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Advancing Inclusive Educational VR: A Bibliometric Study of Interface Design

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Abstract

While virtual reality (VR) has shown transformative potential in education, its accessibility and inclusivity for learners with disabilities remain insufficiently explored. This study offers the first bibliometric mapping of educational VR interface design for inclusivity, analysing 4,735 documents from 1,714 sources (2020-2025) using Biblioshiny and VOSviewer. The analysis reveals a 13.22% annual publication growth rate, an average of 10 citations per document, and an international co-authorship rate of 25.85%, reflecting both rapid expansion and increasing collaboration. Dominant research themes include user experience, usability, and the metaverse, while underexplored areas such as cognitive accessibility and neurodiverse learners highlight emerging opportunities. The findings demonstrate a concentration of scholarly activity in North America and Asia, with limited representation from the Global South. Practically, the study informs developers on designing adaptive interfaces, guides educators in implementing inclusive VR pedagogies, and provides policymakers with evidence for promoting equitable digital learning ecosystems. By identifying trends, gaps, and collaboration patterns, this research advances the discourse on inclusive educational VR and underscores the need for interdisciplinary, AI-driven accessibility strategies that ensure equitable participation for all learners.

Keywords: virtual reality, accessibility, inclusivity, interface design, bibliometric analysis, learners with disabilities

1. INTRODUCTION

The integration of Virtual Reality (VR) into education has transformed learning by enabling immersive, experiential, and interactive environments that enhance engagement and conceptual understanding learning [1], [2] [3], [4]. From virtual laboratories to historical simulations, VR has redefined how students interact with knowledge. However, while pedagogical applications have expanded, research focusing on inclusivity and equitable access for learners with disabilities remains limited [5]. Current VR systems often lack adaptive interfaces, inclusive input methods, and feedback mechanisms suitable for diverse users.

Despite growing awareness of universal design principles [6], [7], their consistent application in educational VR remains fragmented. This study is distinctive in

combining bibliometric analysis with inclusivity research to systematically map the intellectual, thematic, and geographic evolution of interface design and accessibility in educational VR. By doing so, it advances understanding of how inclusivity has been conceptualised, operationalised, and neglected across the global research landscape.

Accordingly, the study addresses the following research questions: (1) What are the research trends and developments in inclusive VR interface design for education? (2) Who are the leading contributors and collaboration networks? (3) Which interface design aspects most enhance inclusivity? (4) What key innovations have shaped accessibility in educational VR? Finally, (5) what emerging directions can guide future inclusive design efforts?.

To answer these questions, the study adopts a bibliometric research design that enables a systematic and quantitative exploration of the intellectual structure, research trends, and collaboration networks in inclusive educational VR. This approach allows for a comprehensive overview of global scholarship, highlighting both dominant and underrepresented themes. By leveraging Biblioshiny for performance analysis and VOSviewer for visual network mapping, the study identifies key contributors, thematic clusters, and emerging directions that shape the discourse on accessibility and interface design. This dual-tool methodology ensures analytical rigour and provides a reliable evidence base for advancing inclusive educational technologies.

2. METHODS

2.1. Research Design

This study employed a bibliometric analysis to systematically explore research trends, thematic evolution, and collaboration networks in interface design and accessibility for educational VR targeting learners with disabilities. The bibliometric approach was selected for its capacity to quantitatively synthesise a large body of literature, uncover citation dynamics, and visualise the evolution of scholarly themes. Unlike traditional literature reviews, bibliometric mapping offers objectivity and replicability by relying on measurable indicators such as publication growth, citation impact, and co-authorship networks [8]. This methodological choice is particularly novel within inclusivity research, as it integrates data-driven insights with the social dimensions of accessibility discourse. By combining performance analysis and science mapping, the study provides both a descriptive and conceptual understanding of how inclusivity and interface design intersect in educational VR, thereby offering evidence-based foundations for future scholarly and practical interventions. Figure 1 depicts the flowchart of the bibliometric workflow from data collection to analysis.

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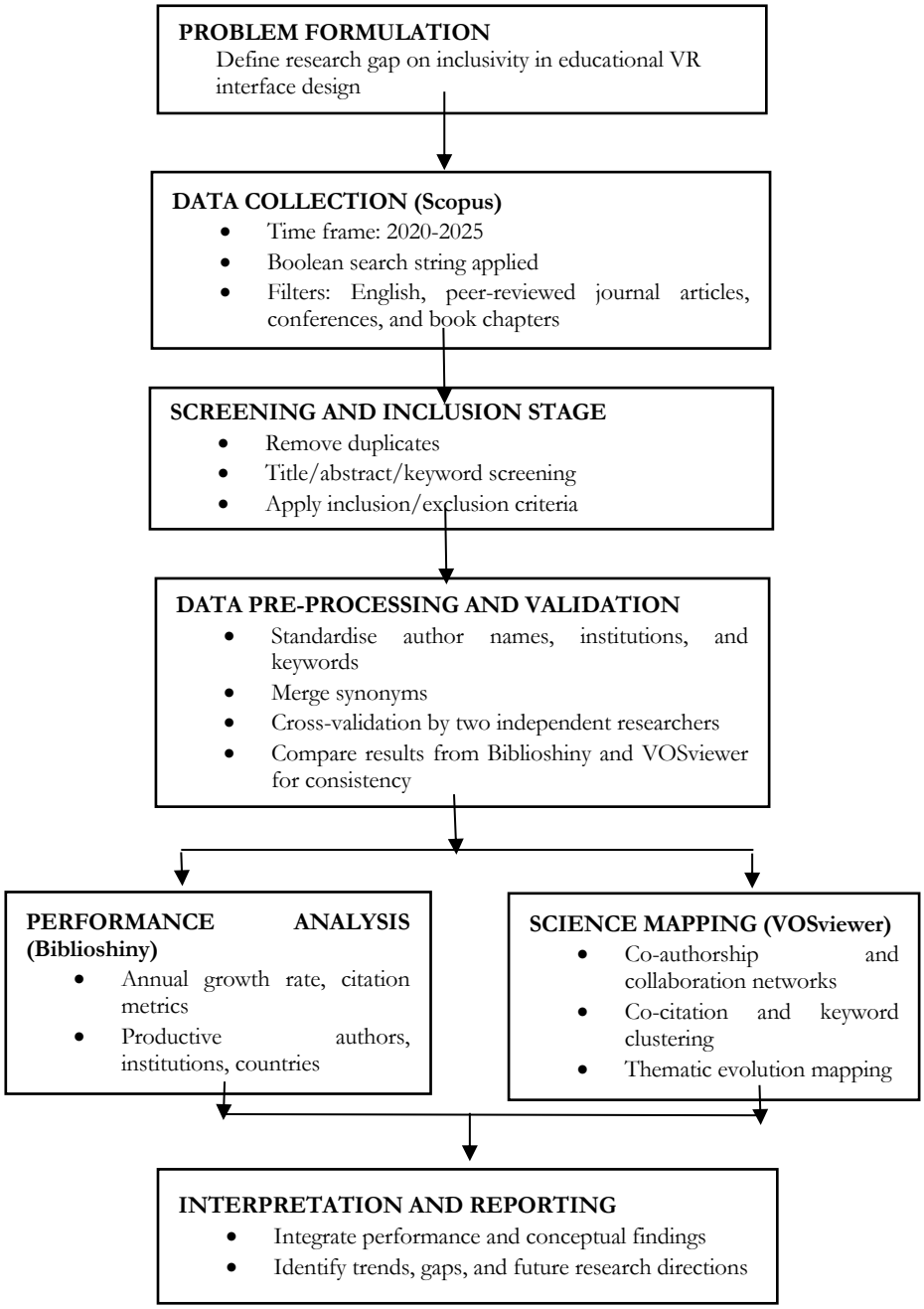

Figure 1. Bibliometric workflow

2.2. Database and Search Strategy

In the data collection process, the researchers were guided by a structured search strategy. The study utilised the Scopus database owing to its extensive coverage, multidisciplinary scope, and reliable indexing standards, which make it ideal for bibliometric research [9], [10], [11]. The search was conducted on 28 June 2025, targeting literature published between January 2020 and June 2025 to capture post-pandemic advancements in immersive learning technologies and accessibility innovations. A structured Boolean search string was developed to identify studies situated at the intersection of virtual reality, interface design, and accessibility within educational contexts:

("virtual reality" OR "VR") AND ("inclusive design" OR accessibility OR "universal design" OR "assistive interface" OR "accessible interface") AND ("interface design" OR "user interface" OR "UI" OR "interaction design" OR "usability" OR "interactivity") AND PUBYEAR > 2019 AND PUBYEAR < 2026

To ensure quality and relevance, filters were applied to include only peer-reviewed journal articles, conference proceedings, and book chapters written in English. Exclusion criteria eliminated studies focusing exclusively on technical VR engineering without educational application, non-English publications, and non-scholarly sources. Following de-duplication, articles were screened by title, abstract, and keywords to confirm alignment with the study's objectives.

2.3. Data Analysis

Data analysis was conducted in two complementary phases: performance analysis and science mapping [12].

1) Performance Analysis

This phase examined publication growth, citation trends, prolific authors, institutional affiliations, and leading countries. Using Biblioshiny, descriptive metrics such as total publications, annual growth rate, and average citations per document were computed. These indicators provided a quantitative foundation for assessing research productivity, collaboration, and impact within the field.

2) Science Mapping

This phase explored the cnceptual and intellectual structure of the research landscape using VOSviewer. Co-authorship, co-citation, and keyword co-occurrence networks were generated to reveal collaboration patterns, influential sources, and emerging research clusters. The clustering algorithm grouped related

terms, enabling the identification of dominant and underexplored themes in inclusive VR interface design. This dual-tool strategy provided both breadth and depth, with Biblioshiny offering macro-level performance metrics while VOSviewer providing micro-level visual insights. Together, they ensured analytical triangulation and enhanced the validity of interpretation

2.4. Data Preprocessing

To ensure accuracy, bibliographic data were preprocessed before analysis. This included standardizing author names and institutional affiliations, merging synonyms and variations of keywords, and removing irrelevant or redundant terms [8], [13]. These steps ensured consistency and reliability in the analysis.

2.5. Validation and Reliability

The methodology incorporated several measures to ensure the reliability and validity of the findings. Two independent researchers reviewed and refined the search strategy to minimize bias [14]. Data preprocessing steps were cross-validated to reduce errors, and results from Biblioshiny and VOSviewer were compared to ensure consistency and complementarity [15]. This dual-tool approach enhanced the analysis's robustness by leveraging both tools' strengths. The entire process adhered to ethical research principles, as all data were sourced from publicly available records. No personal or confidential information was used, and all methods were transparently documented to support reproducibility and scholarly integrity.

3. RESULTS AND DISCUSSION

The results were presented according to the research questions as follows:

3.1. What are the research trends and developments in interface design and accessibility of educational VR for learners with disabilities?

An in-depth analysis, as depicted in Table 4.1, summarises the results. In the table, a 2020 - 2025 dataset encompasses 4,735 documents with a 13.22% annual growth rate, indicating a rapidly expanding field. The average citation per document (10) reflects moderate academic impact, while the high international co-authorship rate (25.85%) highlights significant global collaboration. However, the dominance of conference papers (2,040) over journal articles (2,352) suggests a preference for rapid dissemination over peer-reviewed validation. The average document age of 2.01 indicates a relatively young and evolving research area. The high number of keywords (16,880) and authors (15,216) suggests a broad and diverse research landscape, but the relatively low number of single-authored documents (320)

points to a strong emphasis on collaborative efforts. This table underscores the field's growth and highlights the need for more rigorous, journal-based research outputs.

Table 1. Summary of results

Description	**Results**
MAIN INFORMATION ABOUT DATA	
Timespan	2020:2025
Sources (Journals, Books, etc.)	1714
Documents	4735
Annual Growth Rate %	13.22
Document Average Age	2.01
Average citations per doc	10
References	0
DOCUMENT CONTENTS	
Keywords Plus (ID)	16880
Author's Keywords (DE)	11284
AUTHORS	
Authors	15216
Authors of single-authored docs	291
AUTHORS COLLABORATION	
Single-authored docs	320
Co-Authors per Doc	4.38
International co-authorships %	25.85
DOCUMENT TYPES	
Journal articles (2360), conference papers (2073), book chapters (302)	2735

Figure 2 illustrates the annual scholarly output on educational VR inclusivity from 2020 to mid-2025 to further elaborate on the research trends. It shows a steady increase in article production from 438 in 2020 to a peak of 1,378 in 2024, representing heightened academic interest and rapid scholarly advancement in this area. However, a notable decline in 2025, potentially due to partial-year data availability, indicates caution in interpreting recent trends. Overall, this trajectory underscores significant and growing attention to inclusivity and accessibility in VR education, reflecting increasing recognition of its critical role in accommodating learners with disabilities.

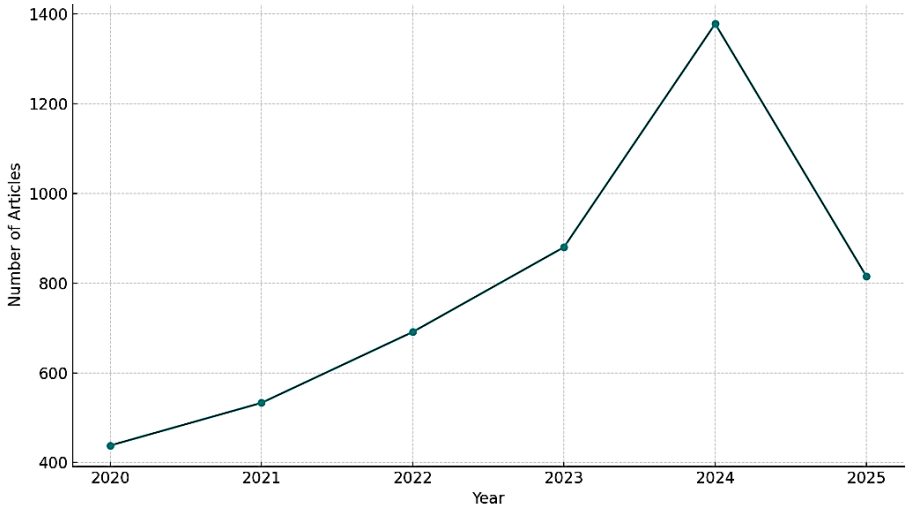

Figure 2: Annual production

Research trends can be visible if connections within the scholarship of VR inclusivity are made using thematic clusters. Figure 3 depicts a thematic map.

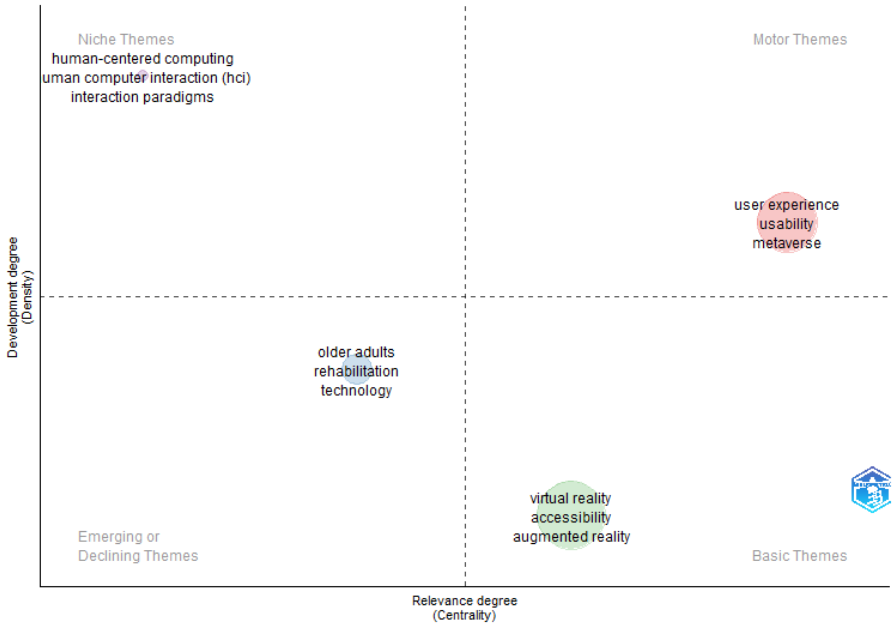

Figure 3. Thematic map

The themes are organized based on their "development degree" (density) and "relevance degree" (centrality). The motor themes are located in the upper right

quadrant, signifying their centrality and substantial level of development. The covered themes are "user experience," "usability," and "metaverse." The specialized themes are located in the upper left quadrant; despite being less central, they demonstrate significant advancement. They encompass "human-centered computing," "human-computer interaction," and "interaction paradigms." The basic themes are located in the lower right quadrant, occupying a central position yet exhibiting minimal growth. The subjects include "virtual reality," "accessibility," and "augmented reality." Emerging or dropping themes are in the lower left quadrant, marked by low centrality and restricted development. The themes include "older adults," "rehabilitation," and "technology." This map is essential for determining which subtopics are oversaturated and which are inadequately explored. Focusing on the latter may provide significant innovations. Thematic mapping offers a diagnostic of the field's structure and a guide for strategic academic inquiry.

3.2. Who are the leading contributors (authors, institutions, countries) to research on inclusive VR interface design in education, and how are they interconnected?

To answer this research question, an analysis was done for the impact of authors within the VR scholarship space. Table 2 highlights the author's local impact by h-index.

Table 2. Author local impact by h-index

Author	h_index	g_index	m_index	TC	NP	PY_start
LI J	12	25	2.40	650	36	2021
ZHANG Y	10	17	2.50	315	30	2022
LI Y	9	16	1.80	280	25	2021
LIU Y	9	23	1.50	572	30	2020
WANG Y	9	16	1.80	315	44	2021
LI Z	8	12	1.33	167	23	2020
VATAVU RD	8	14	1.33	213	22	2020
ZHAO Y	8	16	1.33	290	27	2020
AZENKOT S	7	13	1.17	182	16	2020
COLLEY M	7	11	1.17	216	11	2020

LI J ranks highest with an h-index of 12 and a total citation count of 650 from 36 publications, highlighting prolific output and scholarly recognition. Other notable contributors include *ZHANG Y, WANG Y,* and *LIU Y*, each with over 25 publications and strong citation performance. Many top-ranking authors entered the field post-2020, indicating a surge of emerging thought leaders. Authors like

AZENKOT S and *COLLEY M* contribute significantly despite fewer publications, suggesting high-quality outputs. Most authors are from technical backgrounds, as evidenced by their publication venues. The author list reflects diversity in academic lineage and concentration in East Asia and North America. Expanding collaboration to include underrepresented regions and interdisciplinary voices would benefit the field. Thus, this table is both a productivity metric and a diagnostic for diversity.

Equally, Table 3 reflects the most relevant institutions in VR for inclusivity, with the University of Washington leading with 72 publications, followed closely by institutions like the University of California (65), the University of Toronto (54), and Stanford (50). These top producers are mainly North American, signaling a geographic research concentration in well-funded, technologically advanced institutions. Monash University and Tsinghua University bring notable representation from Australia and China, respectively, indicating some regional diversification. Carnegie Mellon and Cornell also contribute substantially. This distribution points to a strong foundation in developed countries but also exposes a gap in output from the Global South. Increasing contributions from diverse geopolitical and linguistic contexts would strengthen inclusivity not only in VR design but also in the research ecosystem itself. Funding equity and global collaboration remain crucial.

Table 3. Most Relevant Institution

Affiliation	Country	Articles
University of Washington	USA	72
University of California	USA	65
University of Toronto	Canada	54
Stanford University	USA	50
Monash University	Australia	49
University of Florida	USA	49
Tsinghua University	China	48
Carnegie Mellon	USA	46
Cornell University	Qatar	46
University of Michigan	USA	43

The corresponding author countries shown in Table 4 reflect the number of articles published by each country and the international collaboration rate on the subject matter. The United States and China lead in article volume, contributing 410 and 377 publications, respectively. While publishing fewer documents, the UK records the highest international collaboration rate (MCP% %) at 38.01%, highlighting its global engagement. India and Korea also show significant

productivity, though their lower MCP percentages reflect a more insular research approach. Canada's and Australia's mid-range output and high MCP percentages (over 29%) suggest robust international collaboration. While research remains concentrated in technologically advanced regions, these figures indicate a slow but promising shift toward a more diversified and interconnected scholarly community. Promoting collaborative frameworks across continents, particularly those involving the Global South, will ensure equitable innovation in inclusive VR education.

Table 4. Corresponding author countries

Country	Articles	Articles %	SCP	MCP	MCP %
USA	410	8.65892291	332	78	19.0243902
China	377	7.96198522	288	89	23.6074271
United Kingdom	171	3.61140444	106	65	38.0116959
Germany	170	3.59028511	137	33	19.4117647
Italy	156	3.29461457	126	30	19.2307692
Korea	148	3.12565998	117	31	20.9459459
Spain	127	2.68215417	93	34	26.7716535
India	122	2.57655755	103	19	15.5737705
Australia	97	2.04857445	68	29	29.8969072
Canada	89	1.87961985	62	27	30.3370787

Table 5 also adds leading publishers in the VR domain by depicting the source local impact, with the "Conference on Human Factors in Computing Systems" leading with the highest h-index (35), citation count (4,370) and number of publications (270), followed by the "International Journal of Human-Computer Interaction" and "IEEE Transactions on Visualization and Computer Graphics." These sources hold strong h-index and g-index values, reflecting productivity and impact. Most of these publication venues started publishing in this domain post-2020, aligning with the spike in virtual learning demand. The consistently high m-index values suggest rapid citation accrual, indicative of relevant, timely research. The dominance of computing and HCI journals suggests the field is still primarily engineering-oriented, reinforcing the importance of integrating inclusive design principles at the technical level.

Table 5. Source local impact

Source	h_index	g_index	m_index	TC	NP	PY_start
Conference on Human Factors in Computing Systems - Proceedings	35	49	5.833	4370	270	2020

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Source	h_index	g_index	m_index	TC	NP	PY_start
International Journal of Human-Computer Interaction	17	41	2.833	1723	64	2020
IEEE Transactions on Visualization and Computer Graphics	14	25	2.333	658	35	2020
Proceedings of the ACM on Human-Computer Interaction	14	22	2.333	624	81	2020
Virtual Reality	14	27	2.333	775	45	2020
ACM International Conference Proceeding Series	13	18	2.167	740	180	2020
ACM Transactions on Accessible Computing	13	19	2.167	381	25	2020
Applied Sciences (Switzerland)	13	28	2.167	860	59	2020
IEEE Access	13	23	2.167	655	65	2020
International Journal of Human-Computer Studies	13	20	2.167	448	38	2020

To add more clarity, Figure 4 shows the country's scientific production, indicating how active a country is in terms of inclusive VR scholarship.

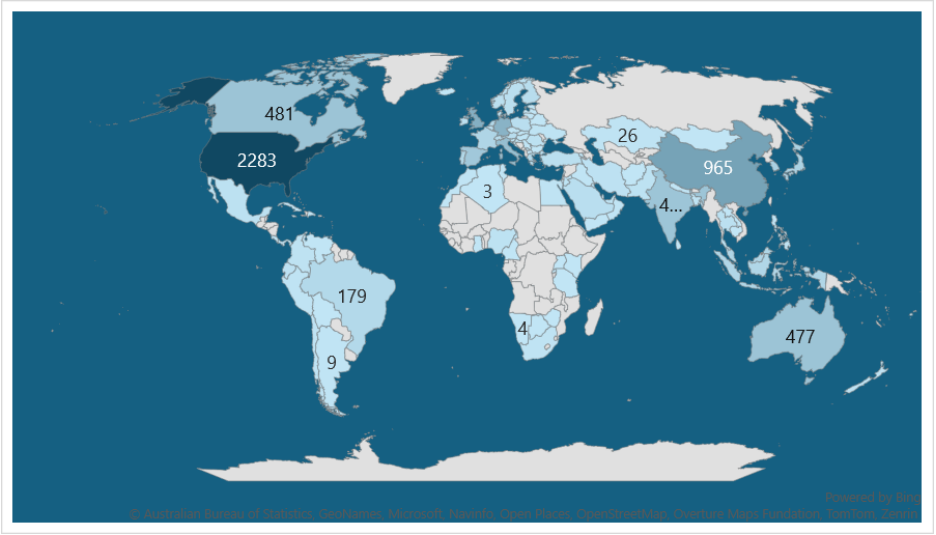

Figure 4. Country scientific production

The figure confirms the dominance of the United States (2,283) and China (965) regarding total scientific output related to inclusive VR education. The UK,

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Germany, and Italy, with 783, 724, and 533, respectively, also contribute significantly, forming a cluster of European engagement. Canada and Australia's presence indicates growing involvement from the Asia-Pacific region. However, the visualization reveals an underrepresentation of the Global South, particularly Africa and Latin America, suggesting geographic imbalances in research contributions. Encouraging equitable access to publishing platforms, international funding, and academic exchanges can help bridge these disparities. Building a truly global research ecosystem on inclusive VR design will require increased inclusion of diverse contexts and user perspectives.

Figure 5 presents the temporal trajectory of country-level research output, revealing how engagement in inclusive VR scholarship has evolved across regions over time.

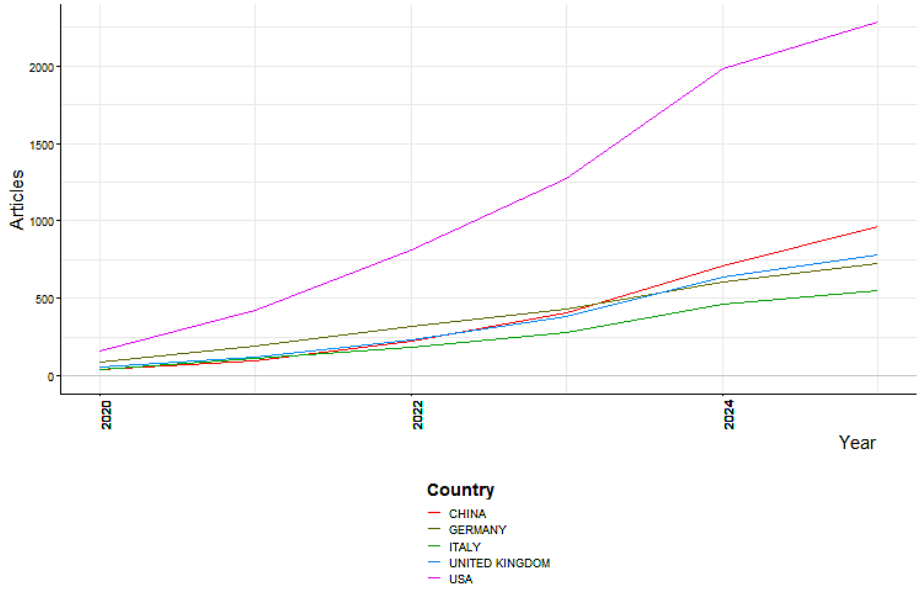

Figure 5. Country production over time

This figure traces the evolution of research output in inclusive VR over time. It shows steady leadership by the United States and China, with European nations gradually increasing their presence after 2021. This trend suggests a growing recognition of inclusivity and accessibility within immersive learning research. Nevertheless, the minimal participation from developing regions highlights the persistent challenges of unequal access to research opportunities and digital infrastructure. The upward trajectory since 2020 mirrors the post-pandemic emphasis on virtual learning, yet true inclusivity in this domain requires greater

international collaboration and sustained engagement from underrepresented regions.

Complementary, Table 6 depicts the most cited countries. India and the UK exhibit the highest average citations per article (23.9 and 23.2, respectively), signaling that although they produce fewer documents than China or the USA, their work resonates strongly within the field. China leads in total citations (5,526), reflecting the scale of its output. The USA also demonstrates substantial reach, though with a lower average citation rate, suggesting quantity over per-paper influence. Countries such as Korea and Spain maintain a steady impact, while Germany and Italy trail in citation efficiency. These trends imply that while volume matters, focused, high-quality research, often from smaller contributors, plays a critical role in shaping scholarly dialogue.

Table 6: Most cited countries

Country	TC	Average Article Citations
China	5526	14.7
United Kingdom	3967	23.2
USA	3697	9
India	2916	23.9
Korea	2227	15
Spain	1454	11.4
Canada	1234	13.9
Italy	1159	7.4
Germany	1033	6.1
Australia	973	10

To complement these citation metrics, Figure 6 visualises the distribution of the most cited countries, illustrating disparities in research influence across global regions. This figure illustrates the distribution of research influence across countries involved in inclusive educational VR. The data reveal that China, the United Kingdom, and the United States are leading contributors, reflecting their well-established research infrastructures and consistent investment in technological innovation. However, the limited representation of African and Latin American countries underscores enduring regional inequalities in academic participation. Broadening access to research funding and advancing collaborative partnerships could help strengthen the visibility and contribution of Global South scholars in this rapidly developing field.

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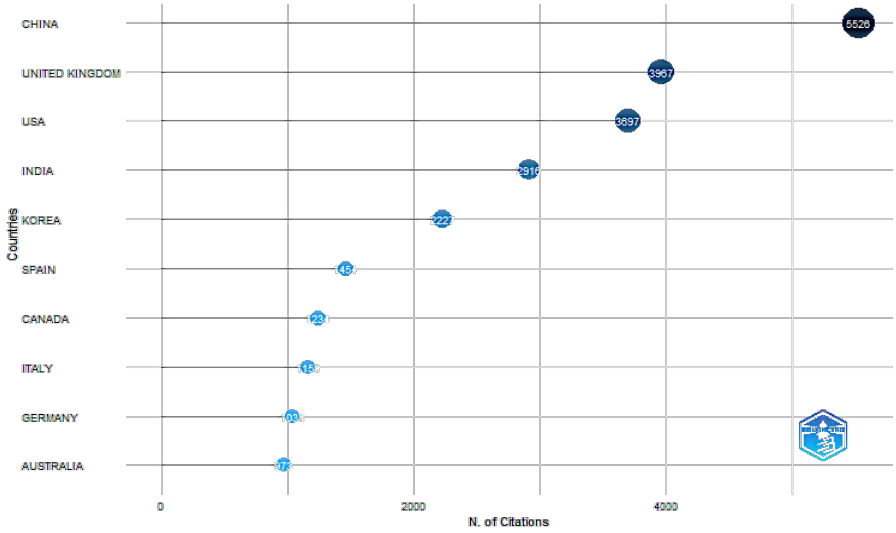

Figure 6. Most cited countries

A collaboration network can augment this, as shown in Figure 7, which reveals tightly knit clusters among authors from the USA, China, and the UK, indicating strong intra-regional partnerships. However, the overall structure also suggests fragmentation, with fewer bridges connecting Global North and South institutions.

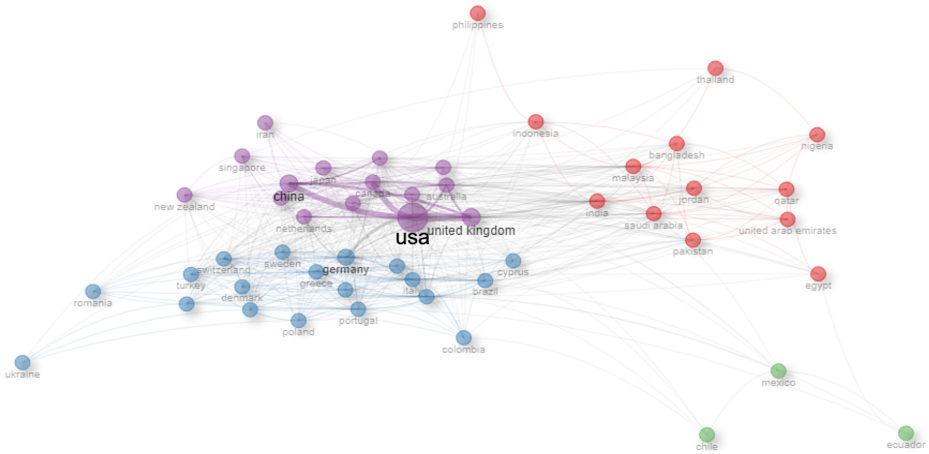

Figure 7. Country collaboration network

This pattern highlights a critical barrier to equitable knowledge production. The lack of integration may stem from disparities in funding, access, and academic recognition. Increasing international collaboration, particularly with

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underrepresented regions, could bring new perspectives to inclusive VR research. Strengthening cross-border partnerships ensures that VR technologies reflect diverse cultural, linguistic, and educational contexts. Furthermore, based on Figure 8, high co-citation levels between countries like the USA, China, and Germany suggest these nations are foundational in shaping shared scholarly references.

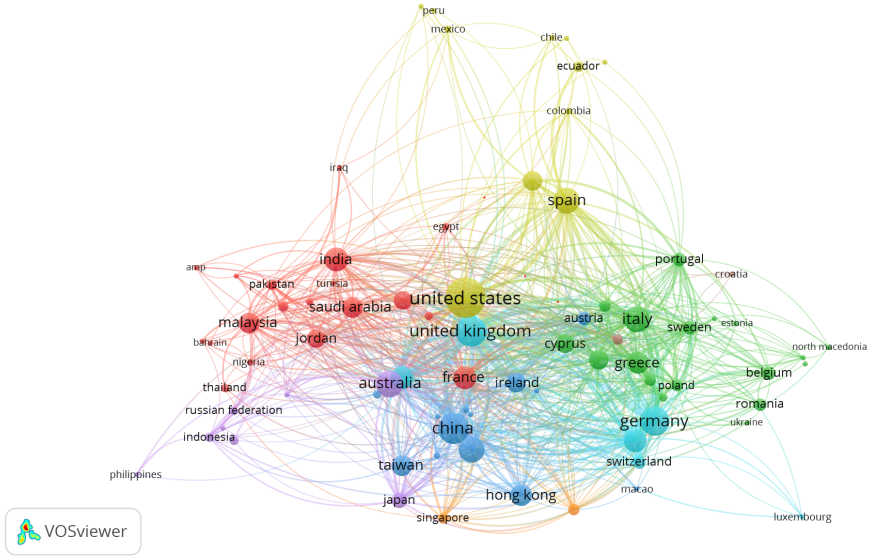

Figure 8. Country co-citation

This clustering indicates consensus in the literature's intellectual base. However, countries from Africa and Latin America remain peripheral, reflecting under-citation and perhaps under-participation in the global dialogue. This epistemic imbalance warrants intervention through citation inclusion strategies, co-authorship incentives, and language accessibility reforms. A more representative co-citation network would enrich the diversity of theoretical and empirical contributions to the field.

3.3. Which aspects of interface design have been most frequently addressed to enhance inclusivity in educational VR for learners with disabilities?

To ascertain the VR interface design aspects, the research used the most relevant words, including the word cloud. The bar chart in Figure 9 shows the most frequently occurring keywords in the dataset, revealing the thematic focus of the research field.

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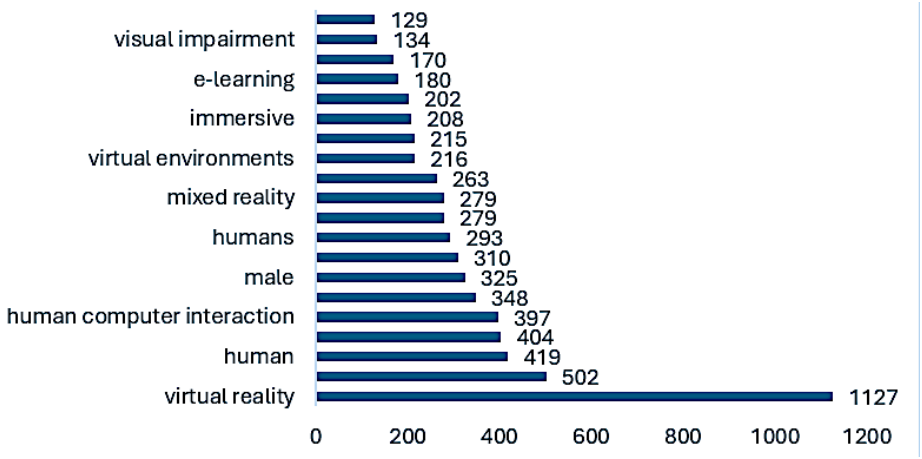

Figure 9. Most relevant words

Unsurprisingly, "virtual reality" dominates with 1,127 mentions, reinforcing its centrality to the discourse. "Human" and "human computer interaction" follow, with 419 and 404, reflecting a strong user-centered approach in interface design. Notably, keywords such as "male," "humans," and "visual impairment" indicate demographic and accessibility-focused sub-themes. Terms like "e-learning," "immersive," and "mixed reality" point to the educational and experiential dimensions being actively explored. However, "visual impairment" appears relatively low (129 mentions), signaling a research gap in addressing this key accessibility area.

Additionally, a word cloud depicted in Figure 10 shows that terms such as "accessibility", "virtual reality", "inclusive learning", "human-computer interaction", and "interface design" dominate, reflecting the study's focus on inclusivity in educational VR. These keywords demonstrate thematic consistency around user-centered design, assistive technology, and learner diversity. Their recurrence suggests stable research priorities across the corpus. However, the absence of terms like "disability", "inclusive education", or any other pedagogical or policy-oriented terms suggests a gap in targeted research addressing specific learner needs. The prominence of technical terms like "haptic feedback" and "immersive learning" indicates a strong focus on technological advancements. However, the lack of policy-related keywords highlights a need for systemic approaches to inclusivity. This figure underscores the importance of aligning research priorities with the practical needs of disabled learners, ensuring that technological innovations translate into meaningful educational outcomes.

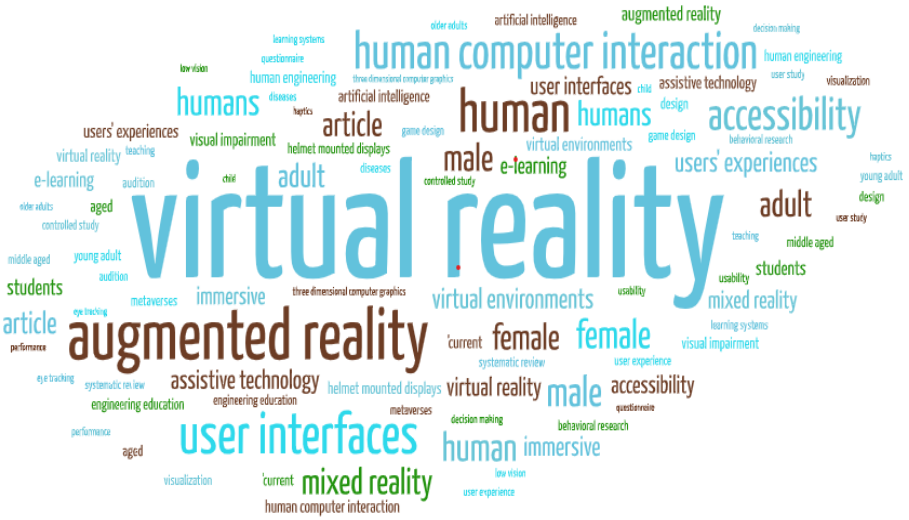

Figure 10. Wordcloud

3.4. What key developments and innovations have significantly influenced the accessibility and inclusivity of VR educational tools for disabled learners?

The research also aimed to ascertain the key developments and innovations that have impacted the accessibility and inclusivity of VR educational tools, particularly for disabled learners. The most globally cited documents were also critically analyzed and depicted in Table 7. The results indicate that Dwivedi et al. (2022) and Chang et al. (2020) stand out for their foundational contributions; one tackling the Metaverse's educational potential and examining VR sickness. Sreeramoj and Batcha (2025) offer a forward-looking framework, signifying emerging thought leadership. These top-cited works balance empirical insight, conceptual development, and technological exploration. Many documents emphasize interdisciplinary intersections, ranging from AI to cultural preservation, which broaden the scope of accessibility discourse. Their high normalized citation scores indicate sustained relevance. These landmark studies provide scaffolding for subsequent research, revealing key innovations and persistent challenges in designing inclusive virtual learning environments.

Table 7. Most globally cited documents

No	Author(s), Year, Article title, Publication, DOI	TC	TC/Year	N_TC
1	Sreeramoj CC & Batcha SB, 2025, *Advancing Digital Libraries through Augmented Reality and Virtual Reality: A Comprehensive Framework*, International Conference on Data Science, Agents & Artificial Intelligence (ICDSAAI) 10.1109/ICDSAAI65575.2025.11011726	2025	2025	363.44

No	Author(s), Year, Article title, Publication, DOI	TC	TC/Year	N_TC
2	Wang M, 2025, *Research on Digital Protection and Inheritance of Yellow River Cultural Resources Based on Intelligent Technology*, Frontiers in Artificial Intelligence and Applications 10.3233/FAIA250274	2024	2024	363.26
3	Dwivedi et al., 2022, *Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice, and policy*, International Journal of Information Management 10.1016/j.ijinfomgt.2022.102542	1669	417.25	103.29
4	Gorski LA, 2021, *Infusion therapy standards of practice*, Journal of Infusion Nursing 10.1097/NAN.0000000000000396	699	139.8	33.33
5	Chang E, Kim, HT & Yoo B, 2020, *Virtual Reality Sickness: A Review of Causes and Measurements,* International Journal of Human–Computer Interaction 10.1080/10447318.2020.1778351	613	102.17	28.76
6	Elkin et al., 2021, *An Aligned Rank Transform Procedure for Multifactor Contrast Tests*, UIST '21: The 34th Annual ACM Symposium on User Interface Software and Technology 10.1145/3472749.3474784	420	84	20.03
7	Scavarelli A, Arya A & Teather RJ, 2021, *Virtual reality and augmented reality in social learning spaces: a literature review.* Virtual Reality 10.1007/s10055-020-00444-8	275	55	13.11
8	Ozmen et al., 2023, *Six Human-Centered Artificial Intelligence Grand Challenges.* International Journal of Human–Computer Interaction 10.1080/10447318.2022.2153320	237	79	30.09
9	Ming et al., 2021, *How social presence influences impulse buying behavior in live streaming commerce? The role of S-O-R theory*, International Journal of Web Information Systems 10.1108/IJWIS-02-2021-0012	236	47.2	11.25
10	Lu J et al., 2021, *The potential of virtual tourism in the recovery of tourism industry during the COVID-19 pandemic.* Current Issues in Tourism 10.1080/13683500.2021.1959526	229	57.25	14.17

TC = Total number of citations;
TC/Year = Total number of citations per Year.
N_TC = Naturalized total citations.

Figure 11 depicts strong bibliographic coupling among top journals and conferences, notably the Conference on *Human Factors in Computing Systems Proceedings, ACM International Conference, IEEE Transactions on Visualization and Computer Graphics,* and *Virtual Reality*. High coupling strength indicates shared references and alignment in thematic scope and scholarly direction. This interconnectedness implies robust academic consensus on essential principles guiding inclusive design, usability, and accessibility in educational VR, thus providing scholars with a coherent and unified research foundation.

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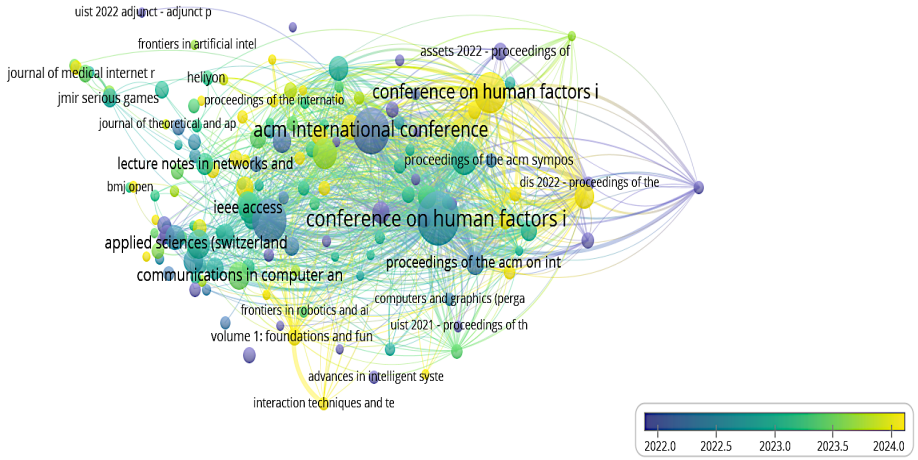

Figure 11. Source coupling

Figure 12 depicts country document coupling across countries, revealing strong alignment between the USA, China, and the UK, indicating mutual referencing and topic convergence.

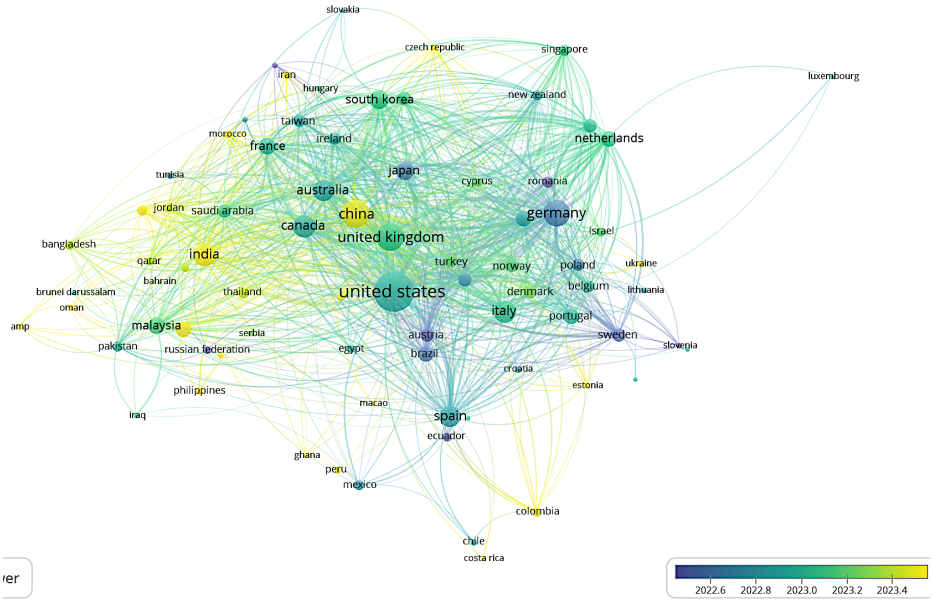

Figure 12. Country documents coupling

This reinforces their leadership in inclusive VR research. Nevertheless, sparse connections to countries from Africa, the Middle East, or Southeast Asia suggest

underrepresentation in the global citation network. Enhancing visibility and collaboration with these regions would balance knowledge flows and ground research in varied lived experiences, making inclusivity more authentic and globally informed. Figure 13 depicts the most relevant sources in the field of VR accessibility.

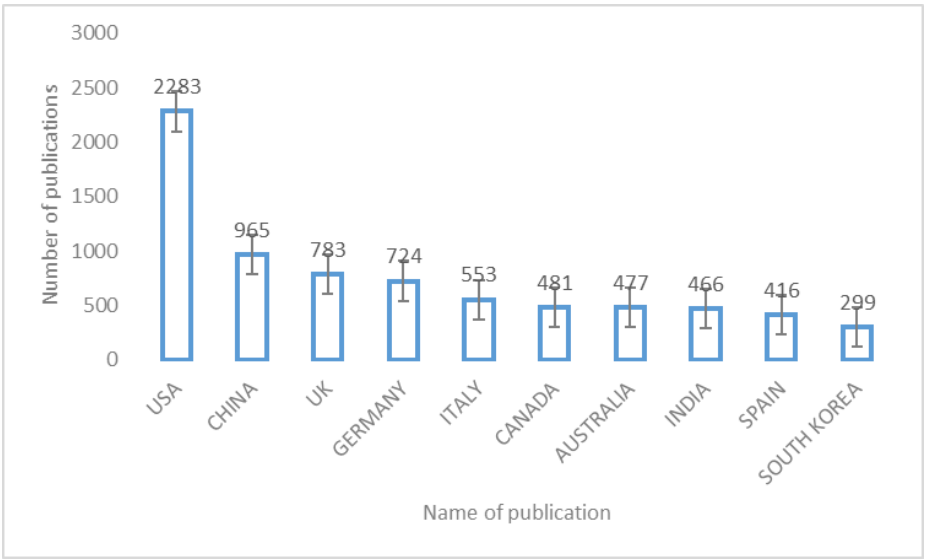

Figure 13: Most relevant source

The top sources include the *Conference on Human Factors in Computing Systems* and *ACM International Conference Proceedings Series*, which dominate due to their focus on human-computer interaction and accessibility. Journals like *IEEE Access*, *International Journal of Human-Computer Interaction,* and *Applied Sciences (Switzerland)* also feature prominently, reflecting the field's interdisciplinary nature. This indicates that researchers prioritize peer-reviewed, high-impact venues. The list demonstrates a healthy balance between theoretical inquiry and applied research, though it emphasizes a need to include more pedagogy-focused outlets to bridge technical and educational perspectives.

3.5. What are the emerging directions and recommendations for advancing inclusivity in educational VR interface design?

The VOSviewer overlay map of author keywords in Figure 14 offers a snapshot of evolving research interests in inclusive educational VR. Central terms like "virtual reality," "usability," and "visual impairment" reflect sustained attention to accessibility. At the same time, newer keywords such as "immersive learning," "user experience (UX)," and "digital cultural heritage" suggest a growing shift

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toward personalized and context-sensitive design. Assistive technologies like "eye tracking" and "haptic feedback" feature prominently, underscoring efforts to accommodate diverse user needs. The inclusion of terms such as "children," "older adults," and "ADHD" indicates expanding demographic considerations. However, the relative isolation of terms like "sign language" and "low vision" points to underrepresented areas. Thus, the figure highlights a vibrant yet uneven landscape, where the conversation around inclusive VR is gaining momentum, though deeper exploration of marginalized needs remains essential.

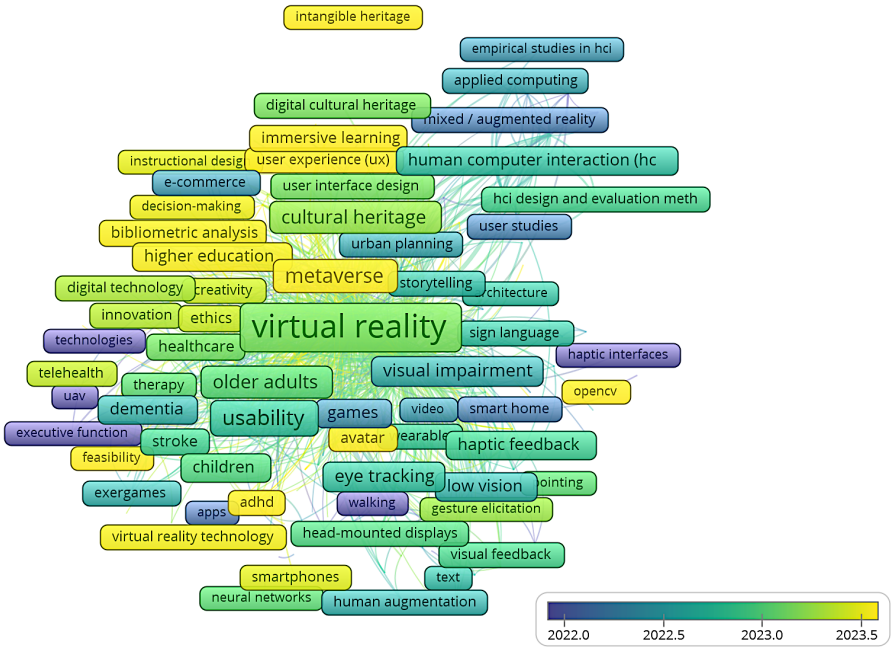

Figure 14: Author keywords

The trend topics visualization in Figure 15 provides a temporal perspective on the field's emergence and evolution of key terms. Early terms like "head-mounted displays," "user experience," and "human engineering" show foundational technical and ergonomic concerns that dominated around 2020. From 2022 onward, there is a notable shift with more socially responsive themes such as "accessibility," "female," "augmented reality," and "virtual reality" gaining prominence, indicating a growing focus on inclusive design and diversity. Most recently, terms like "language model" and "large language model" suggest a cross-disciplinary convergence with AI developments, reflecting the field's adaptation to broader technological trends. The presence of "virtual reality" and "human" across multiple years highlights their enduring centrality. Thus, the chart illustrates a

maturing field, transitioning from hardware-centric beginnings to a more inclusive, user-focused, and AI-integrated future.

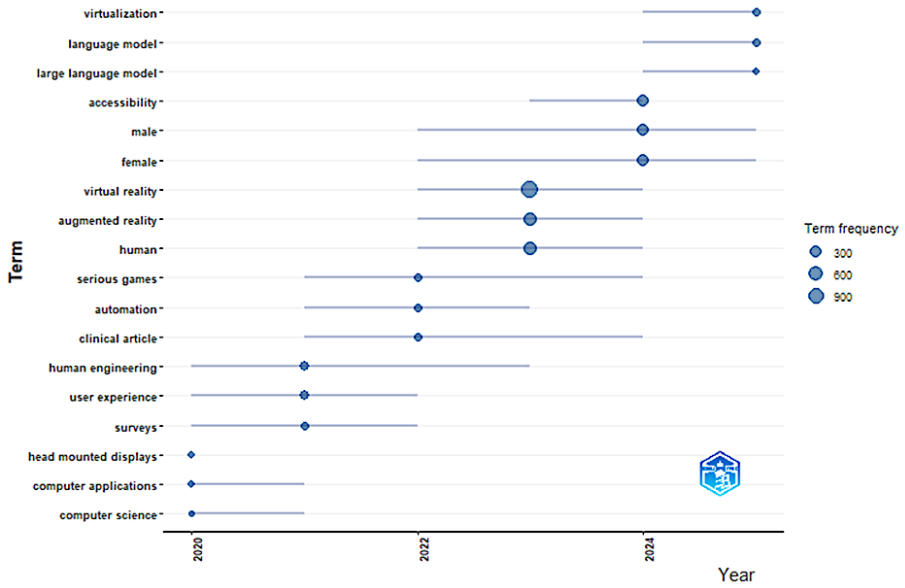

Figure 15. Trending topics in VR inclusive interface design

This bibliometric analysis offers a detailed overview of the research landscape related to interface design and accessibility in educational VR for learners with disabilities. The steady rise in publications from 2020 to 2025, with a 13.22% yearly growth rate, indicates a growing scholarly interest in inclusive VR. This corresponds with [1], who observed an increase in VR research owing to its capacity to revolutionize education for those with impairments. The prevalence of conference papers compared to journal articles (2,040 versus 2,352) indicates a propensity for expedited publication, potentially undermining the depth and rigor of research. This trend aligns with the findings of [16], who noted the same tendencies in VR-related research. The thematic map highlighted key themes such as "user experience," "usability," and "metaverse," which are essential for promoting inclusiveness. These findings correspond with [6], who underscored the significance of user-centered design in addressing accessibility obstacles. Nevertheless, burgeoning themes such as "older adults" and "rehabilitation" remain inadequately examined, suggesting prospective areas for future research.

The analysis identified LI J, ZHANG Y, and WANG Y as prominent authors, with substantial contributions from universities such as the University of Washington and Tsinghua University. The research concentration in North America and Asia reflects patterns identified by [3], who emphasized the preeminence of highly

advanced technological regions in VR research. The underrepresentation of institutions from the Global South highlights the necessity for fairer global collaboration. Esparza et al. [17] similarly observed the marginalization of specific regions in VR research, advocating for enhanced financing and academic collaboration.

The United States and China dominate scientific output, although the United Kingdom's elevated international collaboration rate (38.01%) indicates a more integrated research approach. This discovery corresponds with [10], who underscored the significance of international collaborations in improving research quality. The restricted involvement with Africa and Latin America underscores ongoing geographic inequalities [18].

Keywords such as "accessibility," "interface design," and "virtual reality" prevail in the research domain, indicating a pronounced emphasis on user-centered design. This corresponds with [7] findings, highlighting the significance of universal design principles in developing inclusive VR environments. The infrequent use of phrases such as "disability" and "inclusive education" indicates a deficiency in addressing the particular requirements of learners. This observation aligns with [6], who identified a deficiency in focused research on various disabilities. The prevalence of technical terminology such as "haptic feedback" and "immersive learning" emphasizes technological progress. The lack of policy-related terminology underscores the necessity for systemic strategies to promote inclusion, as noted by [19]. This disparity highlights the necessity of incorporating pedagogical and policy viewpoints into VR research. Noteworthy publications, such as those by [20] and [21], have profoundly impacted the domain by exploring the educational prospects of the Metaverse and the phenomenon of VR sickness, respectively. These studies establish a basis for comprehending the problems and potential of inclusive VR. Nonetheless, the restricted emphasis on disability-specific innovations, as observed by [17], underlines a significant deficiency in the literature.

The significant bibliographic coupling across leading journals and conferences indicates a solid academic consensus on fundamental concepts of inclusive design. This interconnection corresponds with [8] findings, which underscore the significance of shared academic references in furthering research. The few linkages to minority areas emphasize the necessity for more inclusive citation practices. Examining author keywords and emerging subjects indicated a transition from hardware-focused research to more socially pertinent issues, like "accessibility" and "diversity." This trend corresponds with the observations of [22], who identified an increasing emphasis on neurodiverse learners and tailored design. The relative isolation of terminology such as "sign language" and "low vision" signifies underexplored domains [23].

Incorporating AI-related terminology, such as "language model," indicates convergence with overarching technical developments. This corresponds with the findings of [24], who highlighted the potential of AI in improving VR accessibility. Nonetheless, the discipline must guarantee that these innovations are rooted in the practical requirements of impaired learners, as observed by [25].

3.6. Implications for Underrepresented Regions and Global South Researchers

The analysis reveals significant geographic disparities, with most research concentrated in technologically advanced regions. Scholars from the Global South face barriers such as limited research funding, restricted access to publication outlets, and inadequate infrastructure for VR experimentation. This underrepresentation not only limits global knowledge diversity but also reduces contextual relevance for developing countries. The study therefore calls for collaborative funding frameworks, regional research partnerships, and South–North co-authorship initiatives to bridge this divide. Empowering Global South researchers through open-access databases, regional VR research hubs, and targeted capacity-building initiatives will enhance equitable participation and diversify perspectives in inclusive technology design.

3.7. Practical Recommendations for VR Developers and Educators

This study offers practical guidance for VR developers, interface designers, and educators to advance inclusivity in educational environments. Developers and designers should apply universal design principles to create adaptive, user-friendly, and error-tolerant systems that accommodate diverse learner needs. Recommended features include adjustable navigation speeds, multimodal feedback (visual, auditory, and haptic), simplified interfaces, and real-time accessibility feedback to support users with varied cognitive and physical abilities. Integrating inclusive avatars, captioning, and context-aware elements further enhances engagement and social presence for learners with disabilities. Educators are encouraged to incorporate inclusive VR tools into teaching, conduct accessibility testing, and provide learning support to ensure equitable participation. Collectively, these measures embed accessibility from the outset of system design, bridging technological innovation with inclusive pedagogy and ensuring that immersive learning experiences empower, rather than exclude, diverse learners.

3.8. Addressing Gaps: Cognitive Accessibility and Neurodiverse Learners

Despite steady growth in the literature, cognitive accessibility and neurodiversity inclusion remain underexplored domains. The study identifies the need for AI-driven adaptive systems capable of tailoring sensory inputs and interaction

complexity based on learners' cognitive profiles. For instance, incorporating eye-tracking technologies, dynamic text-to-speech systems, and personalised feedback loops can improve engagement for learners with autism spectrum disorders, ADHD, or dyslexia. Researchers are encouraged to explore frameworks that link cognitive ergonomics with VR usability metrics, fostering environments that adapt to individual sensory processing patterns. This approach bridges the gap between technological potential and human-centred inclusivity.

4. CONCLUSION

This study provides a comprehensive bibliometric overview of inclusive educational VR, mapping research trends, collaboration patterns, and thematic evolution in interface design and accessibility. By analysing 4,735 documents from 1,714 sources, it advances understanding of how inclusivity has been addressed, and often overlooked, within immersive learning environments. The findings contribute to the literature on inclusive VR and interface design by identifying dominant themes such as usability and user experience, while exposing underexplored areas like cognitive accessibility and neurodiverse learner inclusion. For policy and practice, the study advocates for embedding universal design principles in educational technologies and calls for policy frameworks that promote accessibility, equitable funding, and global research collaboration, especially in the Global South. Future research should prioritise interdisciplinary collaboration across education, computer science, and cognitive studies, leveraging AI-driven adaptive systems to personalise accessibility in VR environments. Ultimately, this study bridges bibliometric insight with practical guidance, contributing to the creation of equitable, human-centred virtual learning ecosystems that empower every learner.

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