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Research paper

The Computer Science VR Revolution (2000-2025): Virtual Reality Is Rewriting The Rules of Computer Science Education

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Abstract

This study examined the development of virtual reality (VR) technology in computer science education over the past 25 years. As educational institutions increasingly adopt VR tools to teach programming concepts, understanding practical approaches and establishing future research directions are essential for educators and policymakers. This study analysed 341 peer-reviewed publications from the Scopus database (2000-2025) using specialised software to examine publication trends, citation patterns, and research themes. This approach maps the evolution of VR educational research and identifies the most influential studies. The results show dramatic growth in VR research beginning in 2018, with annual publications increasing from 09 to 96 studies by 2024. Five primary research areas have emerged: immersive educational technologies, teaching methods, digital learning frameworks, technology integration strategies, and subject-specific applications. The most cited works were review studies rather than individual experiments, suggesting that researchers build foundational knowledge. This study has limitations, including its focus on English-language publications and reliance on one database, potentially missing international perspectives. Future research should investigate long-term learning outcomes and include diverse geographical perspectives. This comprehensive analysis provides evidence-based guidance for educators and data-driven insights into technology investment decisions in computer science education.

Keywords: *Virtual Reality; Computer Science Education; Bibliometric Analysis; Educational Technology; Immersive Learning.*

1. Introduction

Modern computer science teaching faces unprecedented challenges in presenting abstract computational concepts to heterogeneous learners, because the established pedagogical models do not encourage the successful exploration of intricate programming structures, algorithmic thinking, and software development methodologies. Virtual reality (VR) is a new type of teaching that allows the creation of realistic computer worlds where learners may experience things that are difficult to realise in traditional classrooms. VR allows practising and experimenting in realistic simulations and therefore avoids constraints related to geographical accessibility, safety, and financial barriers [1]. In these virtual environments, students are able to engage with three-dimensional conceptual models of phenomena that are typically construed as abstract and physically inaccessible in conventional learning scenarios.

The educational impact evaluation of VR requires an assessment of the various stakeholder perspectives that are central to its successful implementation. On the side of the educator, VR offers unprecedented opportunities to visualise abstract computational concepts and develop practical programming experiences that are impossible to acquire with traditional methods. Students also have the advantage of immersive environments that transform theoretical algorithms into interactive experiences, which increases their engagement and comprehension. Industry stakeholders are increasingly requiring computer science graduates with practical VR development skills and technological fluency, and educational policymakers are seeking evidence-based insights for strategic technology investment and curriculum reform decisions.

The names used in various academic disciplines to refer to VR in education may be confusing, and there is a significant cross-disciplinary overlap in recent literature. The literature on computer science is mainly concerned with educational VR under the umbrella term “Extended Reality (XR)” and often uses the descriptor “Immersive Learning Technologies.” Education and communication studies research consistently uses terms such as “Multi-User Virtual Environments (MUVEs)” to refer to collaborative virtual learning spaces, and “Immersive Virtual Worlds” for persistent digital environments. The engineering education literature stresses functional terminology, including “virtual simulation”, “manufacturing simulation”, and “intelligent manufacturing systems”, when referring to VR applications. This variation in terms indicates differences in disciplinary focus and demonstrates increasing convergence toward standardised terms as the field matures.

In addition, the advancement of technology, particularly those that make experience accessible and economically feasible, has created a pedagogical surge resulting in innovative applications across diverse fields of study, such as language acquisition, scientific instruction, and vocational education [2]. Moreover, numerous empirical studies have explored specific implementations of VR technology in education and have revealed considerable educational effectiveness in different contexts, ranging from language acquisition [3] to medical education [4] to vocational instruction [5], [6]. Recent meta-analyses have shown significant effects when comparing VR-enhanced learning with traditional instruction across STEM disciplines. Nevertheless, research in various parts of the world shows that there are considerable implementation gaps in VR for computer science education, including technological infrastructure barriers in Australia, resource accessibility constraints in Canada, curriculum integration challenges in Germany, assessment framework limitations in the United Kingdom, scalability concerns in the United States, and pedagogical adaptation needs in developing nations such as India and Malaysia. These international disparities highlight the urgent need for comprehensive research to guide evidence-based strategies.

This transition underscores a significant paradigm shift in the delivery of educational content aligned with contemporary demands for interactive and engaging learning experiences [7].

Despite this progress, researchers have identified five main problems in the current VR education studies. Initially, few studies focused specifically on computer science. Subsequently, Geographical gaps demonstrate that research predominantly originates in developed nations, underrepresenting perspectives and challenges from developing educational systems. Additionally, Temporal gaps indicate that longitudinal studies that track VR implementation effectiveness over extended periods are insufficient. Furthermore, the theoretical gaps reveal that comprehensive pedagogical frameworks designed explicitly for VR-enhanced computer science instruction remain underdeveloped. Finally, Practical gaps indicate that evidence-based implementation guidelines for educators lack systematic synthesis and validation. Although isolated studies have examined specific applications of VR in programming education and computational thinking, no large-scale bibliometric mapping has documented the evolution of research themes, methodological approaches, or citation networks across these multiple gap dimensions in this specialised domain. Our research examines publication patterns, citation networks, and conceptual relationships across a 25-year timespan (2000-2025) to answer five key research questions regarding the evolution and current state of VR in computer science education. This longitudinal perspective enables the identification of both established research clusters and emerging frontiers, providing valuable insights for researchers, educational technologists, and curriculum developers seeking to leverage VR's potential of VR in computer science education.

Addressing these multifaceted research gaps requires an integrated methodological approach that combines systematic literature review principles with advanced bibliometric analysis techniques. This dual strategy enables comprehensive content synthesis while providing quantitative insights into research patterns, collaboration networks, temporal trends, and thematic evolution, which individual approaches cannot capture. The systematic review component ensures rigorous literature selection and quality assessment, whereas bibliometric analysis reveals hidden patterns in large-scale publication data, creating a robust analytical framework for understanding both the content depth and structural characteristics of VR research in computer science education.

This study addresses the following questions:

RQ1. What are the descriptive features of the refined empirical research on VR in computer science education? RQ2. What are the trends in annual scientific publications on VR in computer science education from 2000 to 2025? RQ3. What are the most influential publications by source title in VR in computer science education? RQ4. What are the most globally cited articles on VR in computer science education? RQ5: What are the trending research areas and avenues for future research on VR applications in computer science education?

The research findings provide different values across multiple stakeholder groups. Primarily, Educators will access evidence-based implementation strategies, pedagogical best practices, and technology integration frameworks; Concurrently, Researchers will identify high-impact collaboration opportunities, promising publication venues, and understudied research areas requiring investigation; educational policymakers will receive data-driven insights for strategic funding allocation, technology investment priorities, and curriculum reform initiatives; curriculum designers will obtain validated frameworks for VR integration, learning outcome optimisation, and assessment strategy development; and Ultimately, Educational technology companies will understand market needs, research-practice gaps, and evidence-based product development opportunities for leveraging VR's potential in computer science education through informed decision-making and strategic planning.

2. Literature Review

The theoretical foundation for utilising virtual reality (VR) in computer science education is significantly informed by established educational theories, specifically constructivist learning theories, experiential learning frameworks, and the principles of situated cognition. Educational researcher Piaget found that students learn better when they actively participate in building their understanding rather than just listening to lectures and interacting with the environment, fostering a deeper understanding of complex concepts [8]. Kolb's experiential learning theory complements this by proposing a cyclical model that connects the four stages of concrete experience, reflective observation, abstract conceptualisation, and active experimentation, all of which are crucial for the establishment of immersive learning in the virtual reality domain [9]. The situated cognition principles, as expressed by Brown et al., further affirm the hypothesis that learning is contextual and therefore enhances the transfer of computer skills to real-life scenarios. Taken together, these frameworks imply that the use of VR in an educational setting has the potential to facilitate more engaging and effective learning environments that encourage deep interactions with advanced computing concepts. In the field of educational VR, research has progressed in several phases: initial exploratory experiments, testing whether the technology works effectively, and determining optimal methods for instruction and current scalable integration research. This kind of development bears witness to the technological and pedagogical maturity in the use of immersive technologies in computational education pedagogy.

2.1. Pedagogical Applications and Effectiveness Evidence

Several studies have verified the effectiveness of VR in improving educational outcomes. For example, Marshall et al. demonstrated that immersive VR greatly enhanced the confidence of medical students in terms of radiation safety, indicating the usefulness of VR simulations in medical education programs [5]. Similarly, Yakubova et al. discovered that AR and VR technologies enhance the learning experience, especially among disabled students, thereby promoting skill acquisition and increasing interest in academic tasks [1]. Valenti et al. indicated that VR can provide a more engaging orientation process for distance education students than traditional online modules, emphasising its potential to create immersive learning environments [10].

Kustandi et al. supported the idea that VR can provide a means to present complex concepts, especially in a higher education setting, where interactive environments aid the learning experience [11]. Furthermore, VR has proven to be effective for constructivist learning theory pedagogical approaches, where it provides scaffolded experiential engagement that traditional methods cannot replicate. Hartstein et al. also agreed with these findings in their mixed-methods study by pointing out how VR has been used in orthopedic physical therapy education and yielded high user satisfaction and usability, showing its pedagogical potential [12].

2.2. Stakeholder Perspectives and Implementation Context

Research perspectives on VR effectiveness vary across stakeholder groups: educators' emphasis on pedagogical integration and learning outcome improvements; students' focus on engagement and motivation enhancement; administrators' consideration of cost-effectiveness and scalability; and policymakers' seeking evidence-based guidelines for strategic technology investment.

2.3. Implementation Challenges

The effectiveness and practicality of virtual reality applications in education have received diverse supporting and contradictory evidence from various studies. For instance, Urueta pointed out that adopting VR in language education brings about significant challenges, including usability problems and the adequacy of current VR applications for educational purposes [3]. Hsin et al. documented VR-related simulator sickness as a potential educational issue that may adversely affect students' learning experiences, indicating the need for careful implementation [13].

Furthermore, Hamilton et al. performed a comprehensive literature review of the quantitative learning outcomes associated with the application of VR and doubted the long-term advantages and applicability of VR educational interventions. This study suggests that despite VR's promising potential of VR, it might still fail to realize all educational objectives [14]. Some studies have expressed skepticism about the long-term benefits of VR in education, arguing that most evidence comes from short-term quantitative outcomes across diverse contexts. In contrast, other research has shown significant improvements in students' confidence and skill acquisition when immersive VR is implemented through longitudinal mixed-methods interventions. This apparent contradiction can be explained by methodological differences: short-term evaluations across heterogeneous contexts often highlight limitations, while targeted interventions with extended follow-up capture more sustained benefits. These variations suggest that the effectiveness of VR depends not only on the technology itself but also on research design, implementation context, and evaluation metrics. Recognizing these distinctions provides a more balanced understanding of VR's potential and limitations in computer science education. Owing to economic reasons, VR application in education becomes even more complicated, as cost-benefit analysis demonstrates significant disparities in access and infrastructure demands, which may further deepen educational inequalities instead of narrowing them. Similarly, as Anifowose et al. discussed, there are issues with user adaptability and technological barriers, which indicate the need to improve the applicability of VR in a manner that enhances learning outcomes without causing negative experiences [15].

2.4. Global Perspectives and Geographical Coverage

Research on virtual reality (VR) education is a clear demonstration of strong geographical imbalances, in which developed countries are over-represented, whereas the developing world is highly underrepresented. This difference reveals considerable gaps in academic knowledge in the sphere of the integration and implementation of VR technologies in various socioeconomic educational environments [2]. Recent research suggests that most studies that gauge the usefulness of VR or explain its pedagogical utility are conducted in high-income countries and therefore do not provide an understanding of how such technologies could be used in low-income contexts. Studies also show that despite the various efforts geared towards improving the quality of education using VR, the use of this technology is often limited by the fact that technology transfer is time-consuming, and the infrastructure in developing nations is lacking. The issues facing educators, such as poor access to technological resources and a lack of professional development in terms of VR applications, also demonstrate the need to implement special approaches that consider the local situation. In conclusion, it is necessary to fill this research gap to achieve the full potential of VR in education and to guarantee equal access to new learning opportunities.

2.5. Methodological Approaches and Research Design Critique

More recent criticism has highlighted serious methodological gaps in the existing body of VR educational research and argued that these gaps impede the creation of a robust, evidence-based foundation upon which VR implementation is based. Among the main offenders, one can mention the lack of standardised methodologies, insufficient theoretical frameworks, and the prevalence of inadequate assessment measures. Research often contains a limited period, a small sample size, and an inadequate description of instruction sessions, all of which reduce external validity and generalizability [16].

The limitations of research in the context of Virtual Reality (VR) education have also begun to be recognized as a significant impediment to creating a strong and evidence-based approach for the use of VR in educational settings. A systematic literature review highlighted methodological challenges, noting that existing studies often lack rigorous experimental designs, leading to inconclusive findings regarding the effectiveness of immersive VR in educational contexts [14].

Although a substantial body of research exists on how VR applications may be used in an educational context, particularly in computer science, it is unclear how these studies connect and how contradictory findings may be related to methodological differences, contextual variables, or evolutionary stages of the technology itself. This analytical gap highlights the need for systematic bibliometric analysis to map the intellectual landscape of this evolving field, particularly to understand how contradictory findings might reflect methodological differences, contextual variables, or the evolutionary stages of the technology itself. This analytical gap highlights the need for a systematic bibliometric analysis to map the intellectual landscape of this evolving field.

2.6. Bibliometric Analysis, Positioning, and Research Gaps

Previous bibliometric studies have broadly examined educational technology or focused on related concepts, such as augmented reality, with notable examples of analysis of AR/VR trends in education and meta-analysis of AR in education. However, these analyses either subsume VR within broader technological frameworks or examine adjacent technologies without capturing VR's distinctive educational applications of VR. Specific bibliometric analyses targeting VR in computer science education contexts remain absent from the literature, representing a critical gap given the significant developments in the field, particularly the surge in publications post-2018 and the emergence of AI and metaverse integration. This study addresses this critical gap by conducting a comprehensive bibliometric analysis specifically targeting VR in computer science education across a 25-year timespan (2000-2025), employing advanced bibliometric techniques to elucidate publication patterns, citation structures, and conceptual relationships that have previously remained unexplored.

This study advances the field by employing multiple complementary bibliometric tools (VOS viewer, Bibliomagika, and Biblioshiny) to triangulate findings and enhance analytical robustness. Unlike previous studies, our analysis employs temporal overlay mapping to track conceptual evolution, revealing the field's progression from foundational educational technology frameworks (2020-2021) to specialized domains, including AI integration and human-computer interaction (2023-2024). This chronological perspective provides unprecedented insights into the developmental trajectory of the field and emerging research fronts. By synthesizing publication metrics, citation impacts, and thematic developments, our analysis offers a comprehensive bibliometric portrait that can guide future research investments and pedagogical implementation.

3. Methods

Research databases are similar to extensive digital libraries that store academic papers. Some covered many subjects, while others focused on specific topics. Multidisciplinary databases include CrossRef, Dimensions, Microsoft Academic, Web of Science, and Scopus, whereas specialized databases include ArXiv, Cochrane, EconBiz, IEEE Explore, and PubMed. Scopus is a bibliometric database that contains the highest number of journal-published articles compared to other databases [17], [18]. As Scopus has a comprehensive compilation of double-blind peer-reviewed papers in high-impact factor journals [19], [20]It was used as the primary data source for this study.. Among the comprehensive bibliographic databases, SCOPUS provides access to a wide range of online sources, including extensive citation databases; however, not every article or journal is included in SCOPUS[21]. Therefore, the present study used the search engine of the Scopus database, a prominent repository for scholarly abstracts and citations containing approximately 50 million articles published since 1823 [22].

The methodology encompasses three main phases: data collection and screening, software selection and validation, and data analysis and interpretation (Fig. 1).

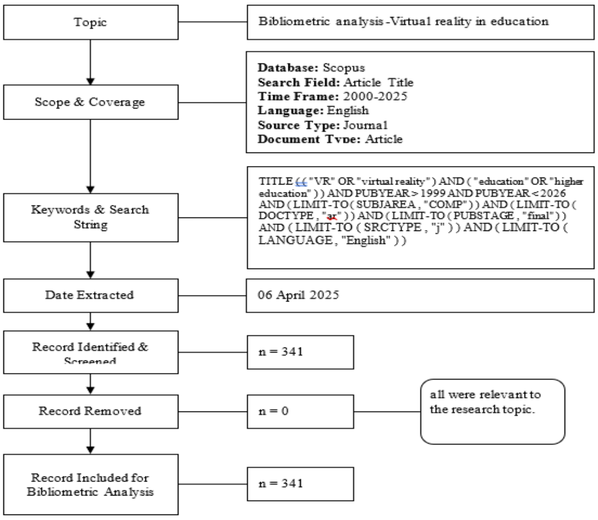

Fig. 1: Search Strategy of Flow Diagram. Source:[23].

A systematic bibliometric analysis was conducted using the Scopus database to examine the research trends in educational reality. The search strategy targeted articles containing "VR" or "virtual reality" in conjunction with "education" or "higher education" in their titles, limited to English-language journal articles published between 2000 and 2025. The 25-year timespan strategically captures the evolution of VR education from early experimental implementation to mainstream pedagogical adoption, encompassing critical periods of technological maturation, educational integration, and computer science curriculum transformation. The search string employed was: TITLE (("VR" OR "virtual reality") AND ("education" OR "higher education")) AND PUBYEAR > 1999 AND PUBYEAR < 2026 AND LIMIT-TO (SUBJAREA, "COMP") AND LIMIT-TO (DOCTYPE, "ar") AND LIMIT-TO (PUBSTAGE, "final") AND LIMIT-TO (SRCTYPE, "j") AND LIMIT-TO (LANGUAGE, "English"). This query was executed on 6 April 2025 and yielded 341 records that underwent systematic screening using predefined criteria. The inclusion criteria were Primarily Peer-reviewed journal articles and additional English language publications, published between 2000 and 2025. Moreover, it is limited to VR applications in computer science education, empirical studies, and theoretical frameworks. The exclusion criteria were conference proceedings without peer review, subsequent non-English publications, and duplicate entries. The bibliographic data were exported to Microsoft Excel in CSV format for cleaning and processing. Data cleaning involved standardising author names, removing incomplete entries, and correcting inconsistent institutional names. Author keywords were standardised through manual review and consolidation of synonymous terms using Bibliomagika. For example, the terms 'virtual reality,' 'VR,' and 'immersive virtual reality' were merged under the standardized keyword 'virtual reality.' This process minimised redundancy and improved the accuracy of the co-occurrence and trend analyses.

Rigorous analysis of extensive scientific information relies primarily on bibliometric analysis, which is one of the most widely used and rigorous methods. This technique reveals the developmental perspectives of a particular domain and new development directions within the same field[24]. Bibliometric analysis comprises a collection of tools that examine and measure written content using numerical processes [25]. Compatible software is required to perform accurate bibliometric analysis. Different tools support bibliometric analysis, including content and quantitative analysis with visualisation capacity, or tools that combine these capabilities. These tools include "Bibliomatrix," "Vosviewer," "Citespace," "Gephi," "HistCite," "Pajek," "N Vivo," "Maxqda," and "Bibexcel." [26]. This research used the latest Bibliometrix R package, Biblioshiny, and VOS viewer programs, along with Bibliomagika. Among these, Biblioshiny and VOS viewer were chosen for this study because of their ease of use, detailed visualisation, and strong analytical features [27]. [28]. Unlike other software solutions, Bibliometrics and VOS viewer software solutions offer quick analysis and generate data matrices for the performance evaluation and scientific visualisation of bibliographic databases[29]. Methodological triangulation employs multiple analytical tools to process identical datasets, validate the findings, and minimise tool-specific biases. Convergence of results across VOS viewer, Biblioshiny, and Bibliomagika confirmed analytical robustness, while divergent findings prompted additional investigation to ensure a comprehensive understanding. VOS viewer software was used to visualise and analyse the relationships between several study units [30]. Bibliomagika[31] is a tool designed for a comprehensive bibliometric analysis. It uses bibliometric data and converts them into meaningful metrics, such as citation counts, h-index, and g-index. It also makes the job of cleaning and harmonising author, affiliation, and country data easier, thereby ensuring accuracy and reliability [32]. Methodological limitations include Scopus database exclusivity, potentially omitting relevant publications from other repositories. In addition, English language restrictions limit the global research perspective. Moreover, Journal articles focus on excluding valuable conference proceedings and grey literature. Furthermore, Keyword-based search potentially misses studies using alternative terminology, and temporal boundaries exclude very recent developments in post-data collection.

4. Results

4.1. Descriptive Features of The Extracted Data

Table 1: Descriptive Features of the Extracted Data

Main Information	Data
Publication Years	2000 – 2025
Total Publications	341
Citable Year	26
Number of Contributing Authors	1214
Number of Cited Papers	283
Total Citations	11,075
Citation per Paper	32.48
Citation per Cited Paper	39.13
Citation per Year	443.00
Citation per Author	9.12
Author per Paper	3.56
Citation sum within h-Core	10,127
h-index	44
g-index	98
m-index	1.692

Source: Generated by the author(s) using biblioMagika®.

Table 1 presents the descriptive characteristics of the extracted data. A bibliometric analysis of virtual reality (VR) in education shows substantial scholarly engagement with 341 publications from 2000 to 2025, 06 April, demonstrating established research foundations and continued academic interest. The field's influence is evident through 11,075 citations (32.48 average per paper). The citation distribution revealed that 83% of the publications (283 papers) accounted for all citations, indicating a concentrated influence among core works. The higher citation rate of cited papers (39.13) suggests that impactful research has attracted significant attention. With an h-index of 44, a g-index of 98, and an m-index of 1.692, the field demonstrates balanced productivity, impact, and sustained scholarly influence over time. Multi-researcher collaborations are familiar (with an average of 3.56 authors per paper), with 1,214 contributing authors collectively shaping the discipline. The concentration of 91.4% of citations within the h-core reinforces that a small subset of publications drives the field's discourse, suggesting that canonical works have defined VR's educational applications and theoretical foundations of VR. These citation patterns align with constructivist learning theory principles, indicating that VR's effectiveness of VR stems from active knowledge construction through immersive experiences. The concentrated influence among core works suggests paradigmatic development consistent with Kuhn's scientific revolution framework, in which foundational studies establish a theoretical groundwork for subsequent research directions.

4.2. Publication Trends of Annual Scientific Publications in VR in Education

Table 2: Publication by Year

Year	TP	TC	C/P	C/CP	h	g	m
2000	1	15	15.0	15.0	1	1	0.038
2001	1	44	44.0	44.0	1	1	0.040
2002	2	73	36.50	36.50	2	2	0.083
2004	1	3	3.0	3.0	1	1	0.045
2005	1	11	11.0	11.0	1	1	0.048
2006	5	114	22.80	22.80	2	5	0.100
2008	1	250	250.0	250.0	1	1	0.056
2009	1	14	14.0	14.0	1	1	0.059
2011	1	51	51.0	51.0	1	1	0.067
2012	2	23	11.5	11.5	2	2	0.143
2013	3	45	15.0	15.0	3	3	0.231
2014	3	1219	406.33	406.33	2	3	0.167
2015	2	284	142.0	142.0	2	2	0.182
2016	5	546	109.2	109.2	3	5	0.300
2017	2	32	16.0	16.0	2	2	0.222
2018	9	602	66.89	66.89	9	9	1.125
2019	15	1176	78.4	78.4	13	15	1.857
2020	19	2483	130.68	130.68	16	19	2.667
2021	33	1778	53.88	53.88	18	33	3.600
2022	48	1198	24.96	26.62	19	33	4.750
2023	73	826	11.32	11.80	17	24	5.667
2024	96	280	2.92	4.91	8	13	4.000
2025	17	8	0.47	2.00	2	2	2.000

Total	341	11075	32.48	39.13	44	98	1.692

TP = total number of publications; NCA = Number of contributing authors; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index.

Source: Generated by the author(s) using biblioMagika®.

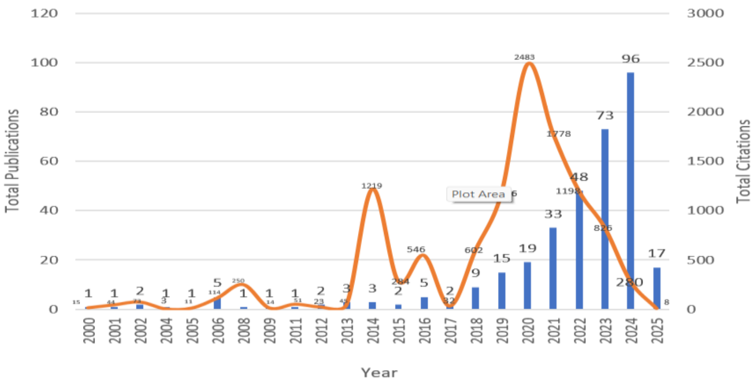

Fig. 2: Total Publications and Citations by Year.

Source: Generated by the author(s) using biblioMagika®.

Table 2 shows the publications by year, while Fig.2 describes the total number of publications and citations by year. Bibliometric data have revealed the evolution of VR research in education over 25 years (2000–2025) in distinct phases. The initial period (2000–2013) showed limited activity, with 1–5 papers published annually and modest citations, although occasional high-impact publications, such as 2008 (250 citations from a single paper) and 2011 (51 citations), established foundational concepts. A pivotal transition began in 2014, marked by 1,219 citations across three publications, indicating the growing recognition of VR's educational potential of VR. This momentum continued through 2017, with citation metrics consistently exceeding publication volume. The most significant development occurred during 2018–2024, with the publication volume increasing from 9 in 2018 to 96 in 2024, a 967% increase, confirming the emergence of VR in education as a mainstream research domain. This surge coincided with major citation peaks, particularly in 2020 (2,483 citations across 19 papers), and strong performance in 2019 (1,176 citations) and 2021 (1,778 citations). The declining citation-per-paper ratio—from 130.68 in 2020 to 2.92 in 2024- reflects the recency of publications with insufficient time to accumulate citations. The h-index progression, which rose to 19 by 2022 and reached 44 overall, substantiates the growing scholarly impact of this field. The g-index reached 33 by 2022 and peaked at 98 by 2025, thus confirming its cumulative influence. Preliminary 2025 data (17 publications, 8 citations) indicate continued robust research engagement, demonstrating the transformation of VR in education from a niche interest to an established discipline.

4.3. Most Influential Publications

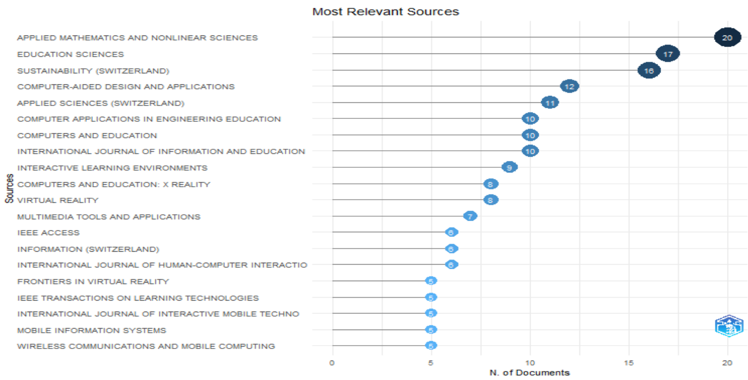

Fig. 3: Top 20 Most Influential Source Titles by Total Citations.

Source: Generated by the author(s) using Biblioshiny.

Fig.3 shows the top 20 most influential source titles based on the total citations. Our research shows that many academic fields have contributed to VR education studies. Applied Mathematics and Nonlinear Sciences stood out, with 20 publications. In comparison, Education Sciences followed 17 publications, alongside sustainability with 16 publications, which further supports the mathematical basis, together with educational theory and sustainable development principles. Publications dedicated to computer science and engineering demonstrate dual technological and education-oriented perspectives through Computer-Aided Design and Applications (n=12), Computer Applications in Engineering Education (n=10), IEEE Access (n=6), Computers & Education (n=10), and Interactive Learning Environments (n=9). These publication patterns reveal the interdisciplinary nature of VR in computer science education, which requires collaboration between educational theorists and technological developers to achieve optimal pedagogical outcomes. Educational technologists, together with curriculum developers and funding agencies, gain essential insights into prestigious publication venues from this distribution, which also helps new scholars to choose their best publication options. Significant VR educational research requires both teaching principles and technological expertise because compartmentalised approaches do not work effectively. Thus, educational institutions that adopt VR solutions require cross-domain team collaborations between academic professionals and technical developers.

4.4. Top Five Globally Cited Articles

Table 3: Top 05 Highly Cited Articles

	Author(s)	Year	Title	Source Title	TC	C/Y
1	Radianti J.; Majchrzak T.A.; Fromm J.; Wohlgenannt I.	2020	A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda	Computers and Education	1721	286.83
2	Merchant Z.; Goetz E.T.; Cifuentes L.; Keeney-Kennicutt W.; Davis T.J.	2014	Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis	Computers and Education	1178	98.17
3	Hamilton D.; McKechnie J.; Edgerton E.; Wilson C.	2021	Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design	Journal of Computers in Education	602	120.40
4	Kamińska D.; Sapiński T.; Wiak S.; Tikk T.; Haamer R.E.; Avots E.; Helmi A.; Ozcinar C.; Anbarjafari G.	2019	Virtual reality and its applications in education: Survey	Information (Switzerland)	295	42.14
5	Alhalabi W.S.	2016	Virtual reality systems enhance students' achievements in engineering education	Behaviour and Information Technology	289	28.90

Source: Generated by the author(s) using biblioMagika®

Table 3 presents the top five highly cited articles in the field. Citation analysis has revealed research trends in VR education. The systematic review [33] by Radianti et al. leads with 1,721 citations (286.83 citations per year), indicating significant influence in the field. The meta-analysis by Merchant et al.[34] It is influential, as it has received 1,178 citations since its publication in 2014. The citation pattern suggested three research clusters: systematic reviews, quantitative outcome analyses, and applied engineering education studies. The high citation rates for review papers compared with original research indicate the field's focus on knowledge synthesis and evidence-based approaches, consistent with systematic knowledge production models [35]. These patterns inform curriculum designers, educational technologists, and funding bodies about the evidence shaping VR implementation decisions. Citation concentration in review papers signals opportunities for high-impact primary studies to address gaps in current knowledge, particularly in new technologies and pedagogical approaches.

4.5. Keywords Co-Occurrence Analysis

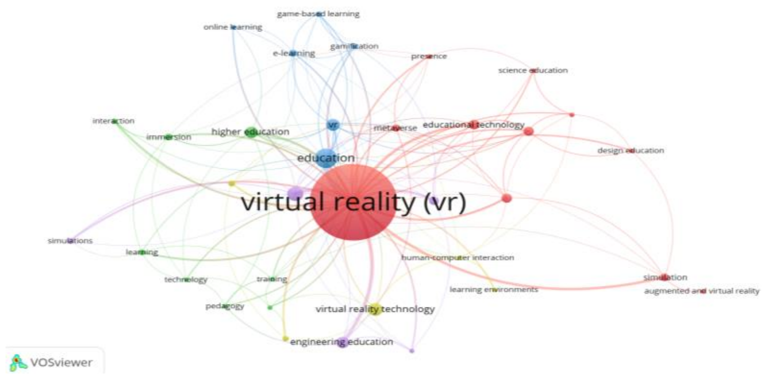

Fig. 4: Network Visualisation of Keyword Co-Occurrence Analysis by Author.

Source: Developed by the author(s) using VOS viewer.

Fig.4 shows the network visualisation of keyword co-occurrence analysis by the authors. A keyword co-occurrence network analysis revealed the conceptual structure of VR education research. Using VOS viewer with fractional counting and a minimum threshold of five keyword occurrences, 35 keywords were mapped from the 957 original terms, forming five distinct thematic clusters. Cluster 1: Immersive Educational Technologies (red) – This cluster is centered on the term "virtual reality (VR)", which has the highest occurrence (209) and the strongest total link strength. It is closely connected to "simulation," "educational technology," "immersive virtual reality," "metaverse," "presence," "science education," and "interactive learning environments." These keywords reflect technological and content frameworks that support immersive VR applications in educational settings. Cluster 2: Pedagogical Foundations (green) – Comprising keywords such as "immersion," "interaction," "higher education," "learning," "training," "pedagogy," and "physical education," this cluster represents the theoretical and instructional principles that guide VR's integration into educational contexts. The high average citation values for terms such as "immersion" (55) and "interaction" (50.67) highlight their pedagogical significance. Cluster 3: Digital Learning Modalities (blue) – This cluster includes "education," "e-learning," "online learning," "gamification," and "game-based learning." This illustrates VR's synergy of VR with broader digital education ecosystems, including online learning approaches. Cluster 4: Yellow Cluster 4 examines the technological integration aspects with broader themes. The cluster includes essential terms such as "artificial intelligence," "human-computer interaction," "internet of things," and "virtual reality technology." The included studies followed recent research trends (post-2022 average publication dates), emphasising sophisticated learning environments in computer science education. Cluster 5: The purple section under Cluster 5 groups context-specific implementations like "augmented reality," "engineering education," "immersive learning," and "simulations." Among these, "simulations" had the highest average citation rate (296.57), indicating the foundational importance of simulation-based approaches in VR educational applications.

These thematic clusters demonstrate the evolution of VR education research from technology-focused investigations to pedagogically grounded applications, with an emerging emphasis on AI integration and human-computer interaction representing future research frontiers. In general, this network structure provides a high-resolution view of the research areas in VR education. This can assist educational technologists in understanding conceptual clusters, guide curriculum developers in identifying high-impact applications, and support funding agencies in identifying emerging research fronts at the intersection of VR and newer technologies.

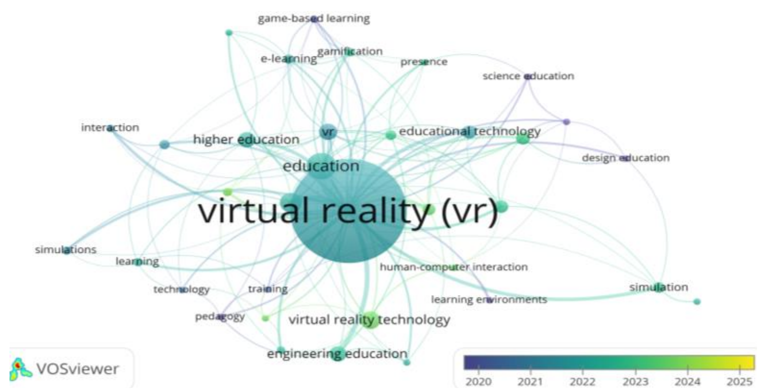

Fig. 5: Overlay Visualisation Maps by Authors (Chronological Evolution of Research Themes in VR And Computer Science Education).

Source: Developed by the author(s) using VOS viewer.

Fig.5 displays the overlay visualisation maps created by the authors. This figure illustrates the chronological evolution of research themes in VR and computer science education, where earlier studies (blue/green nodes) focused on foundational pedagogical applications, while more recent studies (yellow nodes) emphasised emerging areas such as artificial intelligence integration, human–computer interaction, and metaverse applications. The co-occurrence network analysis uncovers a complex intellectual structure within virtual reality education research, comprising five distinct yet interconnected thematic clusters.' Virtual reality (VR) functions as the core hub, with numerous associations with other prominent concepts such as education and 'learning environments' (5), reflecting the interdisciplinary nature of the field. This research focuses on educational applications (Cluster 1), pedagogical foundations (Cluster 2), emerging approaches (Cluster 3), technical infrastructure (Cluster 4), and disciplinary applications (Cluster 5), based on cluster analysis.

Research into the educational technology foundation expanded from 2020-2021 to specialised work combining artificial intelligence and human-computer interaction starting in 2023-2024. Chronological analysis shows apparent changes in focus in research activities for 'artificial intelligence' and human–computer interaction based on recent average years of publication. An analysis of citing documents establishes that the concepts of simulations, learning, and 'immersive environments' are critical foundational elements in the field. New technological developments featuring artificial intelligence systems and metaverse applications present a growing convergence between educational applications and innovative technology, which benefits the medical domains, engineering, and physical education fields. A comparative analysis based on established bibliometric patterns reveals that VR education research demonstrates dynamic thematic development, suggesting strong responsiveness to emerging educational technology trends. Notably, emerging research fronts demonstrate high normalised citation impact, including 'gamification' and 'metaverse', indicating their growing influence on the field's development.

5. Discussion

This study examined how virtual reality is used in computer science education by reviewing 341 research papers published between 2000 and 6 April 2025. Our results show that VR research in education has grown dramatically since 2018. We found that most research came from a small group of highly cited papers, and that the field has developed into five main research areas: immersive educational technologies, teaching methods, digital learning approaches, technology integration, and specific subject applications.

Our results are consistent with the findings of other studies: new educational technologies typically begin slowly and then grow rapidly once people see their work. VR followed the same pattern of a slow start followed by rapid growth. However, our study is different because it focuses specifically on VR in computer science education, which has not been studied previously. The citation patterns we found are similar to what Hamilton et al. reported about VR research being scattered and needing better organisation. Our results support these concerns by showing that most citations are review papers rather than original research studies. This suggests that researchers are still attempting to understand the basics of VR.

The significant increase in VR research after 2018 could be explained by several factors. Initially, VR technology was cheaper and easier to use around this time. Subsequently, the COVID-19 pandemic has led schools to look for new ways to teach students remotely. Additionally, computer science education has begun to receive more attention as technological jobs have become more critical. Our study found something interesting that differs from earlier research. While previous studies have mainly focused on whether VR works in education, recent research has focused on combining VR with artificial intelligence and other new technologies. This shift shows that the field is moving from asking "Does VR work?" "How can we make VR work better with other technologies?". The five identified research clusters showed how the field developed. Early research focused on the technology itself, but newer studies looked at how students learn and how teachers can effectively use VR. This change makes sense because, as VR technology improves, researchers can focus more on education rather than technical problems. Our results have several important implications for people working in education and technology fields. The rapid growth in VR research has shown that this field is becoming increasingly important. Teachers, school administrators, and technology companies should also consider these developments. Subsequently, the fact that most citations go to review papers indicates that the field still requires additional original research. While it is good to have summaries of what we know, we need more studies that test new ideas and teaching methods using real students.

Furthermore, the emergence of research combining VR with artificial intelligence and other technologies suggests that the future of VR education will become more sophisticated. This means that schools planning to use VR should consider how they will work with other technologies they use. The geographic concentration of research observed in wealthy countries indicates that we do not know enough about how VR works in different cultural and economic settings. This is important because VR solutions in rich countries may not work in places with other resources or teaching traditions. To address this limitation, future bibliometric analyses should integrate multilingual databases, such as CNKI, SciELO, and LILACS, and regional repositories in Africa and South Asia. Beyond databases, building collaborative networks with local scholars can provide critical contextual knowledge and ensure that region-specific challenges (e.g., infrastructure, policy, and cultural learning preferences) are captured. Additionally, gray literature, including government reports, NGO publications, and institutional white papers, should be considered, as these sources often contain innovative practices that are not represented in mainstream journals. Taken together, these strategies will help to reduce geographical bias and create a more inclusive and representative evidence base for VR in computer science education. Finally, our findings suggest that VR in computer science education is moving from an experimental phase to a practical phase. Research is increasingly focused on real classroom applications rather than merely demonstrating that VR can work. This is good news for educators who would like to use VR but need practical guidelines on how to do it effectively. In general, VR can help teachers explain difficult computer science concepts by transforming abstract ideas into interactive visual experiences. For example, instead of only reading how a program works, students can explore it step-by-step inside a virtual environment. VR can also be used to create realistic team-based projects in which students practice collaboration and problem-solving, similar to real workplaces. These applications make learning more engaging and accessible and provide educators with practical tools to improve teaching and learning outcomes. These findings provide a roadmap for future research and assist educators, policymakers, and technology developers in comprehending where VR in computer science education is heading and which areas require more attention.

6. Conclusion

This study aimed to trace the evolution of virtual reality (VR) in computer science education over the past 25 years. The chief objective was to discern the prevailing growth patterns and to identify the most seminal research papers and future directions in this field. By analysing 341 research articles issued between 2000-April 6,2025, this study traced the evolution of VR as a new experimental medium to a significant component of contemporary computer science education. The review generated several significant findings concerning VR in computer science teaching. Initially, studies on this topic increased significantly, especially since 2018. The number of published papers jumped from nine in 2018 to 96 in 2024, indicating that VR has become a popular research topic. This expansion demonstrates that educators and researchers now regard VR as a valuable teaching tool rather than just an interesting experiment. Subsequently, the study found that 1,214 researchers have contributed to this field, with most papers written by teams of about 3-4 people. This teamwork approach demonstrates that VR education research requires different types of expertise to work together. This research has received significant attention, with over 11,000 citations, proving that it is influential and widely read by other scholars. The analysis identified five main research themes: immersive educational technologies, teaching methods, digital learning approaches, technological integration, and subject-specific applications. These themes show that VR research covers both technical (how technology works) and educational (how students learn better with VR) aspects. Recent research has increasingly focused on combining VR with artificial intelligence and improving human interaction with computers, suggesting exciting future developments. The study also revealed that systematic review papers received the most citations, indicating that researchers and educators value comprehensive overviews that help them to understand what works best in VR education. This finding suggests that the field matures and moves toward evidence-based practice.

These findings have critical real-world applications for several research groups. For teachers and educators, the results provide a roadmap showing which VR approaches have proven most effective, and which research sources offer the most reliable guidance. Teachers can use this information to make better decisions regarding incorporating VR into their computer science classes. For school administrators and policymakers, this study offers evidence to support investments in VR technology. The steady growth in research and citations demonstrates that VR is not just a passing trend, but a legitimate educational tool worth funding. The identification of successful implementation strategies can help institutions avoid common pitfalls and maximise technology investments. For researchers, the analysis highlights gaps that require attention and suggests promising collaboration opportunities. The five thematic clusters provided a clear picture of where the field was heading and which areas required further investigation. Technology companies developing educational VR products can use these insights to create tools that address real educational needs, rather than just impressive technical features.

This study had several limitations that readers should consider. First, the analysis included only papers from the Scopus database and those written in English. This means that some valuable research published in other languages or databases might have been missed, particularly in developing countries, where VR education research may be published in local journals. Moreover, this study focused only on journal articles and excluded conference papers, book chapters, and other publications. As technology research often appears first in conferences, some cutting-edge developments may not be reflected in these results. Furthermore, this study only covered publications up to early 2025; therefore, recent developments were not included. Based on these findings, further research in several areas is required. Further studies should examine how VR affects student learning over extended periods. Most current research looks at short-term effects; however, educators need to know whether VR benefits persist over time. Subsequently, researchers should focus on developing countries and their cultural contexts. Most current research comes from wealthy nations; however, VR could be particularly valuable in places with limited educational resources.

In addition, future studies should develop better ways to measure the educational effectiveness of VR. This field requires standardised methods to compare different VR approaches and determine which works best for various types of learners. With virtual-reality hardware and software becoming less expensive and easier to use, researchers should investigate how VR can be integrated with artificial intelligence and other emerging technologies to generate superior learning experiences. Combining VR with AI has the prospect of personalising learning in new ways that have never been seen before, which can make computer science education more accessible and effective for all students. Future research on VR in computer science education should pursue three strategic approaches. Methodological innovation: Most current studies are short-term and experimental in nature. Future studies should employ longitudinal mixed-methods designs that capture both learning outcomes and lived experiences over extended periods. For instance, researchers might ask: How does repeated exposure to VR-based programming laboratories affect the development of computational thinking skills across an academic semester? Contextual expansion: The dominance of studies from high-income countries limits their generalisability. Future research should include cross-cultural comparative designs and low-resource educational settings. Example questions include the following: What adaptations are needed for VR-based algorithm visualisation in bandwidth-constrained environments? How do cultural learning preferences shape the effectiveness of immersive pedagogy? For educators, two actionable takeaways emerged from this study. First, VR can be strategically employed to teach abstract and conceptually difficult topics, such as algorithms, data structures, or system architecture, through immersive 3D visualisation, which improves comprehension and retention. Second, VR-based collaborative environments can be used to simulate real-world software development settings, thereby strengthening student teamwork, communication, and problem-solving skills. Together, these practices offer immediate opportunities for practitioners to enhance the effectiveness of computer science education through VR.

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