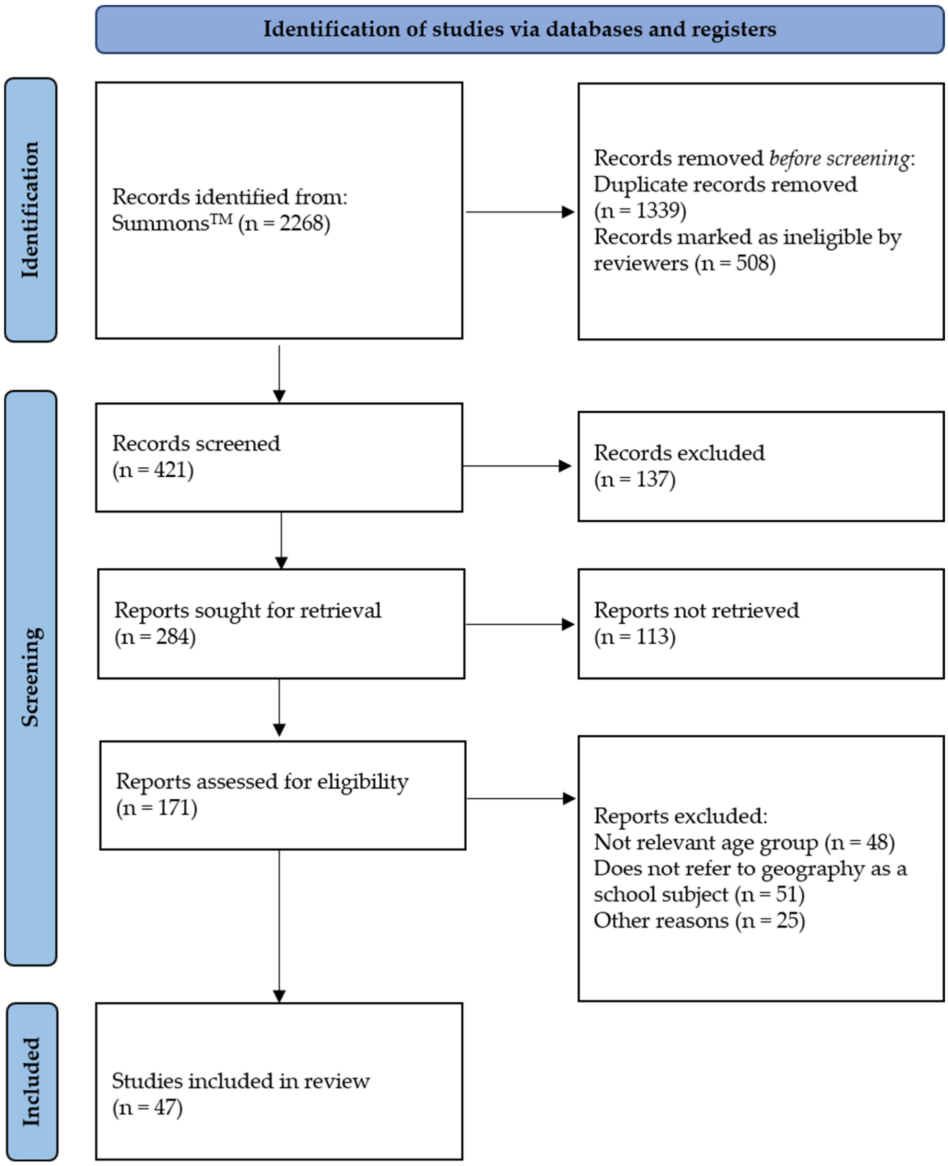


Figure 2. PRISMA diagram of the steps of the selection of works for the systematic review.

We decided to use a mixed-method research analysis combining elements of quantitative (descriptive statistical—what, who, where, when) and qualitative (descriptive—why) analysis using inductive reasoning based on the 47 reviewed works. We read all 47 works and collected data with regard to the formal as well as the contextual features, which we discussed in five–five subtopics in our review.

In the analysis of the formal features, we looked at the authorship and journal relations, focusing on the affiliation of the authors, the journal characteristics, the types of works and the methods applied, the keywords used, and the co-citation networking. We used the Scimago Journal and Country Rank website to obtain information about the scientific ranking and indexing of the journals that published the selected peer-reviewed articles, and we used the Gephi 0.10.1 software to explore the links and connections between the authors and their referenced works. The WordArt online word cloud generator was used to draw the word cloud for keyword analysis.

In our discussion of the content and contextual scopes, we concentrated on the comparative analysis of the objectives set by the authors in their work, the demographic characteristics, the applied VR technology (hardware and software), the advantages and disadvantages associated with VR (with special attention to its use in education), and the conclusions drawn by the reviewed authors. WordArt was used to draw the word cloud and analyze the mentioned positive impacts of VR in education.

All tables and figures were collected, processed, and drawn with the help of Microsoft Excel 2019.

3. Results

3.1. Bibliometric and Methodological Analysis—Descriptive Statistics

3.1.1. Authorship Characteristics

The total number of authors of the forty-seven reviewed works is one hundred fifty-three, representing twenty-five countries from three continents, with a quarter of the works originating in the USA. Only seven works are the results of international cooperation (Finland–Italy–Sweden—1, Iran–South Korea—1, South Korea–Singapore—1, Hong Kong–Taiwan—1, Denmark–USA—1, Indonesia–Vietnam—1, Canada–Finland-Germany–USA—1), the others are written by researchers from a single country. No works are found in Africa or Australia (Figure 3). The geographical distribution of the involvement of researchers (Figure 4) reflects a rather uneven coverage and suggests that the topic of the application of VR activities in geography teaching (K-12 levels) is rather under-researched.

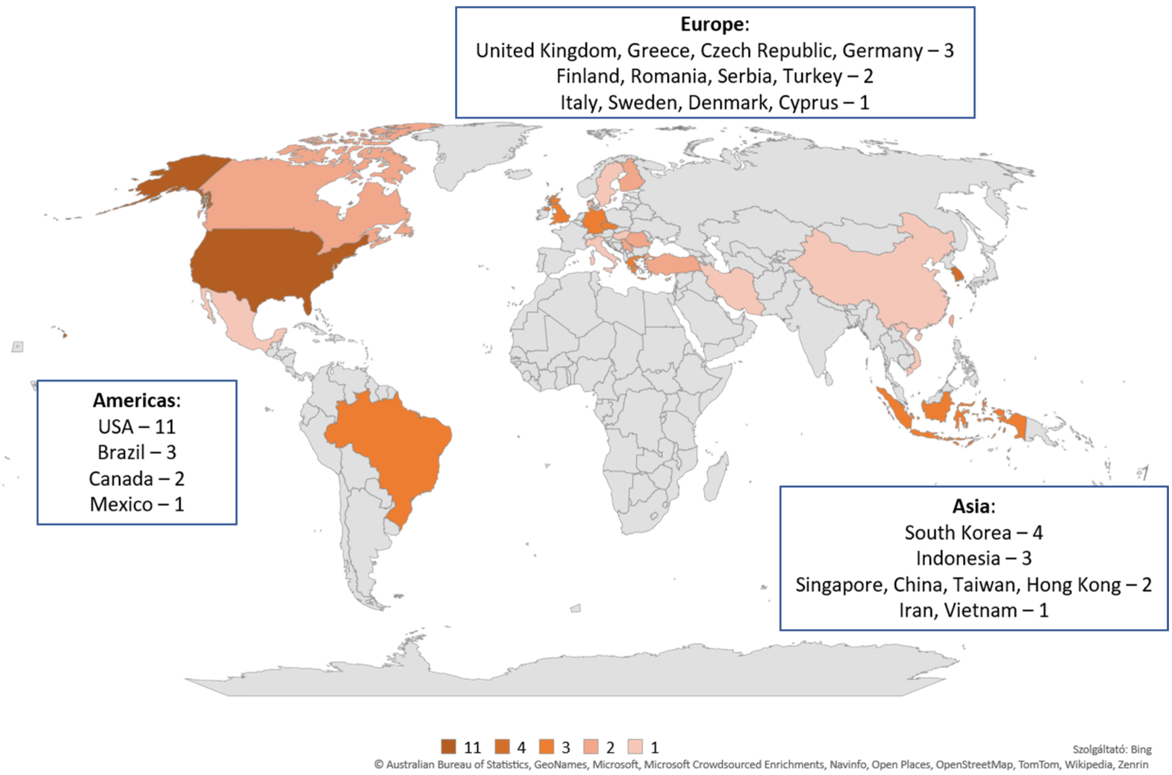


Figure 3. Geographical distribution of the reviewed works (N = 47).

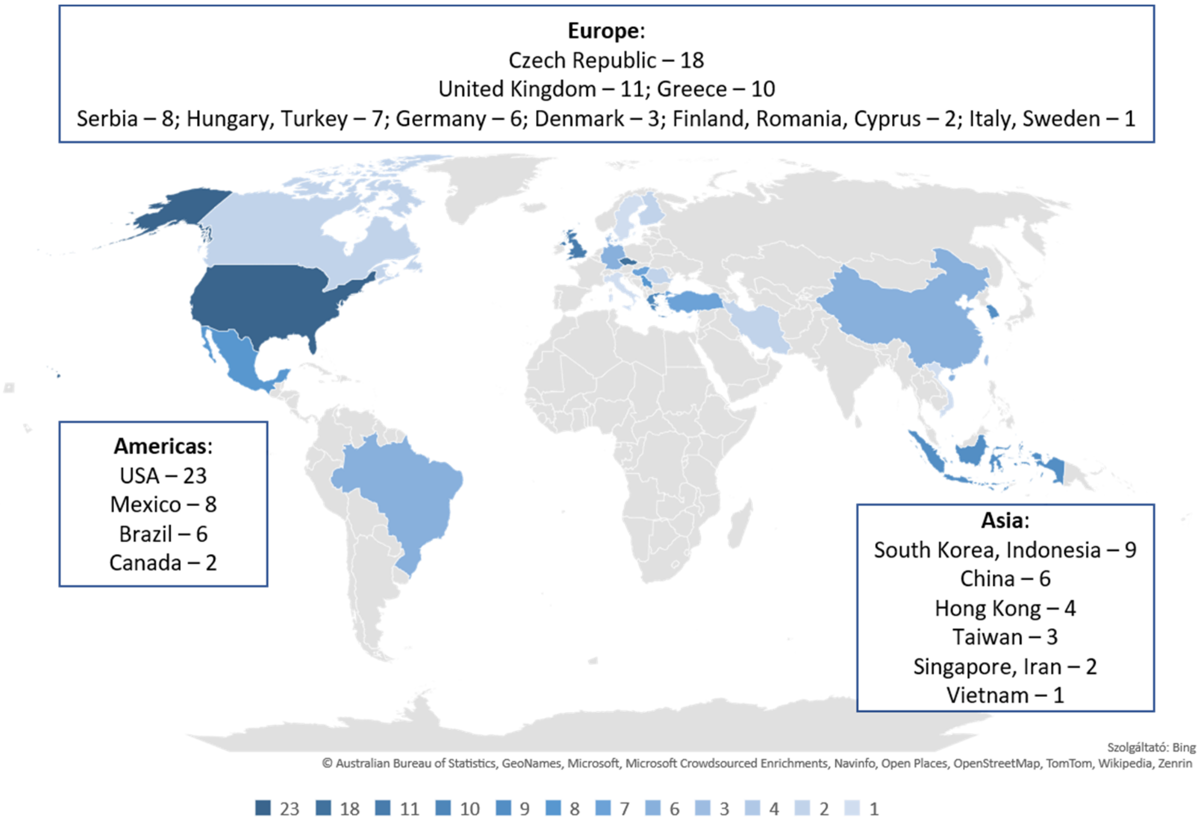


Figure 4. Total number of authors by country of affiliation (N = 153).

3.1.2. Journal Features

A total of thirty-five works were analyzed in our systematic review and published in twenty-two peer-reviewed journals and two peer-reviewed conference proceedings, of which seven (six peer-reviewed journals and one conference proceeding) were published in more than one of the reviewed papers (Table 2). The scope of the journals is predominantly education, computer sciences, and geography. In addition to these, nine conference papers and three doctoral dissertations are included in our present review.

Table 2. Characteristics of journals and proceedings publishing at least 2 of the 47 reviewed studies.

	Number of Papers	Q Ranking (2023)	H-Index (2023)	Publisher	Scope of Journal
British Journal of Educational Technology	5	Q1	110	Wiley-Blackwell	Education; E-learning
Computers and Education	3	Q1	215	Elsevier	Education; E-learning; Computer Science
Educational technology and society	2	Q1	103	National Taiwan Normal University and Society	Education; E-learning; Engineering; Sociology and Political Science
ISPRS International Journal of Geo-Information	2	Q1	62	MDPI	Computers in Earth Sciences; Earth and Planetary Sciences; Geography, Planning and Development

Table 2. *Cont.*

	Number of Papers	Q Ranking (2023)	H-Index (2023)	Publisher	Scope of Journal
International Journal of Emerging Technologies in Learning	2	Q2	48	International Association of Online Engineering	Engineering; E-learning; Education
GeoSaberes	2	-	14	Federal University of Ceará	Geography
Procedia Computer Science	2	conferences and proceedings	109	Elsevier	Computer Sciences

In our scientometrics approach, we use two metrics to find out about the scientific impact of the papers focusing on the application of VR technology in geography teaching. The journal quality ranking system (Quartiles, 2022) and the H-index (the journal's number of articles (h) that have received at least h citations) are used to see the positioning of the journals where the papers were published, and then the individual citation indicators (number of citations in Crossref, ResearchGate, Scopus and WoS) of the Q1 and Q2 papers are consulted to see and compare the scientific impact of the works individually. We found that the majority of the papers are published in Q1 journals with a great variety of H-index but with a dominance of journals with a value of 101–150 (Figure 5). These H-index values may be regarded as considerable in their own subject areas.

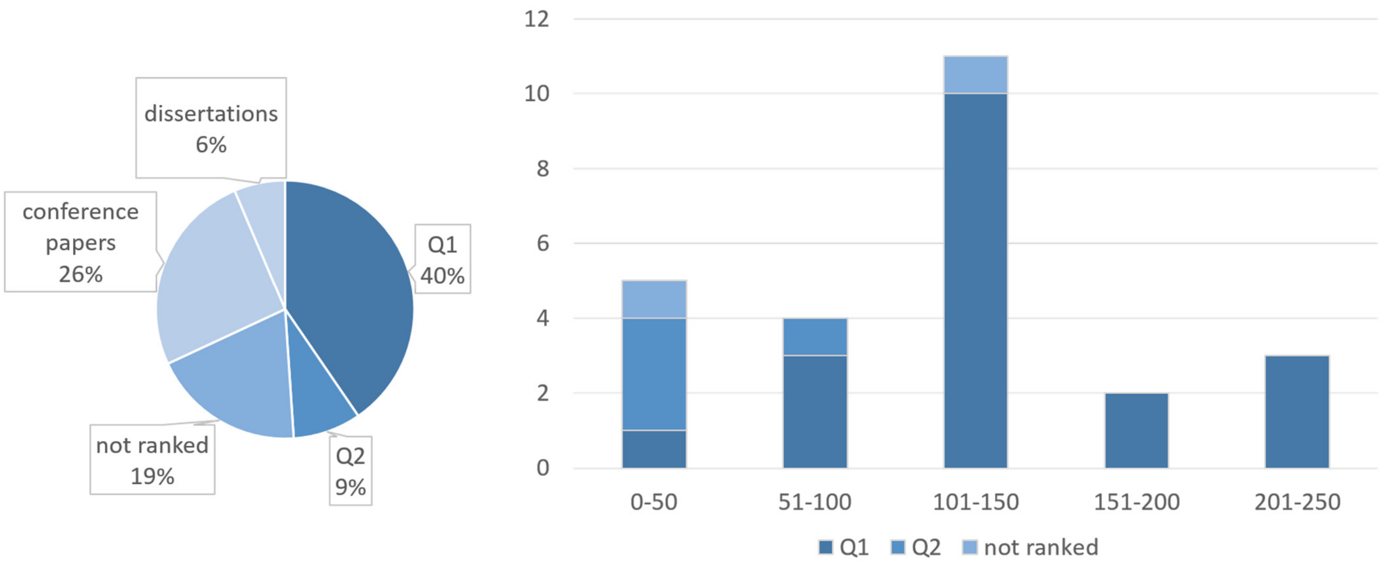


Figure 5. Distribution of journals where the reviewed works are published on the basis of their Q ranking and H–index (as of 18 August 2024).

Altogether, 23 papers published in Q1 (19) and Q2 (4) journals are present only from the year 2000. Three major tendencies can be observed in analyzing data derived from ResearchGate with regard to the reading and citation characteristics (Figure 6).

- Of the six most often read articles (with more than 1000 reads) [2,8,20–23], only three [8,21,22] may be regarded as very influential, with their citations/reading value exceeding 10% (34.35%,10.49%, and 87.42% respectively). However, the number of reads has already exceeded one thousand in the case of the latest review-type work [2]; according to the statistics of researchgate.net, it has not yet been cited. Thus, in this case, the number of readings does not necessarily result in a higher number of citations.

- The most often cited works may be regarded as the most influential works. In our study, four articles reached a citations/readings value of over 20% [21,22,24,25], with especially high values occurring in the case of two works (2011—87.42% and 2020—53.96%).
- The absolute number of citations is the highest in the case of the works published in the early years (2005—506 [21], 2008—641 [8], 2011—1035 [22]). The number of citations is decreasing both in absolute and relative terms. This can be explained partly by the time factor and partly by the fact that the number of works published recently is increasing, which also suggests an increasing number of researchers are researching the possible applications of VR technology in geography teaching. At the same time, these parallel studies have also been found to rely on earlier sources to support their theoretical discussions.

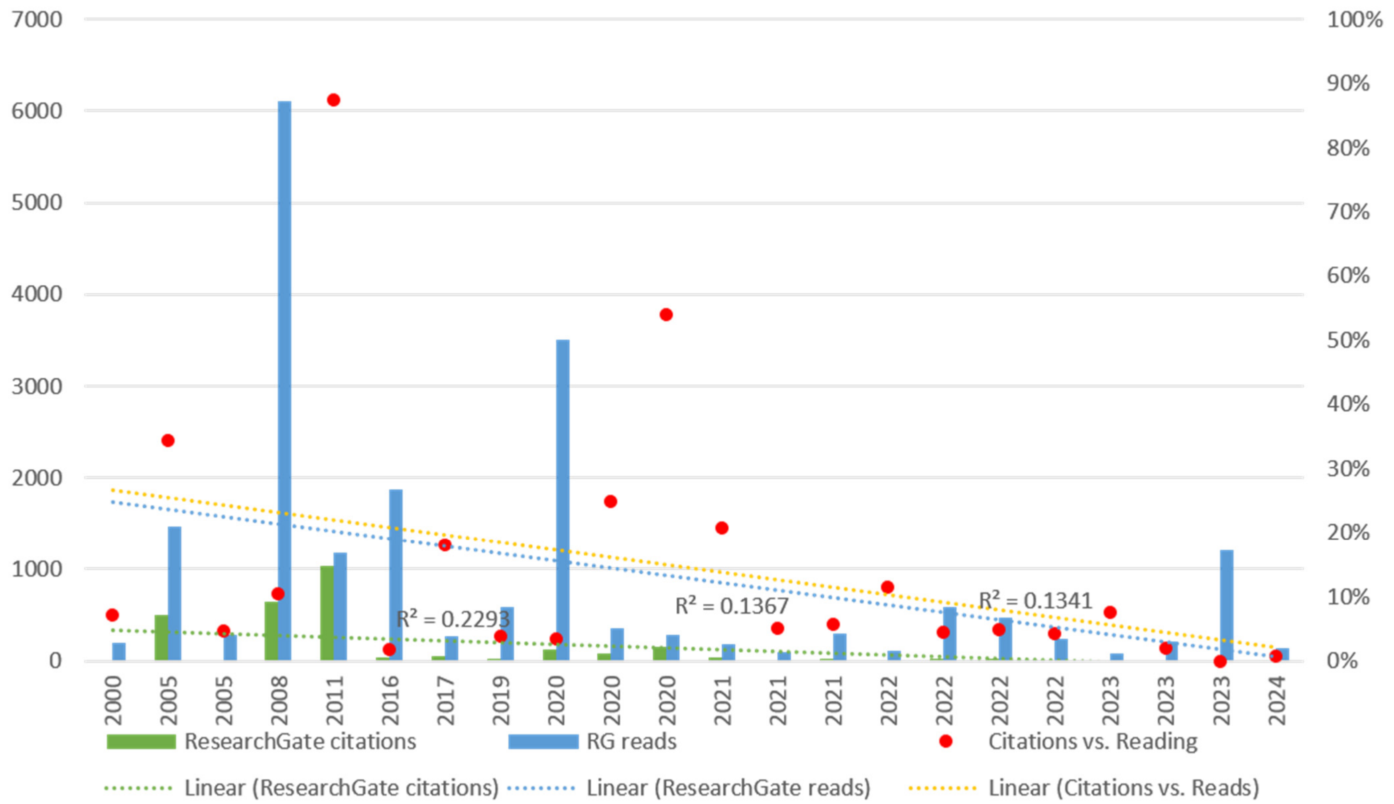


Figure 6. Citations and reads of the reviewed Q1 and Q2 articles and their correlations (based on data for each article retrieved from researchgate.net on 18 August 2024).

Data from Crossref also supported our findings with similar but somewhat lower values (60% less on average) than those provided by the ResearchGate website. The absolute values of the Crossref citations reveal two distinctive groups in terms of the impact of the time factor on the number of citations, with a higher concentration between 2005 and 2011 [8,21,22] and a lower concentration after 2016 [23,25–29]. Unfortunately, no Q1 or Q2 publications could be selected for our review from 2012–2015; therefore, there is a gap in this respect (Figure 7).

The impacts of the type of paper, applied methods, and scope of articles on the citation frequency are discussed below, together with the other types of works selected and included in the systematic review.

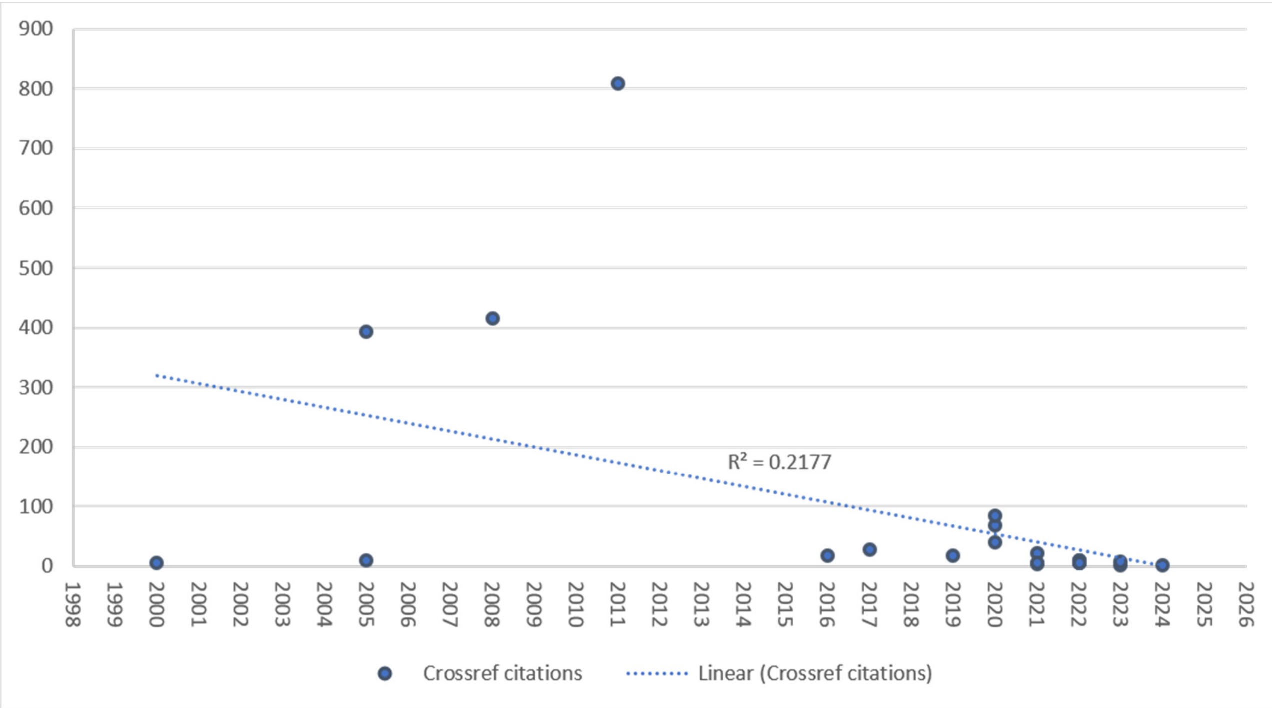


Figure 7. Number of citations of the reviewed Q1 and Q2 articles (based on data retrieved from crossref.org on 18 August 2024).

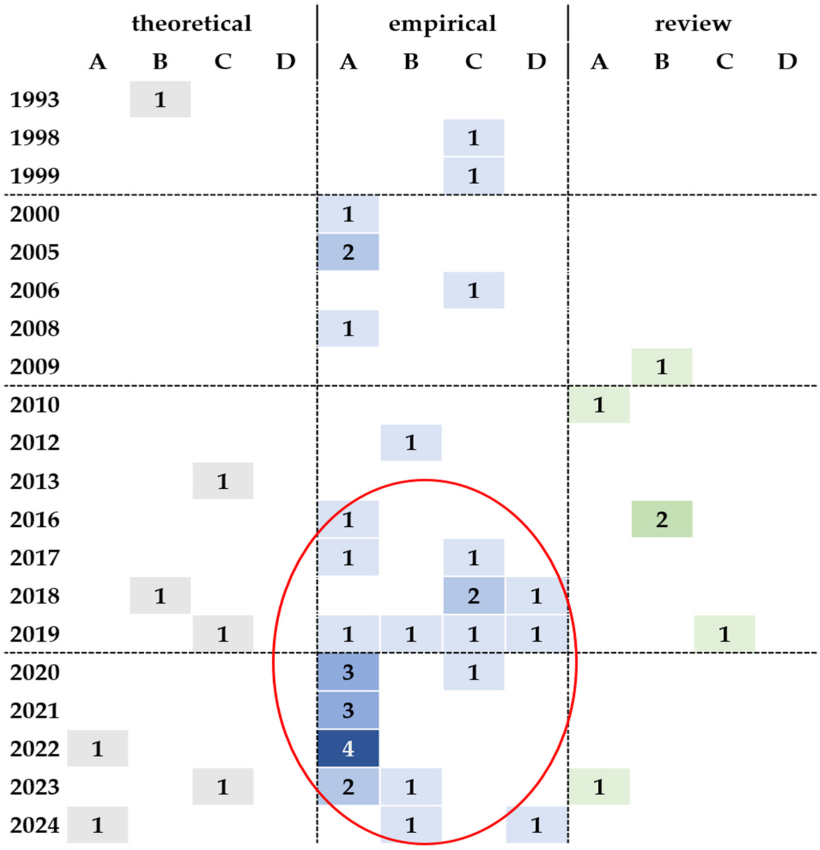
3.1.3. Types of Works and Applied Methods

When defining the research type, we strictly use only one category for each work. In several cases, the consulted works fall into more than one category regarding the type; in those cases, we relied on the 'Conclusions' sections of the work and focused on the area to which the findings were mostly referred (Table 3). This is why, in addition to those three works whose primary objective is to provide a review research, a meta-analysis [30], a systematic review [31], an empirical review [22], and a bibliometric analysis [2], we also added two more works into the review category from our collection including an overview of case studies [17] and an extensive literature review on the usage of virtual reality in education [32]. The three dissertations [33–35] included all three research types in a balanced way, but the empirical results and the applied methods in their cases may be regarded as their most original results; therefore, they were categorized as empirical works.

Table 3. The distribution of works by research paper type.

	Q1/Q2 Articles	Not Ranked Articles	Conference Papers and Proceedings	Dissertations	Total
theoretical	2	2	4	-	**8**
empirical	19	4	7	3	**33**
review	2	3	1	-	**6**
Total	**23**	**9**	**12**	**3**	**47**

When we added the time factor (year of publication), we found that certain trends and patterns can be observed with regard to the type of studies (Figure 8).



	theoretical				empirical				review			
	A	B	C	D	A	B	C	D	A	B	C	D
1993		1										
1998							1					
1999							1					
2000					1							
2005					2							
2006							1					
2008					1							
2009										1		
2010									1			
2012						1						
2013			1									
2016					1					2		
2017					1		1					
2018		1					2	1				
2019			1		1	1	1	1			1	
2020					3		1					
2021					3							
2022	1				4							
2023			1		2	1			1			
2024	1					1		1				

Figure 8. Frequency of research types by year (Legend: A—Q1/Q2 journals, B—not ranked journals, C—conference proceedings, D—dissertations. The shades of colours indicate the number of studies per year by study type: grey—theoretical, blue—empirical, green—review. The red circle marks the highest concentration of studies analysed in the review).

Almost three-quarters of the works present findings of empirical research in all four categories, while there is a higher share of theoretical works than reviews discussing methodological or technological aspects. The most often occurring combination is the publication of empirical studies either in Q1/Q2 journals or conference proceedings, which were predominantly published after 2017. An obvious increase can be observed in the number of papers in all four categories since the year of the first publication included in the present review.

We looked at the empirical works from the aspect of the applied methods and strategies, finding that the majority of the works use a mixed-method research approach, emphasizing the importance of both qualitative and quantitative measures in the study of the topic (Table 4). Almost all authors apply pre- and post-tests to measure the effectiveness of VR-based activities in education. Ten works use the method of comparing an experimental group with a control group, which allows the authors to decide whether the VR-based teaching-learning environments or the traditional teaching-learning strategies are the more effective. There are two works where, instead of the traditional learning environment, two technological learning environments are compared [24,36].

The great variety of research methods also reveals the differences between the availability and accessibility of the hardware and software and also shows dependence on the location as well as the social and economic characteristics of the sample areas. For example, in a research conducted in a public, rural school district with a lower-middle-class community and 63% of the students receiving subsidized lunch based on their family income in Northeast Mississippi (USA), the author found the availability of technological supports such as VR devices and wireless Internet as the strongest limitations to implementing VR in classrooms [34]. Researchers in Taiwan listed the proper quality of mobile devices as a limitation, highlighting that the fine game scenes and pictures burdened the memory and rapidly consumed the battery life of mobile phones [48]. The authors of a study conducted in a private K-8 elementary school embedded in a state university in Central Turkey, where the social and economic status of the participating students' families was above average, also encountered technical-related problems with freezing down computers but support was accessible throughout the research [8]. The lack of demanded computer features or system requirements is also discussed in a literature review on the use of VR systems and devices in education [32].

Table 4. Research methods and tools, teaching-learning strategies, and study area focus in the 32 empirical works.

Authors	Research Methods and Tools		Teaching-Learning Strategies	Study Area Focus
	Qualitative	Quantitative		
[36]	student virtual reality experience questionnaire, attitude survey, interview	post-tests (closed-ended, multiple-choice questions), competency tests, VR lab attendance record, statistical analysis	VR-based teaching vs. video-based teaching	world geography
[37]	post questionnaire (content evaluation, pedagogical evaluation, software quality evaluation, attractiveness of the application)	-	constructive and collaborative learning, activity sheet	agriculture
[38]	-	pre- and post-tests, statistical analysis	constructivist approach, collaborative learning	map-reading, orientation
[21]	-	interview, pre- and post-tests, t-test statistics	educational-game based learning	world geography, topography
[39]	longitudinal	statistical analysis	collaborative working	-
[8]	observations, interviews, open-ended questions, digital records, photographs	pre- and post-tests; achievement test (17 multiple-choice questions), motivation scale, five-point Likert scale	game-based learning environment	world continents and countries
[40]	satisfaction test based on a 7-item Likert scale, 6-item preference survey	power analysis; initial pilot validation study, 11-item multiple-choice test,	immersive learning environment (cooperative learning, discussion, discovery (inquiry-based learning)) vs. PowerPoint	motions and forces (Newtonian physics)—space exploration
[23]	session observations, video recordings	pre- and post-test knowledge quizzes (12 open-ended questions), in-built game analytics, statistical analysis	experiential learning (Kolb's model), cognitive load theory (Sweller), gamification techniques vs. outreach presentation	volcanic hazards

Table 4. *Cont.*

Authors	Research Methods and Tools		Teaching-Learning Strategies	Study Area Focus
	Qualitative	Quantitative		
[26]	-	pre- and post-tests: motivation survey (5-point Likert scale), comprehension test (5 multiple-choice questions), application test (sketching), group performance, statistical analysis (Cohen's kappa), ANOVA test	whole-class discussion, collaborative learning (collaborative problem solving, collaborative observation) vs. teacher-directed discussion	topographic maps
[41]	-	pre- and post-tests	inquiry-based learning, think-pair-share activity	tropical rainforests
[33]	instructional materials motivation survey (39 questions)	quasi-experimental, pre- and post-tests, non-equivalent control-group design, teacher-designed social studies test (36 multiple-choice questions), a priori power analysis, 5-point Likert scale, statistical analysis (ANCOVA test)	combination of traditional instruction (textbooks, notetaking, instructional videos, and lecture) and virtual reality field trips vs. traditional teaching methods (direct instruction)	geographic, political, economic, and cultural structure of Europe during the Middle Ages
[42]	short interview (collecting end-users opinions), QUIS scale, recording	usability tests, post-test questionnaire	collaborative learning, game-based evaluation	geography of Europe (countries, capitals, flags and neighbors
[43]	semi-structured interviews, in-class lessons, post-lesson semi-structured interviews	-	inquiry-based fieldwork, experiential learning in fieldwork-based education, inquiry-based learning, ISM (initial stimulus material), virtual field trip, observation, post-field trip activity	coral bleaching, rainforests
[44]	consultations, satisfaction questionnaires (4-point Likert scale), focus group interviews,	online demand survey (open-ended questions, 4-point Likert scale),	experienced-based training program, cooperative learning, lecture, practice, fieldwork, group activities	geography in secondary education
[27]	-	questionnaire (open and closed questions, MLR scale, 5-point Likert scale), statistical analysis (descriptive statistics, cluster analysis)	-	physical geography, regional geography
[34]	interviews, observation protocol, phenomenological reflection	-	discussion, confrontation, preliminary student activities, virtual expedition/tour	Giza Pyramids of Egypt

Table 4. *Cont.*

Authors	Research Methods and Tools		Teaching-Learning Strategies	Study Area Focus
	Qualitative	Quantitative		
[45]	survey	-	debate, presentation, video discussion, VR short film, guided questions, intervention	Indigenous people in Brazil
[46]	observation, interviews	-	tutorial, interaction in a collaborative virtual environment, feedback	states, islands, oceans, and mountains on maps
[20]	virtual presence survey (7-point Likert scale), reflection papers	statistical analysis, inductive content analysis	immersive virtual field trips vs. traditional virtual field trips (teacher-guided exploration)	San Diego Zoo Reef Sharks
[25]	knowledge test (structured questions), semi-structured interviews (open-ended questions)	statistical analysis of the results of the knowledge tests	LIVIE (experimental manipulation, 5 inquiry-based learning phases) vs. conventional textbook-based approach	coastal process and landform
[24]	-	pre- and post-assessment, statistical analysis	inquiry-based learning, narrated pretraining vs. narrated training, plenary discussion, collaborative work, conceptualization, investigation, presentation	climate change
[47]	questionnaires (5-point Likert scale)	statistical analysis	video, images, slide presentation, instruction through a presentation, inquiry-based learning, problem-based learning, immersive VR-based educational game (IVREG), VR and gamification learning environments vs. traditional learning environments	topology relations
[28]	students' reflection papers, class observation, teacher interviews	content analysis	(1) instruction-based virtual exploration, teacher-led discussion, (2) immersive virtual field trips vs. traditional virtual field trips (teacher-guided exploration)	(1) life in cities around the world, (2) San Diego Zoo Reef Sharks
[29]	satisfaction survey (5-point Likert scale), interviews (step-by-step questions)	pre- and post-tests, questionnaire (cognition of, interest in, scientific attitude), statistical analysis	preparatory learning phase (traditional teaching method), instruction-based virtual exploration, review paper submission	geology, rock types, geological structures
[48]	expert interviews, student interviews	pre- and post-tests, spatial ability test, learning achievement test, statistical analysis	VR-based learning (VALID) vs. traditional teaching methods (textbooks, PowerPoint, teachers' dictation, writing on blackboard)	glacier terrain

Table 4. *Cont.*

Authors	Research Methods and Tools		Teaching-Learning Strategies	Study Area Focus
	Qualitative	Quantitative		
[49]	research through design, reflection, focus group interviews, experience in the CIVE, audio and video recordings	-	collaborative learning	hypsography-contour lines principle
[50]	-	preparatory questionnaire (multiple-choice test), achievement test, app and worksheet evaluation test (only yes/no questions)	flipped classroom approach, active and collaborative learning, inquiry-based learning, textbooks, online teaching materials, educational games	remote sensing, Earth observation, landforms, agriculture
[51]	simultaneous triangulation, presence questionnaire (5-point Likert scale), student interviews, observation, video recordings	pre-test and post-test (academic achievement tests: 20 multiple-choice questions), statistical analysis	VR-based interactive teaching-learning environment vs. expository instruction methods, ASSURE instructional model	shape and movements of the Earth
[52]	knowledge test (paper-based mode, 3 structróured questions), semi-structured interviews (open-ended questions), qualitative triangulation	statistical analysis of the results of the knowledge tests	design-based research (DBR) collective, LIVIE (experimental manipulation, 5 inquiry-based learning phases) vs. conventional textbook-based approach	coastal process and landform
[53]	student response questionnaire, N-Gain Score test, ASSURE development model, practicality questionnaire	pre-test and post-test, Wilcoxon test, curriculum analysis, user experience analysis	immersive learning experience, constructivist approach	physical geography, earth's crust, volcanic areas, endogenous and exogenous processes
[54]	ASSURE Model, closed questionnaire (Lee and Owen model), Likert scale, validity tests	comparative tests (Arikunto formula, Aiken formula), instructional design test	virtual reality learning media, virtual reality instructional design	solar system, planet Earth as a living space
[35]	survey, Likert scale, semi-structured interviews, field notes, grounded theory, methodological triangulation of qualitative and quantitative methods	pre-tests, difference scores, post-scores, statistical analysis, factorial ANOVA, post-hoc tests	virtual vs. augmented vs. outdoor field trips, experiential learning	environmental studies, green spaces
[55]	online questionnaires, Likert scale, qualitative description research	descriptive analysis of learners' perceptions, distribution of frequency, percentage, and average	technology-based virtual reality learning media (MilleaLab)	geosphere phenomena, volcanoes, earthquakes

The compilation of the teaching-learning strategies applied in the empirical works reveals the main concerns regarding the use of VR-based technology in geography classes and provides a wide range of techniques depending on the specific focus areas. There are certain recurring elements, including collaborative learning, inquiry-based learning, discussion, and interactivity, which are regarded as the most effective elements of teaching and learning geography. Inquiry-based learning and, more especially, problem-based learning are often regarded to have the ability to "support or encourage the development of geographic knowledge skills, and practices" for instance, Bazargani, Sadeghi-Niaraki, and Choi quote [47] (p. 8) from the Report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education project [56].

The empirical works proved that VR-based learning environments can be used successfully and effectively for any focus areas of geography; therefore, its inclusion in the curriculum would be reasonable and progressive. For example, Chen and Chen highlight that the use of VR technology in learning about glacier terrains improved the learning outcomes [48]. Han points out that in a formal elementary school classroom, immersive virtual field trips give students a sense of being in a virtual space and provide a sense of realism [28]. Jerowsky highlights the benefits of reification to support environmental literacy [35], and Bazargani et al., in their case study on the application of a VR-based educational game for learning topology relations at schools, reveal that students gained higher scores in the post-tests [47]. Although some of the works [25,28,37,39–41] were not specifically geography-teaching centered, they used geography-related elements, references, and methods that also made these works eligible for inclusion in our review. These works also strengthened our notion that geography is closely related to all other sciences. As Lindner, Rienow, Otto, and Juergens also summarised, "Geography is the subject that brings other STEM subjects together to apply them to the real world and is thus chosen as the main subject to focus on" [50] (p. 14), and it confirms that geography implies a multidisciplinary approach with a special role in linking sciences.

3.1.4. Keyword Analysis

The 47 works use 179 keywords, of which 16 appear more than once; thus, the total number of different keywords used by the authors is 128. The most often occurring keyword is "virtual reality," used in 24 works, followed by "augmented reality" with 6, "education" and "geography education" with 5 appearances, while "geography" and "virtual field trip" appear 4 times each. The words "geo" and "VR" are used only in two works, while there is one occurrence for "geography teacher," "teaching geography," "cartography," "geographical learning," "geospatial," and "maps." The rest of the keywords (112) either focused on areas related to geography (such as STEM, remote sensing, field trips, hypsography, etc.), technology (such as virtually-rendered environment, VR support, CAD models, mobile devices, etc.), or methodology (such as formal education, innovations in teaching, academic achievement, collaboration, etc.) (Figure 9).

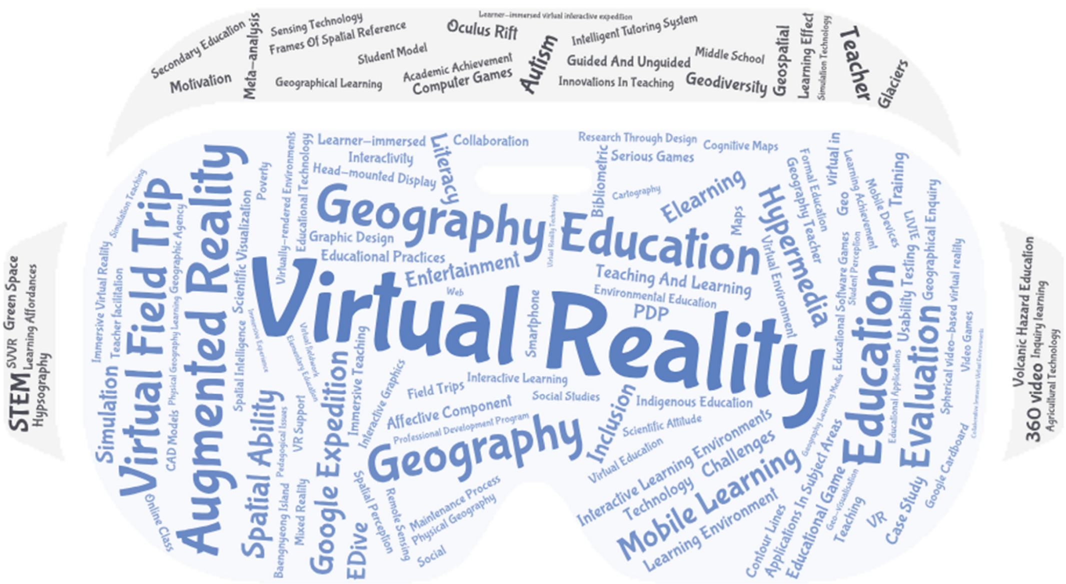


Figure 9. Word cloud (WordArt)—based on the keywords of the reviewed works (N = 179).

This relatively great variety of keywords reflects the versatility of the topic and its close links with specific areas. The analysis of keywords, however, confirmed our preliminary assumption that a simply keyword-based search might not be enough; there is not one pattern to follow, even in the case of the most closely related works. Therefore, in addition to the keywords, the analysis of words or expressions related to specific thematic aspects (such as the advantages/disadvantages of the use of VR) should result in more topic-relevant findings. These findings are discussed below (Section 3.2.4).

3.1.5. Co-Citation and Bibliographic Coupling Networks

The references made in studies can have a very strong time limitation—as works published earlier are more likely to be referenced than works published later. The time factor is, therefore, an absolute parameter that may limit the number of citations and co-citations. There is also a likeliness of geographical boundedness, as, for instance, geographical, cultural, or language similarities can make some works more well-known and widespread, thus making the so-called location factor more relative. We looked at the lists of referenced works in the 47 reviewed works and found that although there is a relatively great variety in the geographical origin of the works, some works are still more connected through the common references they used.

The total number of works cited in the 47 works analyzed in our systematic review is 1862, with a total referencing of 2085. Of these, 162 works are cited in at least 2 of the 47 works (Figure 10).

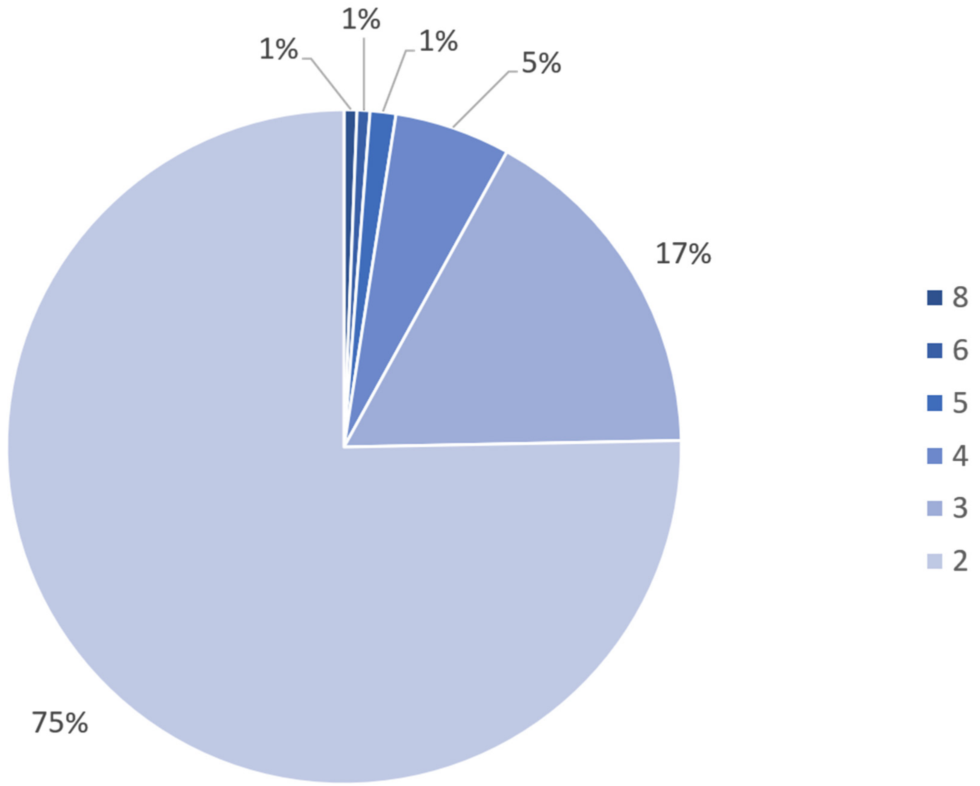


Figure 10. References appearing in 2 or more works (N = 162).

The number of reviewed works co-citing the same sources, at least in two cases, shows a great variety with no obvious limitations caused by the time factor. Han [20,28], Mikropoulos and Natzis [22], Di and Zheng [30], and Jerowsky [35] have 20 or more citations in common with the other reviewed authors. While Han [20,28] belongs to those authors who cite works that are also cited by others, with approximately 50% of the works cited by him being cited in one or more works, Yerowsky has a list of references with over 300 items [35], and thus proportionately that work has less in common with the other works. Six works use literature studies that are not found in any of the other reviewed works; thus, these seem to be isolated from the rest. Interestingly, the geographical origins of the authors of these six works show a great variety with no specific regions (United States [57], Mexico [58], Czechia [46], Cyprus [2], China [1], and Indonesia [55]), while there is a concentration in time (two-thirds of the being published after 2020) (Figure 11).

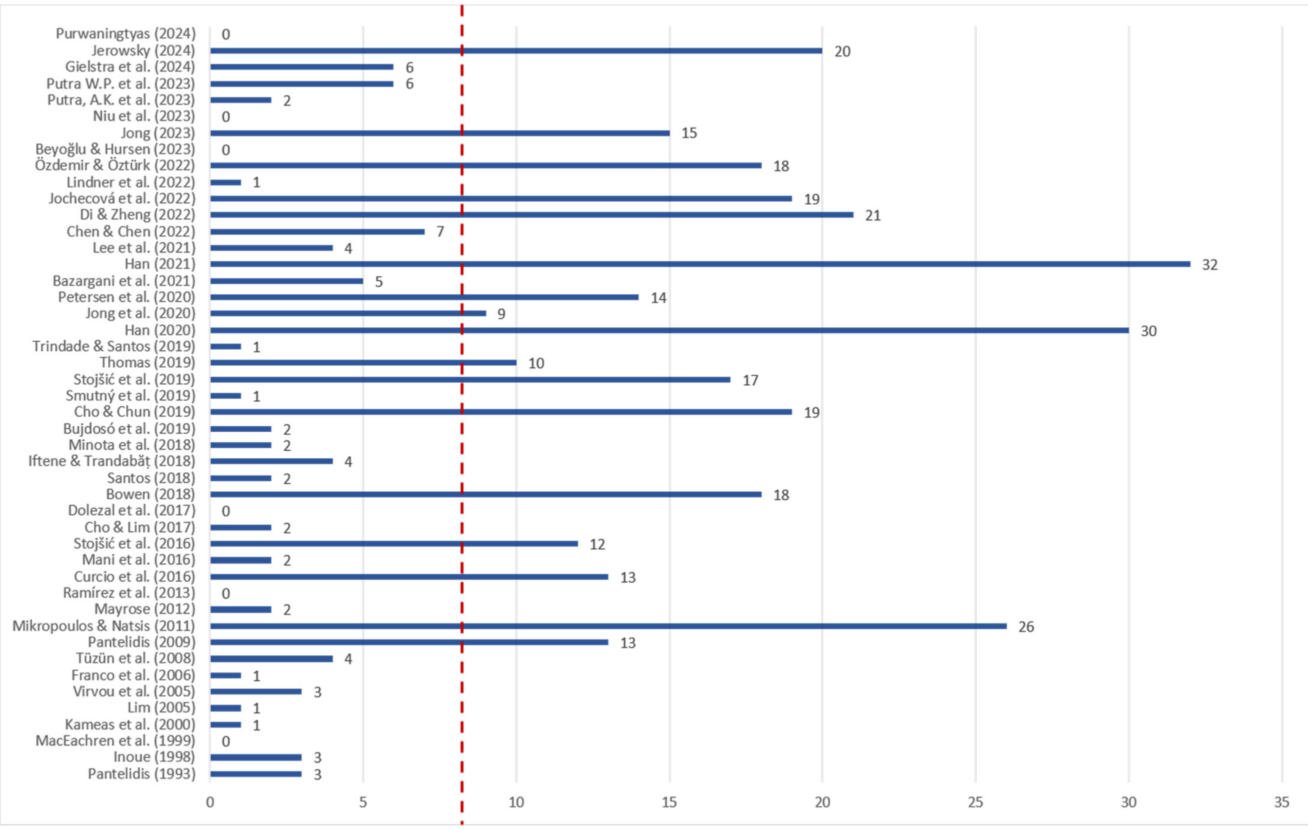


Figure 11. The number of literature items by reviewed works that are included in the bibliography of at least two reviewed works (bibliographic coupling) (red dotted line marks the average number of literature items) (N = 371) [1,2,8,17,19–37,39–55,57–62].

All references used in the reviewed works were collected in an Excel spreadsheet to find links between the works and to enable the detection of a network to see the influence of the various sources. Figure 12 shows the result of the Gephi out-degree ranking processing of the 1862 nodes (referenced works) and 2085 edges (references) (Figure 12).

The most often cited work—17.4% of the reviewed articles referred to it in their works [20,27,28,30,32,33,49,51]—is a meta-analysis on the effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education [63] by Merchant, Goetz, Cifuentes, Keeney-Kennicutt, and Davis written in 2014. The second most often referenced work was Winn's report on the conceptual basis for educational applications of virtual reality [64], which was quoted in six works [23,32,34,35,44,62]. Two of the references were cited in five works, one of which was an early work defining virtual reality [65] and a more recent journal article on the emotional value of immersive virtual reality in education [66]. Finally, approximately 20% of the reviewed works referenced the following: international virtual field trips as a new direction [67], evaluation of the effectiveness of combining software games with education [21], effects of computer games on primary school students' achievement and motivation in geography learning [8], learning affordances of 3D virtual environments [68], desktop virtual reality enhancing learning outcome [69], the experiential learning theory [70], immersive virtual reality field trips facilitating learning about climate change [71], a taxonomy of mixed reality visual displays [72] and the discussion of the potentials of virtual reality as the ultimate display [16]—of which two are included in the present review [8,21]. The time factor in this approach is not found relevant since the most often referenced works were published in 2014, 1993, 2018, and 1992, while the rest are also evenly shared in the years (1965, 1984, 1994, 2000, 2005, 2009, 2010, 2010, and 2018). As for the topics of the most often referenced works, they show a great variety specializing in the different aspects of the application of VR technology in education.

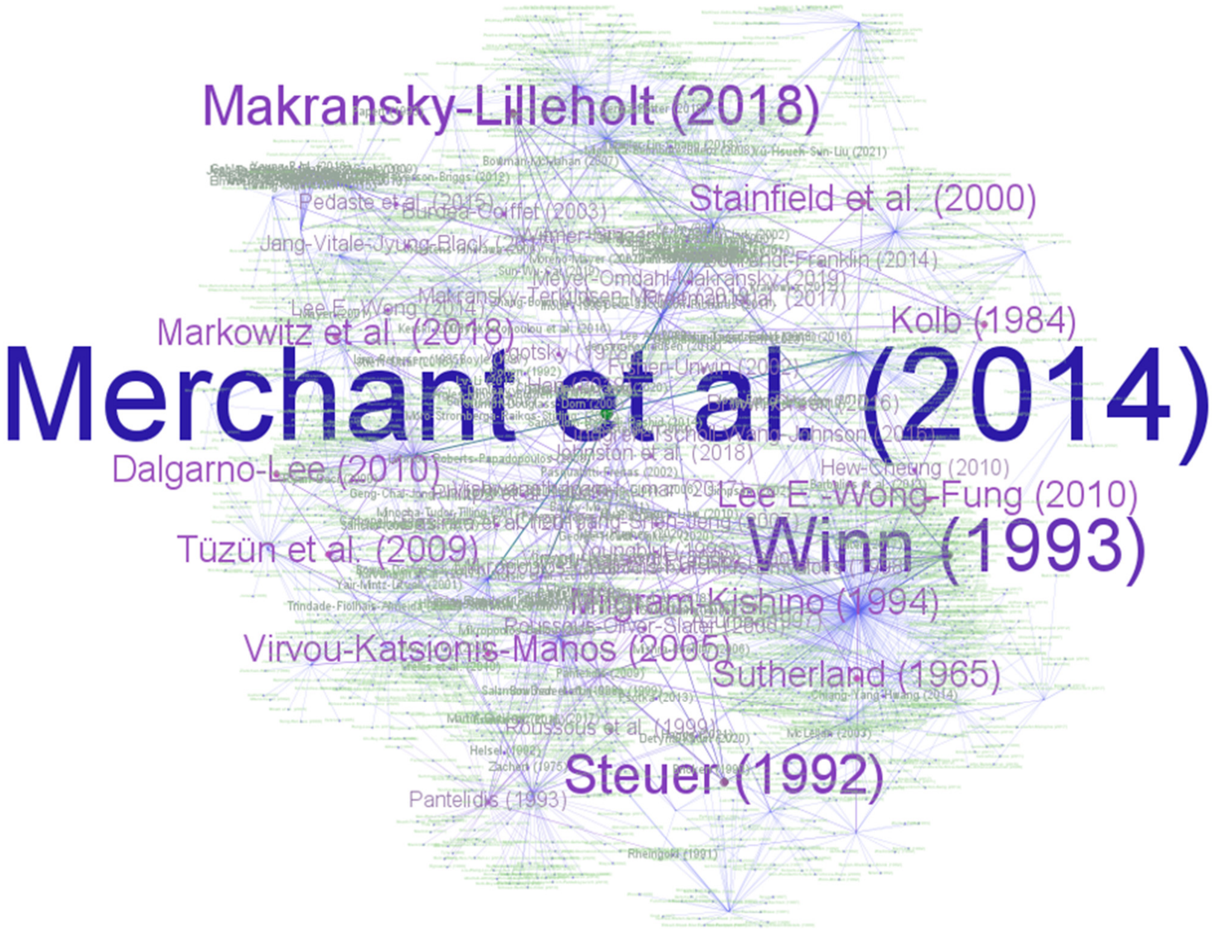


Figure 12. Bibliographic coupling network based on the reference lists of the 47 works reviewed (with names of authors and year of publication, exported from Gephi) (N = 2085). (The font colour and font size refer to the number of occurences. Blue—8, Shades of purple—6, 5, 4 and 3; Shades of green—2 and 1) [8,16,21,63–72].

Our analysis also showed that 14 works [17,20,22,24,27,28,30,33,44,49,51,54,59,62] have at least two references in common. In this case, we processed data for 162 referenced works (nodes) and 389 references (edges) using Gephi in-degree ranking (Figure 13).

Agreeing with Mérő that "Scientific publications form a network, some of which cite each other, others do not" [73] (p. 185), we decided to check on the strength of networking in the case of the reviewed works. Approximately 25% of the works had strong links, as they did not only use references for the same works, but they were even cited in the reviewed works. In this respect, the ten-year review paper of empirical research on educational virtual environments [22] and a conference paper discussing the teachers' perspectives in Korea [44] were the most active, with four references each, with the former being also referenced in another work [30], followed by two articles published in Q1 journals [51,54] with 2 references made in them to the reviewed works (Figure 14). All five works with more than one co-citation were published after 2010; thus, there is an obvious time limitation in this respect. The two most often, four times, cited works [8,21] were not only the most often read papers measured on ResearchGate but also had very high citations/reads values so that they can be regarded as the most influential work both in terms of the reviewed works and in general. Pantelidis [19] was cited in three works [22,44,62] included in our present review. There are two small groups of works that are not connected to the other nineteen works.

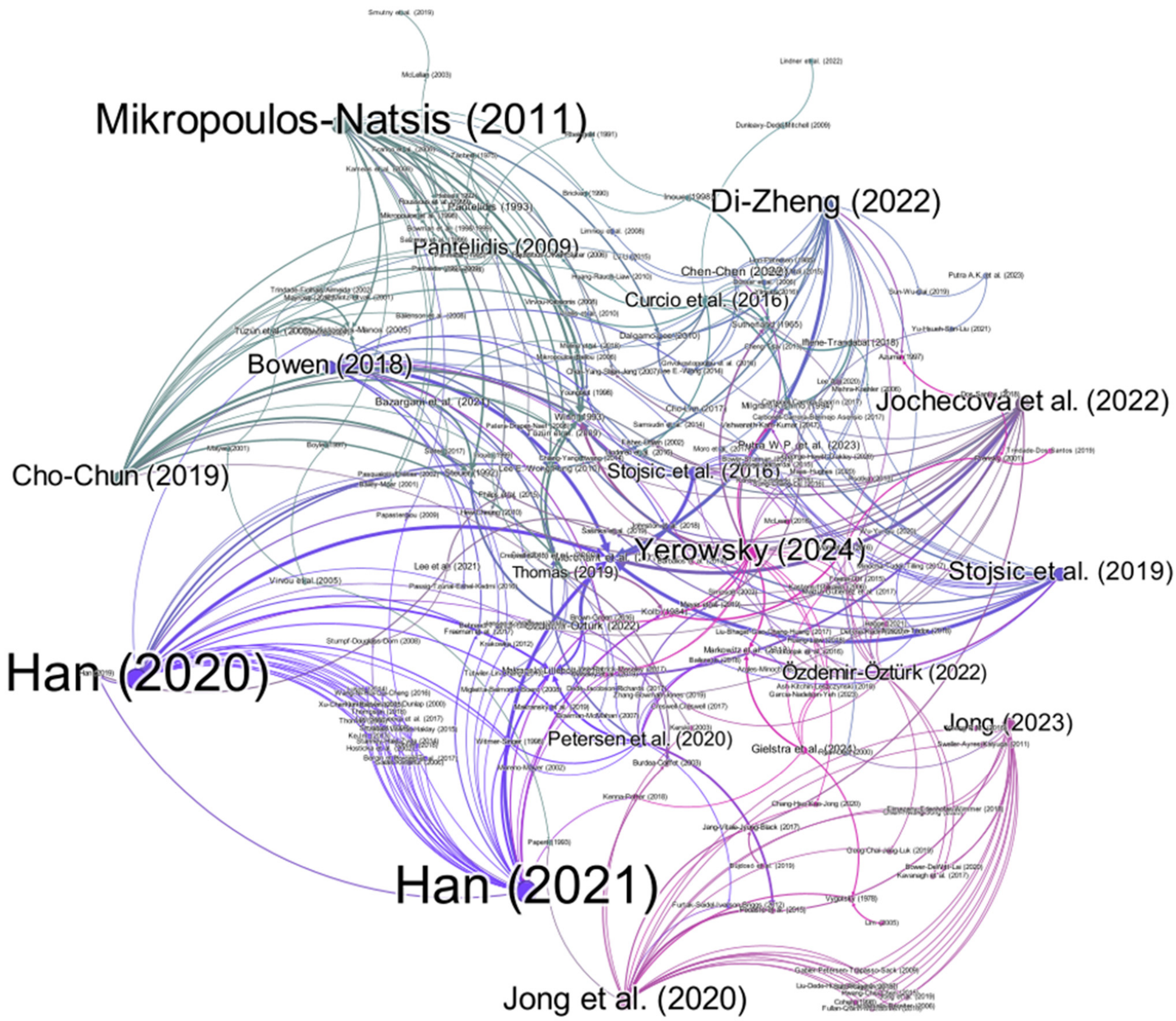


Figure 13. Co-citation and bibliometric coupling that appeared in more than 2 studies (including the referenced works) (with names of authors and year of publication, exported from Gephi) (N = 389). (The colour and thickness of the arrows refer to the number of references. Blue—8, Shades of purple—6, 5, and 4; Shades of green—3 and 2) [17,20,22,24,25,27,28,30,32–35,44,49,51,52,62].

The references listed in the forty-seven works show a great variety in terms of their year of publication and can be grouped into four distinctive periods that correspond with the milestones observed in the history of VR technology. The works included here do not necessarily belong to the literature on VR directly, but some of them may have relevance from the aspect or approach of the researchers that quote them; thus, they are indirectly related to the topic of VR (Figure 15).

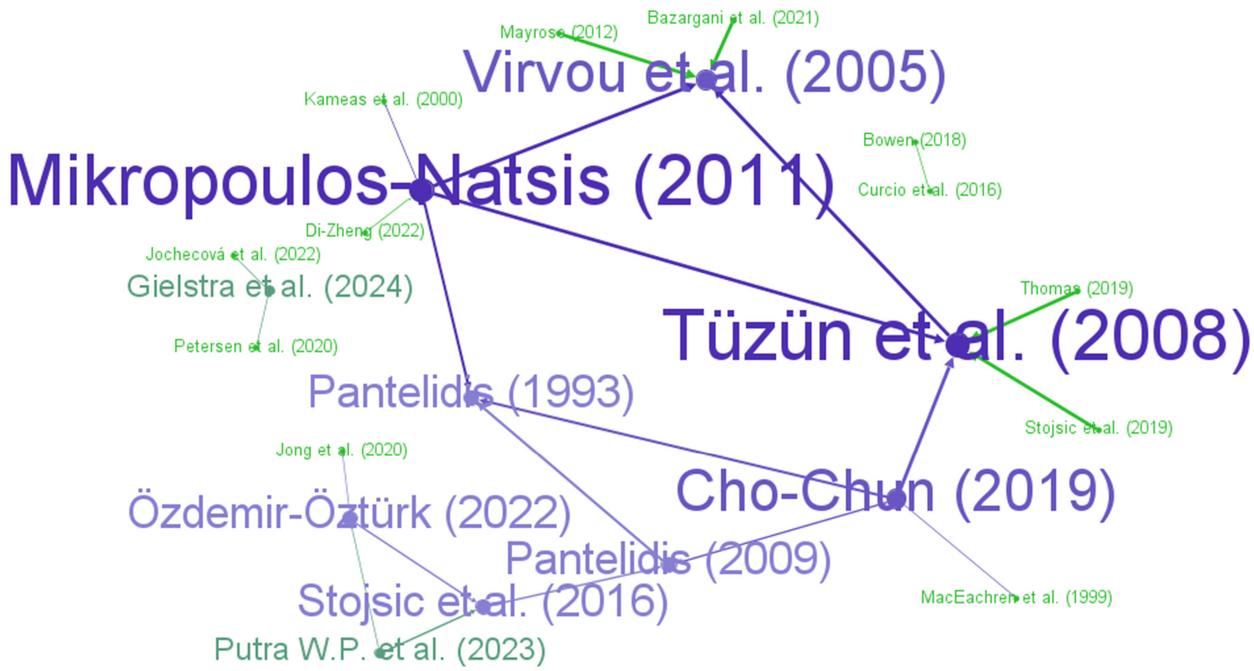


Figure 14. Bibliographic coupling among the reviewed works (exported from Gephi) (N = 12). (The colour of the arrows and text mark the source of references, and the thickness of the arrows and the font size of the text mark the number of references given to a work. Dark blue—5 links, Shades of blue—3 or 4 links, Shades of green—1 or 2 links) [8,17,19,21,22,24,25,27,30,32–34,37,40,42,44,47,49,51,54,59,62].

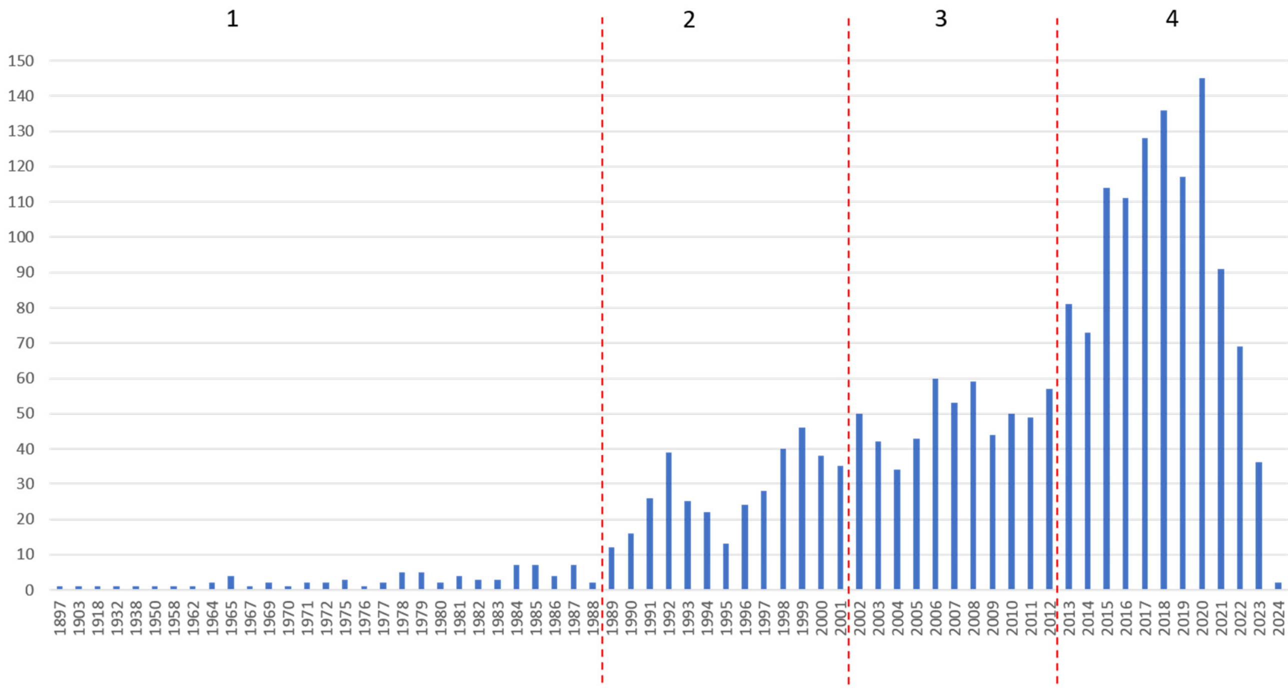


Figure 15. Number of referenced works by year (Legend: 1 = very rare appearance; 2 = initial interest rising; 3 = stability of appearance; 4 = increasing trend; the Phases are separated by the red dotted line; N = 1862).

Phase 1. Very rare appearance: the longest period (1897–1988) with a very wide range of topics, with even a futuristic dystopian novel included [15]. The number of referenced works is less than 10 per year.

Phase 2. Initial interest rose when the first company, which sold goggles and gloves for VR activities, was established. The number of works published between 1990 and 2001 is over ten, with two peaks in 1992 and 1999.

Phase 3. Stability of appearance: in the continuity of the consecutive years of publication with 30–60 related works each year. This may be interpreted as the result of the introduction of video games and consoles and the launching of the Google Street View maps when VR became more accessible to the public as well, which saw a rise in the number of related research studies.

Phase 4. Increasing trend: With the production of a wide range of equipment, more and more high-tech companies are joining the market by developing goggles and gloves (e.g., Facebook, Google, Samsung, Apple). The number of works exceeds 70 per year, most often (2015–2020) exceeding 110. The very low number of works cited from 2023 and 2024 is due to the limitation set by the time factor (shortness of time since their publication).

Our findings about the references and co-references used in the reviewed works confirm what we also read in the bibliometric analysis written by Beyoglu and Hursen in 2023 [2] regarding the field of geography, geographic information technologies, and education, that the number of publications and the number of citations has increased over the years.

3.2. Content and Contextual Aspects—Qualitative Analysis

3.2.1. Research Objectives

After a close reading of the works, we found that there is a great diversity of topics addressed by the researchers; therefore, we decided to set up categories to see whether we could find links between the works. The research goals defined by the authors focus on five main subject areas with an over 50% dominance of the topic of the application of virtual/mixed/augmented reality (VR/MR/AR) in education and its educational effectiveness (Table 5). The studies on (immersive) virtual field trips also have a high share, especially if we take into consideration that the first work focusing on the aspect of virtual field trips was published only in 2017. There is an increasing trend in this field of objectives, which can be related to the closing downs during the COVID-19 pandemic, resulting in a growing interest in the application of new methods for conducting fieldwork, as well as virtual field trips. An interesting fact is that the three doctoral dissertations reviewed all concentrated on the relevance of virtual field trips prior to the pandemic [33–35], highlighting the social backgrounds of the students.

Table 5. Categorization of reviewed works based on their objectives (N = 47).

Category	Research Objectives	Authors with Year of Publication	Share from Total
Education (E)	application of VR, MR, and AR in education (E1)	[17,22,31,32,36,37,40,42,45,46,49–55,60,62]	40.4%
	educational effectiveness of educational VR games (E2)	[8,21,23,39,47,58]	12.8%
Fieldwork (F)	immersive virtual field trips (VFTs) (F)	[20,24,25,28,29,33–35,41]	21.3%
Technology (T)	technological development (T1)	[2,19,57,61]	8.5%
	ability/readiness of teachers to integrate immersive/VR/AR/MR technologies (T2)	[27,44]	4.2%

Table 5. *Cont.*

Category	Research Objectives	Authors with Year of Publication	Share from Total
Spatial orientation (S)	improvement of map-reading skills (S1)	[38]	2.1%
	enhancement/improvement of spatial ability (S2)	[30,48]	4.2%
Methodology (M)	collaborative problem-solving and observation (M)	[1,26,59]	6.5%

The reviewed works in the nineties either focus on technological aspects or the application of VR in high school world geography education in technology or education. Then, in the first decade of the twenty-first century, education came into focus, with studies focusing on not only the possibilities of VR in education but also its educational effectiveness. The discovery of VR applications for virtual field trips gained an advantage in the second half of the 2010s, while there is less emphasis on educational effectiveness. Nevertheless, we also detected four research gaps with no signs of any changes occurring in the number of publications with the given objectives in sight, especially in the ten years between 2006 and 2016 (Figure 16).

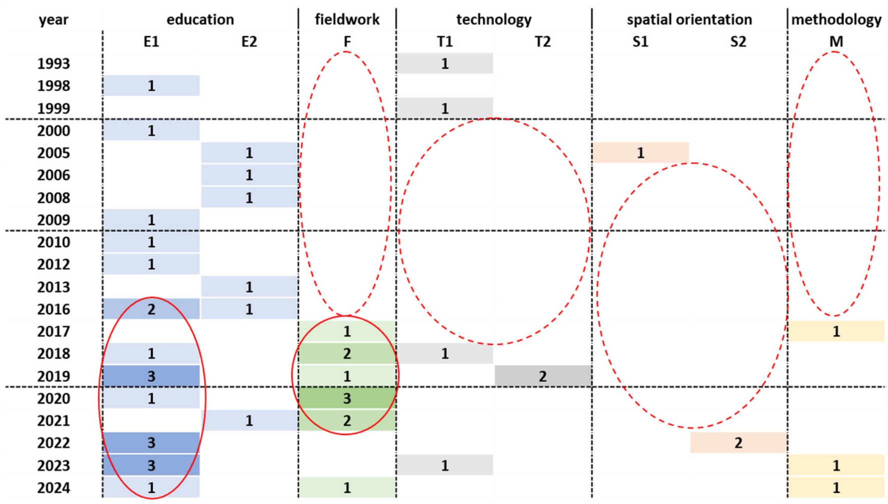


Figure 16. Categorization of reviewed works based on their objectives by year (N = 47) (Legend: solid red line: increasing trend, dashed red line: research gap; shades of blue: education, shades of green: fieldwork, shades of grey: technology, shades of pink: spatial orientation, shades of yellow: methodology).

The first investigation on the educational effectiveness of educational VR games, focusing on the gaming aspect, wants "to find out whether the gaming environment may improve education" [21] (p. 55), then later the "effectiveness of 3D interactive environments on learning, engagement, and preference" becomes the focus [40] (p. 13), while others intend "to provide a sound foundation for the increased integration of emerging technologies within traditional education sessions [23] (p. 1673)." The paper on the effectiveness of collaborative problem-solving (CPS) and collaborative observation (CO) using a virtual world as a learning environment offers a methodological approach and analysis that is unique of its kind [26]. Spatial abilities are also discussed in relation to the effectiveness of VR technologies, which offer a wide scale of features that may moderate the effect, as offered in a meta-analysis [30].

The possible distraction of children's attention is also addressed already in the early 2010s [58], while in the late 2010s, there is a growing interest in the influence of virtual field trips, for example, on middle-school students' social studies academic achievement and motivation [33]. The 2020s have already become a decade with the highest range of objectives set by the authors of the reviewed works. This confirms the belief that there is an increasing tendency regarding the use of VR technology in geography education [2]. The growing number of works on the methodologies and development processes of using VR in teaching [1,59] is a very important step towards the wider application of VR technology in geography education.

3.2.2. Demographic, Gender, and Social Background

Two-thirds of the forty-seven studies report on case studies involving students of all levels as well as teachers. Our review focuses on the application of VR in elementary (primary) and grammar (secondary, high) schools; the additional target groups result from the cross-all nature of ten reviewed works (Figure 17).

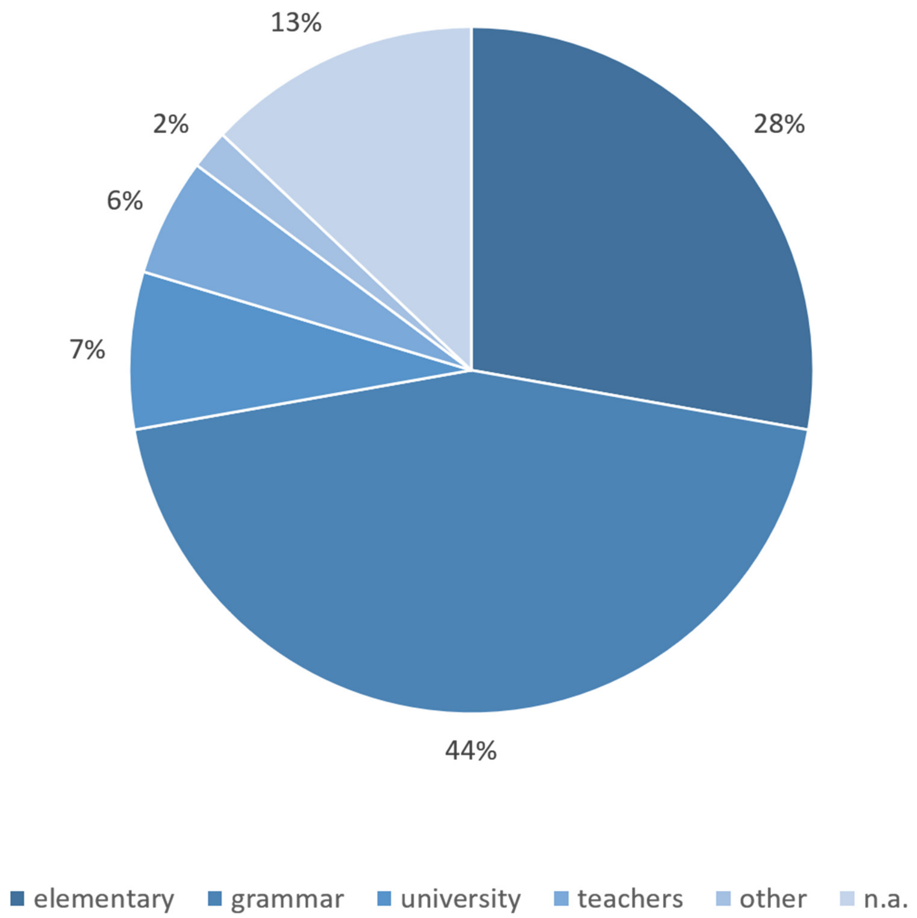


Figure 17. Samples of the studies by school type (N = 47).

As the age of entering secondary-level education varies by country, therefore we further broke down the total number of elementary and grammar/high school students into age groups (Figure 18). Based on that, we found that 45% of the empirical studies focused on Grade 9–12 students aged 15 and 19. The only study where we found a reference to the age-specific nature of the application of VR was the work by Bazargani, Sadeghi-Niaraki, and Soo-Mi-Choi [47]. Their study aimed at designing, implementing, and evaluating an immersive VR-based educational game that involved only 13-year-old boys based on their initiative tests, emphasizing that students younger than 13 years had difficulties in understanding topology relations and using the VR Learning Environment.

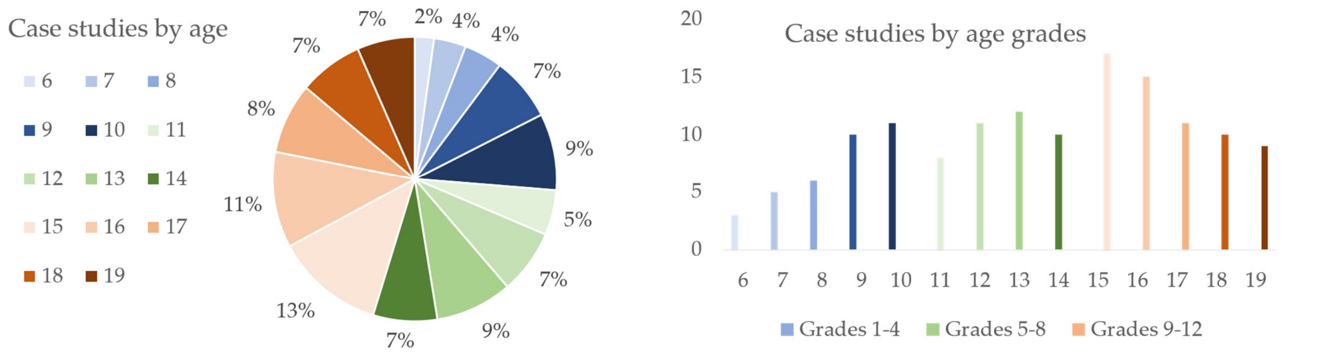


Figure 18. The number of works focusing on elementary and grammar/high school students by age group and grade (N = 30) (blue shades—Grades 1–4, green shades—Grades 5–8, brown shades—Grades 9–12).

Most of the works do not make a distinction based on gender; only 10 works specify the girl/boy or female/male ratio. In a Singaporean case study focusing on map-reading and spatial orientation, the author calls attention to the gender differences, claiming that male students—based on pre- and post-tests as well as interventions—performed better than female students [38]. The study set in Gilan (Iran) involved 37 boys and no girls at all [47], while in the case study set teaching the geography of New Zealand and Australia to students in Taiwan, the female students outnumbered the male students (experimental group: 29 and 9 respectively; control group: 28 and 10 respectively) [48].

Empirical research is conducted in a variety of economic circumstances and social backgrounds. On the one hand, Bowen, for instance, chose a district in a rural, economically depressed county in West Tennessee characterized by generational poverty, and the educational attainment for adults is below the state average [33]. On the other hand, the other end is represented by better-off areas, similar to a South Korean setting where the participating students attended a private elementary school, which means better financial conditions and easier access to equipment [20].

3.2.3. Applied VR Technology

All of the reviewed studies confirmed that the application of VR technology has become more widespread as a result of the development of its hardware and software facilities and their improving accessibility/availability. On the one hand, technological development is required for designing more VR-based educational applications. On the other hand, it is true vice versa. Designing an increasing number of VR-based educational applications and software results in an increasing demand for accessible technological devices. Thus, they generate mutual development and improvement, and this is why it is essential to focus on these two components equally in related research as well.

There is a great variety of information and communication technology (ICT) devices that make VR more integrable in geography education. We found that, in total, 32 specific devices were mentioned or referred to in 70% of the works. Most of them are goggles or head-mounted displays (Google, Samsung, Sony Oculus, HTC, etc.), and they appear 40 times in total. It is very interesting, however, that their first mention appears only in 2016. Prior to 2016 (12 works), the only devices mentioned were televisions [36], networked tablets/laptops/PCs [8,19,37,39,40], with one of the works also referring to the related use of tape recorders, video cameras, microphones, and webcams [37]. Four works referred to monitors and/or televisions with a dominance of televisions as a potential means of enabling VR technology for classroom use. In altogether 18 works, VR is associated with viewers, headsets, or head-mounted displays, the most popular being the Google Cardboard goggles, which are admittedly the cheapest solution for classroom use. The works reviewed strengthen our presupposition that the rapid development of VR devices can have a positive and encouraging impact and may indeed contribute to an accelerated spread of the application of VR in geography education. Several head-mounted displays have been developed in the past decades to provide the most immersive VR experience, with companies developing goggles for public use. “In a review of 21 studies on the use of HMDs in education and training, Jensen and Konradsen (2018) [74] found that although HMDs created a sense of presence and were useful for learning cognitive, psychomotor and affective skills, HMDs offered no advantage over less immersive or traditional instruction or were even counterproductive in other situations [20] (p. 423).” We found that smartphones (also from 2016), tablets, laptops, and PCs connected to networks (from 1993) are the most frequently mentioned ICT devices in relation to the application of VR technologies in geography education.

The reviewed works list and application of a wide range of VR education software and games for educational purposes. In addition to the VR software already on the market, some authors design, implement, and evaluate software that they develop themselves for educational purposes [8,19,37,39,40].

Some of the authors reflect on using VR applications designed by themselves specifically for educational purposes [23,26,49], while others use applications (e.g., QuickTime VR) and video games designed for public use (e.g., River City), serious or educational games (e.g., Appalachian Tycoon), more general and well-known VR teaching tools (Google Expeditions), web mapping platforms and consumer applications (Google Maps), or simulators (e.g., VR ENGAGE, MEteor). The applications and games most closely related to the topic of geography are collected in Table 6 in a timeline order with references to the specific field of geography they can be used for.

Table 6. Application for teaching geography mentioned or used by the authors of the reviewed works (N = 32).

Authors	Application	Type	Area of Science	Referenced Work
[19]	NASA Visualization for Planetary Exploration Project	-	to explore planets	-
[38]	QuickTime VR	cylindrical panorama	orientation	-
[21]	VR-ENGAGE	educational game developed by the authors	geography	-
[8]	VR-ENGAGE	designed for teaching geography to fourth-grade students	navigate through a virtual environment while answering questions related to geography	[21]
	Quest Atlantis	educational game	“Global Village” virtual world, world geography	[75,76]
[62]	Virtual Playground	-	-	[77–79]
[22]	River City	-	-	-
	PUPPET	-	-	-
	ancient city	-	geographic characteristics	-
	Active Worlds	-	students and teachers from Holland and Italy use the chat tool to construct cultural houses in a multi-disciplinary content	[80]
	Appalachian Tycoon	-	the students must maximize both economic and environmental benefits	[81]
[40]	Motions and Forces	virtual environment	Newton’s law of gravitation	-

Table 6. *Cont.*

Authors	Application	Type	Area of Science	Referenced Work
[17]	Desktop VR Earth Motion Systems (DVEMS)	-	astronomy, earth rotation, and related topics	[82]
	Dr. Friction	multiplayer educational game	'motion' and 'forces'	[83]
	VR-ENGAGE	game with 3D avatars	geography	[84]
	River City	VR game	history-sociology-geography	[85]
	FreshAir	-	environmental	-
	Alien Contact	AR game	current events, such as energy crisis, oil shortage, global nuclear threat	[86]
	SMALLab (Situated Multimedia Arts Learning Lab)	MR environment	earth science education	[87]
	MEteor	simulation game	how asteroids move	[88]
[23]	Stop Disasters!	serious game	preparing for disasters	-
	Sai Fah: The Flood Fighter	bespoke game	as a response to devastating floods	-
	"St. Vincent's Volcano"	serious game developed by the authors	-	-
[32]	Google Cardboard	visualization	VR version of Google Earth	[89]
	Google Expeditions	to take students to virtual field trips	more than 200 expeditions available (e.g., Astronomy; The Solar System; International Space Station; Earth Timeline; Rocks, Minerals, and Gems; Fossils)	[90,91]
	Google Street View	provides stereoscopic view	cities, world sightseeing places, nature, museums, and galleries can be explored with this mobile app	[90]
	Titans of Space; View-Master® Space; Mars is a Real Place VR; Star Chart VR; StarTracker VR	-	mathematical geography	-
	EON Experience AVR	gamified educational contents	Planetarium, Earth Continents, Earth Tropics, Earth Oceans, Arizona Crater as well as numerous VR video materials from different countries.	-
	Sites VR	-	sightseeing religious objects, archaeological sites, museums, fortifications, and nature	-

Table 6. *Cont.*

Authors	Application	Type	Area of Science	Referenced Work
	Cardboard Camera	to capture 360° panoramic images.	contents about the local environment, fieldwork, or excursions	-
	YouTube—360° Videos; Discovery VR; View-Master® Destinations; VR Cities; Ascape	-	-	-
[26]	not named—developed/designed by the authors	software developed by the authors	calculating bearings and compass directions	-
[41]	Google Expeditions	to take students to virtual field trips	virtual field trip	-
[33]	Google Expeditions	to take students to virtual field trips	virtual field trips	-
[42]	GeoAR	game developed by authors	geography of Europe (countries, capitals, flags, and neighbors)	-
[61]	Aumentaty Author	to create augmented reality content	-	-
	LandscapAR	to create intriguing islands and terrains	-	-
	Google Maps	-	-	-
	Google Street View	-	-	-
	GeoGuessr	geography game	to guess locations from Google Street View imagery	-
[60]	MaxWhere	immersive VR environment	geography of the Lake Balaton	-
[44]	Google Street View	-	-	-
	Google Earth	-	-	-
[31]	Hoover Dam: Industrial VR	educational VR application	a documentary-style approach with visuals of the dam and powerhouse	-
[46]	-	generic immersive virtual environment for multiple users (CIVE)	cartography, topography	-
[20]	Google Expeditions: (1) San Diego Zoo, (2) Reef Sharks	-	over 500 3D field trips	-
	River City		a science simulation with multiple users communicating and interacting in virtual worlds	[92]
[25]	Explorer	mobile application	virtual field trip	-

Table 6. *Cont.*

Authors	Application	Type	Area of Science	Referenced Work
[24]	a documentary called "This is Climate Change: Melting Ice"	immersive VFT, a 360° noninteractive IVR video	VFT to Greenland: to witness the melting ice sheets and explore the consequences of global warming	-
[47]	IVREG	an educational game designed by the authors	topology relations	-
[28]	Google Earth	to develop VFTs using 360-degree panoramas and helicopter views	to describe how people lived in cities around the world and explain the similarities and differences in life in different cities	[93–95]
	Google Map			
	Google Expeditions	-		-
[29]	PTGui	software to attain a panoramic image	geology	-
	KrPano	panorama viewer	geology	-
[48]	VALID (Virtual Reality Assisted Learning Device)	software developed by the authors	New Zealand and Australia; glacier terrains	-
[49]	eDIVE	a platform for collaborative learning and teaching in virtual reality designed by the authors	hypsography	-
[51]	not named—developed/designed by the authors	-	shape and movements of the Earth	-
[50]	an AR app designed and developed by the main author	-	-	-
[52]	EduVenture-VR	web-based platform (composer, explorer, retriever)	coastal processes and landform	[96,97]
[53]	GeoVirtex—designed by authors	interactive virtual technology application	earth's crust, process of volcano formation, endogeneous and exogeneous processes, impacts on human life	-
[55]	MilleaLab	a cloud-based all-in-one VR platform	geosphere phenomena: volcanoes	-
[35]	Camosun Bog 360°—developed by author	virtual tour panoramic photography and video	environmental education: green spaces	-

The above-listed 63 applications/software (some popular ones used or referred to in more than one work) can be used for various areas of teaching geography, from physical geography to social and economic geography. One of the biggest advantages of these software programs is that they can be used regardless of geographical location while providing access to any geographical location.

3.2.4. VR Advantages and Disadvantages: Possibilities vs. Limitations

The theoretical works and the systematic reviews included in our paper, in most cases, discuss the positive and negative aspects of the application of VR in the classrooms. They highlight a wide range of emotional and pedagogical as well as physical and practical issues. Empirical studies often draw conclusions regarding the positive and negative experiences related to the application of VR technologies in geography education. All of these can be further broken down into two basic categories, namely the device-based (such as the availability of devices, knowhow, openness) and the methodology-based (such as the classroom, personal, and social) advantages and disadvantages (Figure 19).

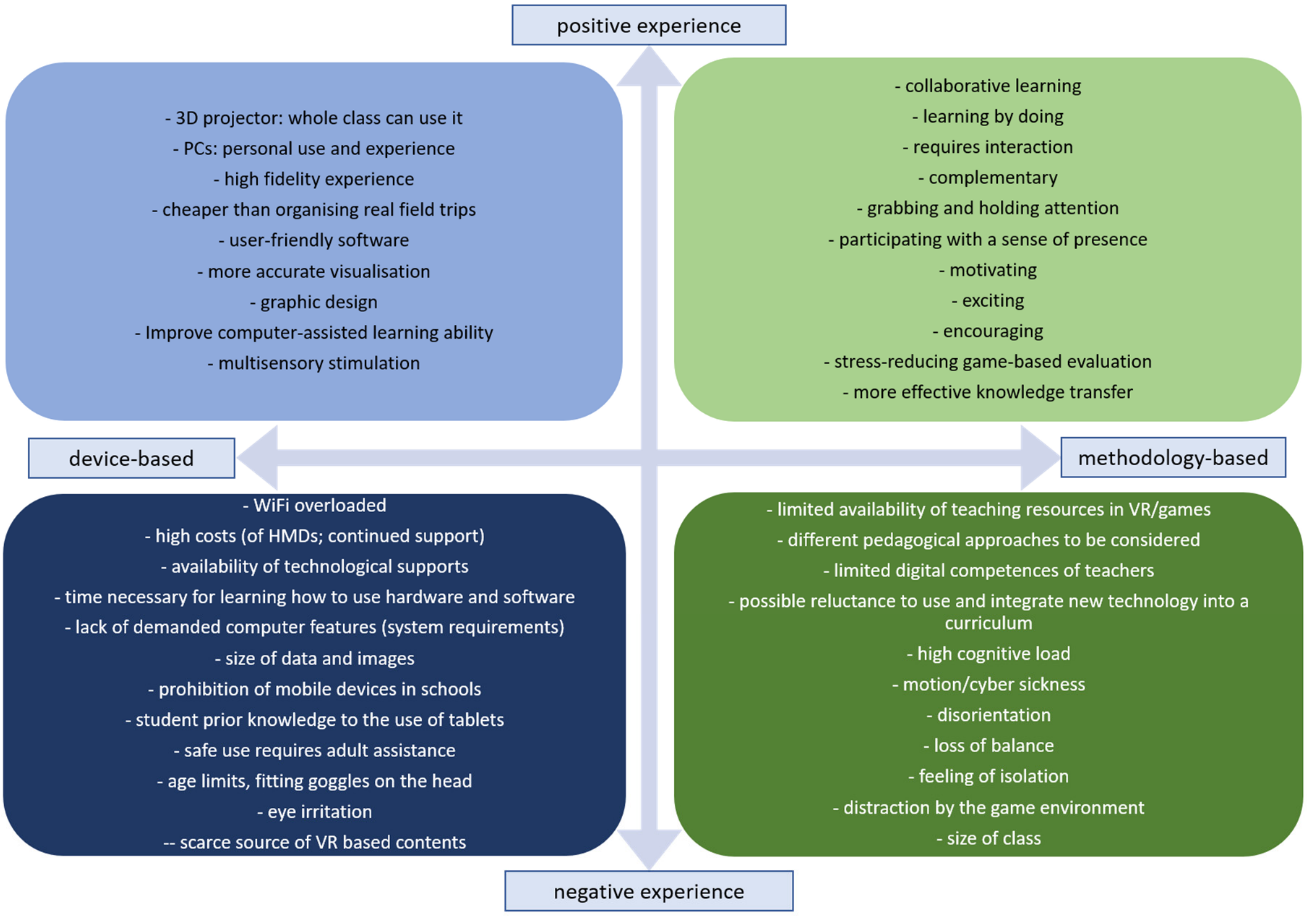


Figure 19. Positive and negative effects (advantages and disadvantages) of the application of VR in classrooms based on the full texts of the reviewed works (N = 47).

Our discussion based on the advantages and disadvantages of the application of VR in geography education includes not only the case study results performed by the reviewed authors but also their findings based on their own literature analysis.

We manually collected those words and expressions in the reviewed works, which were used in the discussion of the impacts of the application of VR in education, and based on that, fifty words and expressions were selected which are used in more than one work in relation to the positive impacts of the application of VR in education. The most frequently occurring words and expressions used by the authors for discussing the advantages and pros include “motivation” (154), “effective” (126), “improve” (119), “interaction” (101), “benefit” (93), “learning outcome” (85), “effectiveness” (76), “explore” (72), “improvement” (69) and engagement (50). Ten of these words are used in relation to the positive impacts of the application of VR in education in more than 20 works: improve (31), motivation (31), interaction (29), effective (29), benefit (27), effectiveness (23), learning outcome (23), explore (21), motivate (21), and engagement (21). The total number of words used for positive impacts is 1696 (Figure 20).

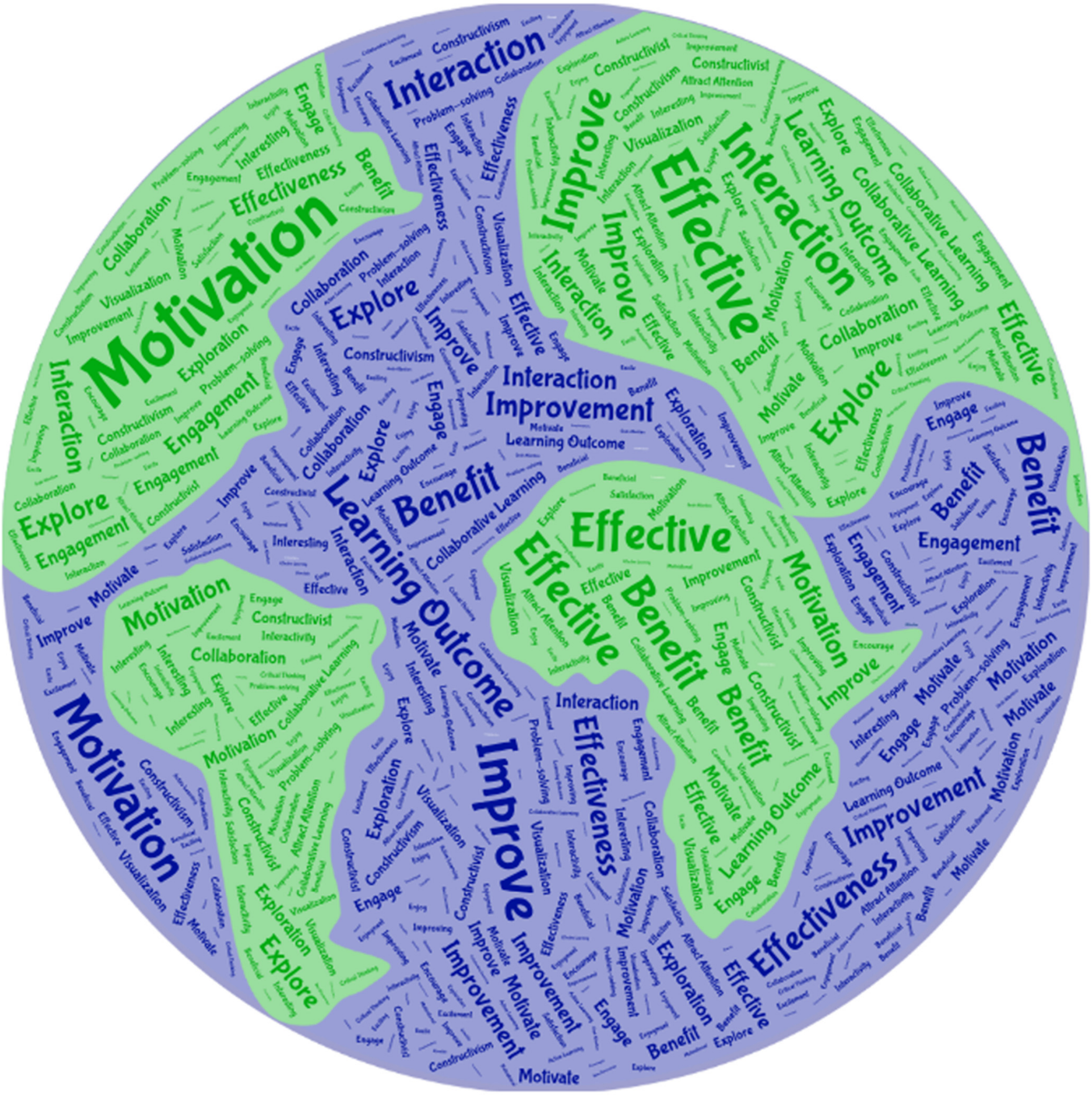


Figure 20. Word cloud of the appearance of words related to advantages and positive opinions about VR in the reviewed works (N = 1696).

The highest number of positive words related to the advantages of VR is 114 in total, which can be found in Jerowsky's doctoral thesis [35]. The most often occurring word is "effective" (24 mentions). The review by Mikropoulos and Natzis [22] also uses as many as 107 words in relation to the advantages of VR in geography education. Bowen, in 2018, is also among those authors who use positive words and expressions in the highest number (97), and she finds that VR plays an important role in "motivation" (27 mentions) [33], similar to Tüzün and his colleagues who also prioritize the motivation (12) effect of the application of VR in geography education [8]. The most often occurring word in one work is "improvement," which is used 35 times [21], referring to the positive impacts of applying VR in education, and Chen and Chen also use the related word "improve" in a high number (24 mentions) [48]. Cho and Lim found VR "effective" (21 mentions) and the impact of VR on "collaborative learning" (13 mentions) as especially important [26]. The word "benefit" is also rather often associated with VR [20–22,28,34]. Interestingly, doctoral dissertations and reviews are mostly the ones that use the highest number of positive words and expressions (Figure 21).

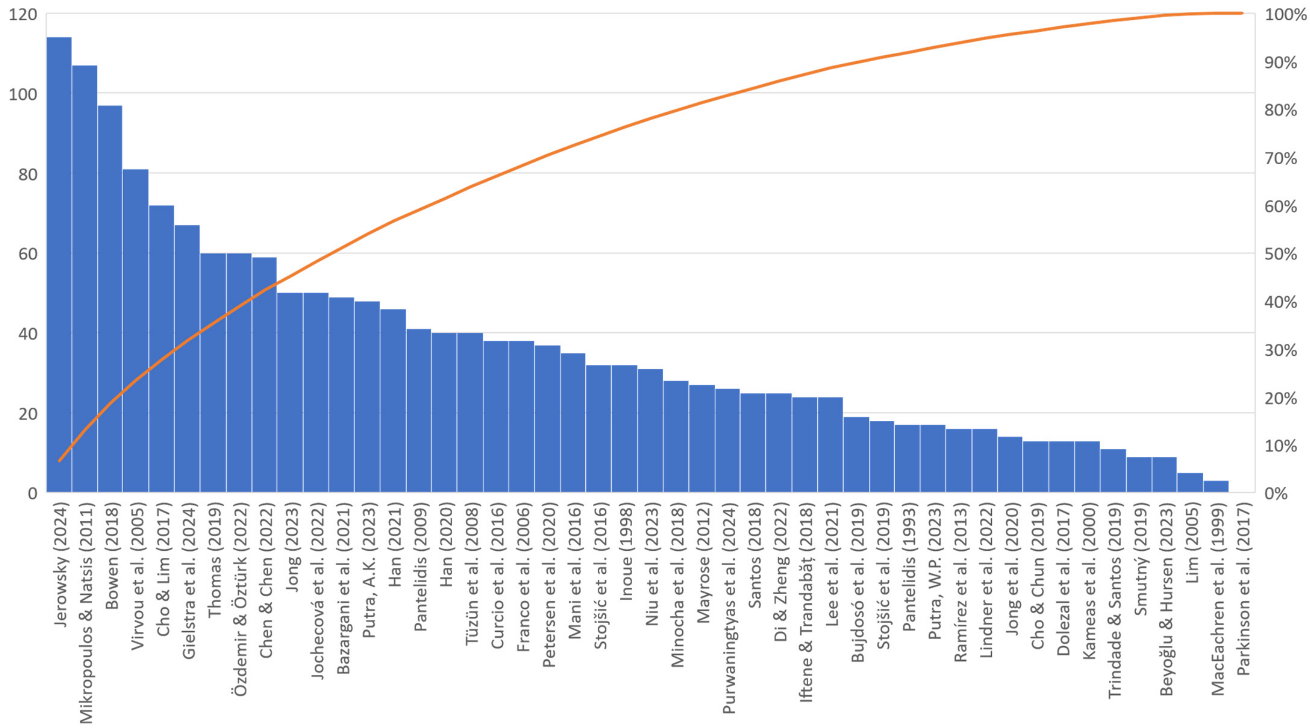


Figure 21. Number of mentions of positive (or related) effects of the application of VR in education (N = 1696) [1,2,8,17,19–55,57–62].

Seven of the authors use at least 20 different words or expressions in relation to the positive impacts of VR in education: 27 [22], 23 [62], 23 [47], 22 [33], 21 [21], 21 [35], and 20 [39] out of the selected 50.

In their review, Mikropoulos and Natsis [22] refer to the highest number of words regarding the advantages (27 out of 50), focusing mainly on the "learning outcomes" (24 mentions). They also refer to the "constructivism" approach very often (16 mentions) which they regard as a positive pedagogical approach. Their empirical review concentrates on the works about educational virtual environments between 1999 and 2009; therefore, this can be interpreted as a positive experience of the application of VR in the early 2000s.

Pantelidis focuses on the advantages and disadvantages of using VR in education and training and presents a model to help teachers, instructors, and educators decide whether to use it. The great number of pros and contras listed in her paper can be used as a guideline for all who are considering the use of VR [62].

Bazargani and his colleagues emphasized the motivation role of VR and the benefits related to the teaching-learning process "by enhancing motivational activities that lead to more effective learning" [47] (p. 6). As they conclude in their work, "benefits from the integration of emerging technologies would make teaching new courses fascinating enough at school [47] (p. 14)".

For Bowen, the words "motivation," "improve," "engage," "collaboration," and "explore" are the most frequently used words when discussing the effects and advantages of VR on the achievement of middle-school students [33].

Virvou, Katsinosis, and Manos [21] relate the words "improvement," "benefit," and "effectiveness" to the evaluation of the impacts of VR on education.

Jerowsky, in her doctoral thesis, compares the effectiveness of VR, AR, and traditional field trips and, in many cases, finds the VR method "effective" and states that "it may improve the students' connection to nature when compared to AR field trips [35] (p. 138)." She also lays great emphasis on the "benefits" and the "motivation".

Franco, Cruz, and Lopes mostly use the words "effective" and "improve/improvement/improving" in relation to the application of VR in education in general. They highlight that using this technology has an overall positive impact, emphasizing that "Also students had fun creating interactive interfaces, improving their knowledge through collaborative work, and using Web based standard languages." [39] (p. 5) and at the end of their work, they conclude that a complex improvement can be observed: "The results of the project include an improvement in educators and children's literacy, communication skills and competencies, and contributed to enhancing their mental models and spatial cognitive abilities [39] (p. 8)".

We also looked at the disadvantages and negative opinions about the application of VR technologies in classrooms and found some common points. Approximately two-thirds of the authors (32 works) claim at some point in their works that VR technology is not necessarily applicable for classroom use. We collected their contras based on the nature of their criticism and grouped them into four collective categories (technological, methodological, social, and medical) (Table 7).

Technological problems are mentioned most often as hindrances to the widespread of VR applications in education where the lack of demanded computer features (system requirements) [23,25,28,32,35,50] and the lack or overloading of WiFi [20,32,34,35,50] are referred in most cases. The second most often named problems are related to the methodological field, including problems such as the limited availability of teaching resources [35,44,47,54] and possible reluctance to use and integrate new technology into a curriculum, as well as limited timeframe [8,33,54,62]. Motion sickness [17,35,46,48,53] is the most often occurring disadvantage among medical issues. The expensive nature of devices and applications [25,32,34,45,62] means the greatest concern in terms of social obstacles—and this problem seems to be geographically the most widespread. Interestingly, at the dawn of the introduction of VR in education, Inoue in 1998 quoted Regian, Shebilske, and Monk [98], who recommended VR for instructional technology for three reasons, the third being "(3) VR may one day prove to be an extremely cost-effective interface for stimulation-based learning. [36] (p. 8)".

Jerowsky mentions the highest number (altogether 11) of limitations and disadvantages that can be encountered when using VR in geography education, more specifically in virtual field trips. She discusses five different issues that are part of the technological disadvantages and limitations, which include WiFi and Internet accessibility, lack of demanded computer features, and availability and quality of devices. Motion, cyber sickness, and other possible health effects are also mentioned as belonging to the medical disadvantages, and as far as the social factors are concerned, she names low social interaction as a disadvantage. The most often mentioned methodological problems of the limited availability of teaching resources and the prohibition of mobile devices in schools also appear in her thesis [35]. Three works name as many as seven different types of disadvantages [20,28,32]. The referred problems that we encounter in [32] include cybersickness, overloaded WiFi, limited digital competencies of teachers, lack of demanded computer features (system requirements), adults being necessary for use, prohibition of mobile devices in schools, and high costs. In both of his works, Han [20,28] emphasizes many of the disadvantages. In 2020, he mentioned cybersickness, overloaded WiFi, age limitations, processing of study materials, participant number limitations, being too complex to intake, and social factors. For instance, he observes that the enhanced presence of elementary school students is not positively related to their perceived learning, but they find it too complex and require more explanation [20]. In 2021, he also mentioned disorientation, possible health and safety effects, psychological side-effects (addiction, confusion about reality), eye damage, lack of demanded computer features (system requirements), technical malfunctions, and low social interactions [28]. The high costs related to VR are often mentioned as a hindrance; in addition to the above, Mikropoulos and Natsis, in their review of empirical research in educational virtual environments (EVEs), report on three studies [22] where the authors claim no positive impact of VR on learning outcomes [99–101].

Table 7. Limitations and problems related to the use of VR in classrooms. (Legend: blue: 1990s, yellow: 2000s, grey: 2010s, green: 2020s).

Authors	Technological	Methodological	Social	Medical	Total
[36]			1		**1**
[37]	1				**1**
[21]		1			**1**
[39]		1			**1**
[8]	1	1			**2**
[62]			1	1	**2**
[22]		1			**1**
[58]		1			**1**
[17]				1	**1**
[23]	1				**1**
[32]	1	1	1	1	**4**
[26]		1			**1**
[33]	1				**1**
[42]	1				**1**
[43]	1	1	1	1	**4**
[44]	1	1			**2**
[27]	1				**1**
[34]	1		1		**2**
[46]	1			1	**2**
[20]	1	1	1	1	**4**
[25]	1		1		**2**
[24]		1			**1**
[47]		1			**1**
[28]	1		1	1	**3**
[29]		1			**1**
[48]	1			1	**2**
[30]		1			**1**
[50]	1				**1**
[51]	1			1	**2**
[1]		1			**1**
[53]				1	**1**
[54]	1	1			**2**
[35]	1	1	1	1	**4**
Total	**19**	**17**	**9**	**11**	**56**

Based on our findings regarding the changes in the approach of disadvantages in time, it may be concluded that the technological and methodological issues addressed dominate each decade, social issues appear proportionally, while there is a slight increase in the medical issues as we approach the present.

3.2.5. Main Findings and Recommendations

Based on the above analysis and the conclusions drawn by the authors, we agreed that the reviewed works can be grouped according to their approach to the application of VR in education. The original grouping also included the category of a doubtful/pessimistic approach, but later, it was removed as no work was found that could have been regarded as merely pessimistic in its tone regarding the application of VR in geography education. More than half of the works have an obvious and clear, optimistic approach regarding the present and future application of VR technologies in education. Certain signs of doubt or doubtful attitude are observed in one-third of the works, while no obvious reference related to this issue is made in five works (Table 8). The doubts and slightly pessimistic attitude are mostly observed in the review type of works, which are based on the comparative analysis of many other works representing a great variety of findings.

Table 8. The attitude and approach of the authors regarding the application of VR in education (the respective shares from total and sub-total are given in brackets) (Legend: T: theoretical, E: empirical, R: review) (N = 47).

	Enthusiastic/Optimistic (55.3%)	**Enthusiastic/Optimistic but Also Doubtful/Pessimistic (34.1%)**	**Not Applicable (10.6%)**
1990s (66.7%–0%–33.3%)	T: [19]	T: -	T: [57]
	E: [36]	E: -	E: -
	R: -	R: -	R: -
2000s (33.3%–16.7%–50%)	T: -	T: [62]	T: -
	E: [8,37]	E: -	E: [21,38,39]
	R: -	R: -	R: -
2010s (73.3%–20%–6.7%)	T: [58,60]	T: [61]	T: -
	E: [26,27,33,34,40,42,43,45]	E: [23,44]	E: [41]
	R: [22]	R: [17,31,32]	R: -
2020s (52.5%–47.6%–0%)	T: [1,59]	T: -	T: -
	E: [25,29,46–48,51,52,55]	E: [20,24,28,35,49,50,53,54]	E: -
	R: -	R: [2,30]	R: -

In addition to evaluating their own findings, most of the authors also recommend future research directions related to the application of VR technologies in education; however, we found no such recommendations in 19 works. Those who provide us with suggestions also list the limitations experienced during their research and the lessons learned, which they will try to avoid next time (Figure 22).

In the empirical review by Mikropoulos and Natsis we find eight methodological recommendations for empirical studies in EVEs (need to "understand how EVEs technology will aid the basic learning process", "to study perceptual features, individual factors, content characteristics, interpersonal, social and cultural context", a need for "longitudinal studies", "larger samples", "methodology of educational research in EVEs", "a systematic effort and more empirical studies in order to show how the characteristics and features of EVEs can be pedagogically exploited", and "a goal-based scenario approach in EVEs" [22]). Mayrose also calls attention to the need for longitudinal studies, larger samples, and a goal-based scenario approach, but he also says that future studies should also be performed individually. In addition, Mayrose also highlights the need for "3D content developers", "additional 3D interactive software to be developed", "additional teachers to be trained in the use of this new technology", and even more specifically, he emphasizes that "a major push from educators with a desire to implement this type of educational technology in the classroom is needed [40]". In her doctoral thesis, Yerowsky made very practice-oriented recommendations, including calls for the reconsideration of policies restricting the use of personal devices, the offer of professional development to support teachers implementing VR and AR in the classroom, the improvement of school access to high-speed internet to support the use of immersive technologies, or to create a shared resource pool where schools and classrooms can borrow or lease VR equipment [35]. Both Mayrose and Yerowsky named seven recommendations in their work.

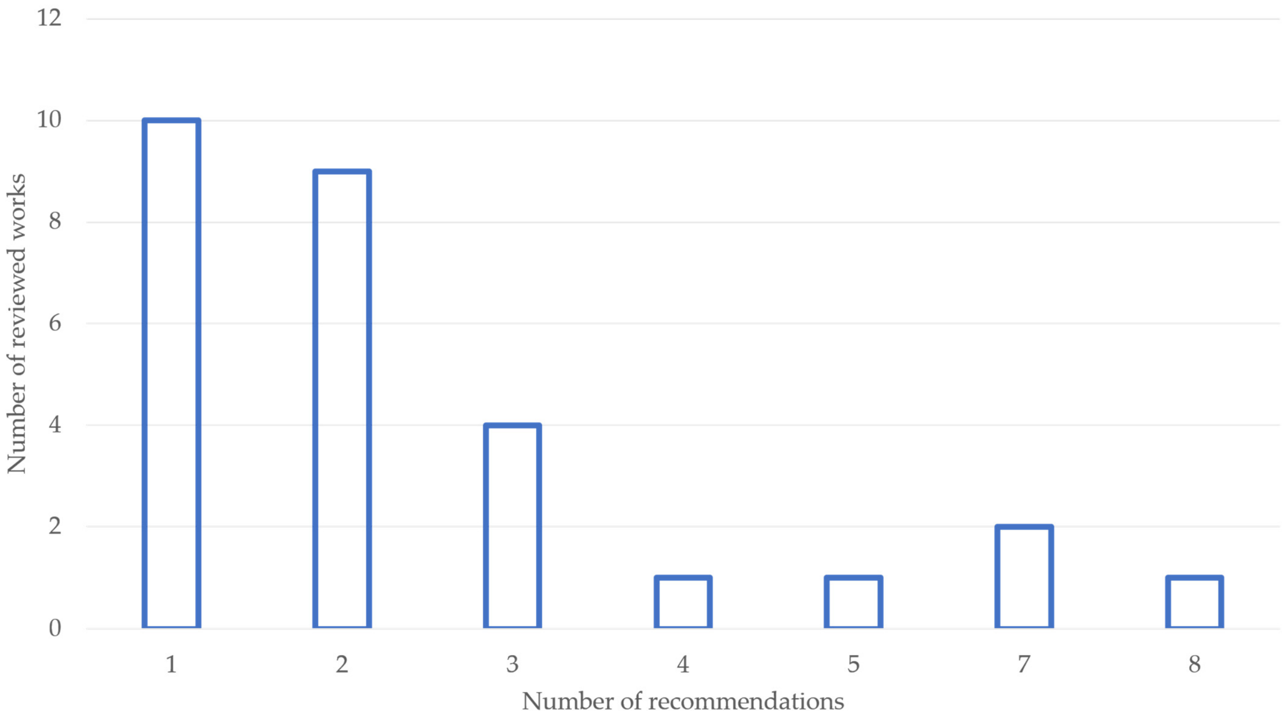


Figure 22. Number and ratio of works providing recommendations for future researchers in the topic (N = 28).

Approximately half of the works formulate predictions about the future role of the application of VR technologies in geography education. In the works published in the 1990s, the authors predict that VR would be incorporated into the curricula in the future, there would be more individualization to what is taught, and it would add new knowledge [19], and VR has the potential to become the most effective learning technology or environment [36]. Interestingly, the works published in the early 2000s do not make any specific predictions for the future of the application of VR in education, except for a paper on the effects of computer games on primary school students' achievement and motivation in geography learning, which concludes that multi-user virtual environments (MUVEs) will be one of the complementary interfaces that people will learn with [8].

The next decade is the most optimistic period, with over 40% of the works mentioning altogether 12 different predictions that are partly similar to the ones listed above. Except for the review of the virtual reality applications in education and training [31] published in 2019, the others are all empirical works (Table 9).

The latest works that we reviewed from the 2020s include predictions in the highest share (75% of the works). These most often concentrate on the pedagogical values, such as "when teachers gain more experience in implementing LIVIE, their germane facilitation acts will become more sophisticated, which can further advance the pedagogical effectiveness of LIVIE" [25] (p. 2075), "high usability and effectiveness of these technologies for educational purposes" [47] (p. 13), "if interested, schools could find a way to make it work" [49] (p. 13), and "More apps of this kind using other sensors' data will be created based on this model with options to use other complex data, such as InSAR, in curriculum-oriented lessons using AR [50] (p. 25)". Di and Zheng ensure us that "future learning activities should prioritize AR to gain a more apparent improvement effect on spatial ability" [30] (p. 90). While Doležal, Chmelík, and Liarokapis share a distinct prediction, stating that "the shared VR environment will be used for cultural heritage [46] (p. 275)". As far as field trips are concerned, the authors all agree that virtual field trips will offer experience for all sorts of reasons in the future: "immersive VFTs can be used in a formal elementary school classroom to provide engaging learning experiences by instilling in students a feeling of being in a virtual space, and delivering a sense of realism" [28] (p. 192), or "VR course materials can be effective experiencing environments that can endanger human health, experiments with high application costs and in general, all applications that require experience [51] (p. 1500)". The pandemic situation, with all its negative impact at all levels, had a positive effect on the development and widespread of technological devices, digitalization, and educational applications, and it proved that "during the periods of health crisis such as COVID-19 pandemic, the VFT will be a good tool of pedagogy [29] (p. 11)". Beyoglu and Hursen believe that "the use of technology in geography education will gain more significance depending on the increasing number of publications and citations in the following years [2] (p. 206)". Niu, Li, Huang, and Yuan conclude that "with the development of computers, the development of virtual reality technology in the field of education will become more and more extensive [1] (p. 19)". The latest prediction found in the reviewed works also expresses the overall positive opinion about the future of the application of VR, where Gielstra et al. conclude in their work that "defining the tools, strategies, and the steps for VLE development will allow to occur more rapidly and with ease [59]".

Table 9. Predictions formulated by the authors in the 2010s regarding the future of the application of VR in geography education (N = 8).

Authors	Predictions
[26]	- CPS and CO will be more effective in learning outcomes than TD- CO will be more effective for knowledge gains than CPS
[33]	- will be an incentive for K-12 schools to consider investing in this technology
[42]	- expect greater engagement of augmented reality applications
[43]	- the most effective use of any form of VR (GEs or 360-degree videos or 3D avatar-based virtual environments) will be when it is combined with other technologies such as videos, podcasts, wikis, blogs, forums, and mobile apps and is situated within the learning outcomes of the lesson/curriculum- the adoption of virtual reality and technologies . . . and its development will progress and mature as the evidence-base on the pedagogical effectiveness of these technologies grows
[44]	- VR still remains a major challenge for school teachers to apply to class and/or creative hands-on activities
[23]	- with the progress in 3D visualization technologies, an increasing range of teaching and training materials can be utilized in virtual reality environments- learning with virtual reality technology seems to be the expected next step in the evolution of education- VR is going to empower teachers to improve their student's learning graph with fun and immersive experience
[27]	- VR and AR technologies can increase the obviousness and interestingness of geographical teaching contents
[34]	- secondary students who participate in virtual reality field trips will have higher achievement scores on concrete geographic knowledge skills than students who participate in real-world field trips

4. Discussion: Educational Tool of the Future or Unrealisable Promise? (Based on Authors' Opinion)

Regardless of the relatively high number of associated works, the topic of the application of VR activities in geography teaching (K-12 levels) is rather under-researched in comparison with its effectiveness experienced by the majority of the authors; therefore, it should be expanded both geographically and thematically.

Despite the development of devices and technology and the growing number of VR software and applications, in Hungarian geography education, VR has not been adopted at any level of education by the end of the 2010s, and there is evidence of its rare presence in other countries as well: "The adoption of virtual reality and technologies, in general, in schools and further and higher education is still in its infancy and its development will progress and mature as the evidence-base on the pedagogical effectiveness of these technologies grows [43] (p. 11)". In her phenomenological work, Thomas states about the potential use of VR technology in geography classrooms: "The use of virtual reality devices within a classroom is considered a new phenomenon, only understood as a possible academic means of bringing field trips to the classroom as students experience it [34] (p. 41)". However, COVID-19, in addition to its absolute negative impact on societies and economies all over the world, has had an immediate impact on technological development, and there is a slightly growing interest in the introduction of VR technologies in education, which was born out of necessity.

The systematic review involving the comparative analysis of 47 works closely related to using VR technology for teaching geography proved that this is an effective and useful way of teaching in spite of the difficulties and limitations. The methods—together with the recommended future research topics and strategies—applied by the authors of the reviewed empirical works are applicable for us to carry out empirical research in the future using the "Balaton VR application" designed by our geography methodology research group (MTA-SZTE Geography Methodology Research Group) supported by the Public Education Development Research Program launched by the Hungarian Academy of Sciences.

The majority of the works use methods, materials, specific fields, and devices that can be effectively applied anywhere in Europe or outside Europe; therefore, using VR may be regarded as a borderless technique with widescale applicability. Many of the works are based on case studies offering good practices and can be replicated. The research focusing on virtual field trips is especially useful and relevant for us, particularly in cases where it is not possible to access geographical places or visit geomorphological formations due to security issues (proximity of the Northern Limit Line dividing the waters between North and South Korea [29], extreme distances (Giza Pyramids in Egypt from Northeast Mississippi, USA [34] or natural hazards such as St. Vincent's volcano [23]).

Though VR is regarded as a disruptive technology by some quoted authors [33,60], there are still only a few who actually believe that it can play a determining role in education. This attitude needs to be changed, and the use of VR in education and inclusion in the curricula should be promoted—of course, only as an effective educational supplement—to traditional teaching methods.

5. Conclusions

The thorough analysis of the reviewed works provided us with sufficient data and information to answer the questions that were initially raised.

1. The reviewed works show a great diversity regarding their formal characteristics, though we may establish that empirical researches dominate (two-thirds) mostly published in Q1 journals with an H-index of 101–150. The reading and citation values also show a great variety, with the number of ResearchGate citations depending the most on the time factor (R^2 = 0.21). We also found that the most read articles are not necessarily the most often cited ones. The timeline of references used by the authors of the reviewed works shows an increasing trend with signs of coinciding with the milestones of the technological development of VR.
2. Respecting the citation and bibliometric coupling analysis, we found that the two most often cited works were not only the most often read papers but also had comparably high citations/reads values; therefore, we regard them as the most influential work both in terms of the reviewed works and in general. The networking between the reviewed works is weaker than expected, which could be explained by the diversity of their objectives, research methods and tools, and study area focuses. The teaching-learning strategies make the reviewed works the most connected with such recurring elements as collaborative learning, inquiry-based learning, discussion, and interactivity. These are all regarded as the most effective elements of teaching and learning geography.

3. They reviewed works and grouped them into five categories on the basis of their chief objectives. There is a clear dominance of the works with an objective related to education, with a total of 40.4% of the works focusing on the application of VR, MR, and AR in education and 12.8% on the educational effectiveness of educational VR games. Together with the works on immersive virtual field trips, these works constitute 74.5%. In this respect, there is a strong correlation between the reviewed works.
4. Both hardware and software specifications are regarded as essential components of the development and improvement of the application of VR in teaching geography. Applications and software used for educational purposes are discussed in three-quarters of the works. They are partly designed for public use and partly designed by the authors themselves. In spite of the 63 applications/software programs used by the authors, there are still major gaps in this area. There seems to be a lack of cooperation between the authors regarding the development of applications/software programs.
5. There are both negative and positive opinions about the application of VR in geography education. The findings suggest, however, that it has more advantages than disadvantages, and the disadvantages, limitations, or negative experiences can be overcome with time.
6. The twenty-first century has opened up space for all generations. Technology has become a means of accessing news, finding information, traveling, learning, meeting people, or keeping in touch. In the past, we had to be geographically present to perform these and similar activities, but this is no longer the case. This is why education should not be left out of it either, since it is through these technological innovations that we can bring geography as a subject even closer to the student. VR tools and applications based on VR are able to bring geography closer to students of the twenty-first century. Methodological reforms are also needed to renew the subject. The use of VR as an educational tool to promote visualization, facilitate better understanding, develop digital competencies, and appeal to the "Z" and "α" generations seems to be a good way to do this.

The findings and conclusions of the comparative content and context analysis published between 1993 and 2024 on topics related to the use of VR technology in K-12 geography education were, in most cases, strengthened and clarified the results of the previously published works. However, our review revealed that the research differed in their recommendations and predictions regarding the future of VR in geography education. The differences can be observed both in terms of time and geographical location.

The majority of the reviewed works shared empirical results, which constituted a firm ground for a comparative analysis. Although we found theoretical, technological, methodological, and practical similarities, we concluded that a coherent research and use policy has not yet emerged in this field. Therefore, we believe that there is a strong need for cooperation between researchers who are committed to the use of VR in geography education, school teachers who are digitally competent, and policy-makers who are open to introducing reforms considering new technologies and methods.

6. Limitations and Future Directions

At the beginning of the research, we identified a set of keywords related to the topic of application of VR technologies in geography education. We restricted the initially found terms to the five most relevant terms (virtual reality, geography, teaching, education, school) and their combinations, and thus we retrieved 2268 works. After reading the works thoroughly, new related words were also discovered due to the differences in the names of the levels of educational systems (elementary and primary, or grammar and high and secondary, etc.). However, their inclusion in the search process resulted in many irrelevant works; therefore, we decided not to specify our search words in this direction. Another similar problem arose regarding the subdisciplines of geography (geology, geomorphology, oceanography, etc.), but as we focused our topic on geography as a school subject in K-12 level education, it was found to be a sufficient term. The selection of the proper search words in this type of research is crucial as the number of findings depends on this step, so we regard it as a limitation.

In the later stages of the visualization and writing of our review, we faced certain limitations regarding the fullness of our selected works. In the beginning, as not all papers were accessible to us, we had to exclude a few from the review at the screening stage. Nevertheless, contacting authors via e-mail resulted in getting access to papers that were later integrated into our review. We also found new potential works when processing the references of the reviewed works. This means that the review is based on a non-exhaustive list, which, if repeated by someone else using a different search engine at a later date, might also include works different from our findings, even if using the same search words.

In conducting our systematic literature review, we aimed to provide as complete a picture as possible of the results of the studies available to us. To accomplish this, we selected five criteria to perform a bibliometric analysis and five criteria for the content and contextual analysis. We did not specifically investigate the case studies presented in the works because that would have required different methods, and we think that should be the subject of another piece of work. Our future plans include carrying out a comparative analysis of the case studies included in the studies to use that as a basis when performing our own empirical research.

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