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Extended Reality in Special Education: A Bibliometric Analysis of Global Research (2015–2024)

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ABSTRACT

This study presents a bibliometric analysis of global research trends on the application of Extended Reality (XR) in special education from 2015 to 2024. XR, which encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has demonstrated considerable potential to enhance inclusive and adaptive learning for students with special needs. Drawing on data from Scopus and Web of Science, a total of 630 scientific articles were analyzed using performance analysis and science mapping techniques. The analysis revealed five major thematic clusters: (1) assistive technologies and inclusive learning, (2) technological integration and psychological dimensions of learning, (3) interventions for individuals with autism and intellectual disabilities, (4) game-based and interactive rehabilitation strategies, and (5) the application of Augmented Reality in the context of sensory disabilities. Dominant keyword nodes such as “virtual reality,” “education,” and “students” reaffirm that XR research is consistently directed toward fostering inclusive, personalized, and adaptive learning environments. Recent trends highlight growing attention to eye-tracking, wearable technologies, and adaptive user interfaces. Beyond mapping research patterns, the findings provide practical guidance for designing XR-enabled learning environments that operationalize Universal Design for Learning (UDL) principles, offering multiple means of representation, engagement, and expression to support accessibility and equity in classrooms. However, the study is limited to English-language journal articles indexed in Scopus and Web of Science,

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which may exclude regional publications and grey literature, particularly from the Global South. To our knowledge, this is the first bibliometric mapping of XR in special education, offering a comprehensive overview of the evolving research landscape and underscoring the need for interdisciplinary collaboration and long-term evaluative frameworks.

Keywords: Augmented Reality; Bibliometric Analysis; Extended Reality; Mixed Reality; Special Education; Virtual Reality

1. Introduction

Immersive technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), collectively referred to as Extended Reality (XR), have emerged as transformative innovations in the landscape of 21st-century education. In educational contexts, XR offers multisensory experiences and simulated environments that foster active engagement, personalized learning processes, and the development of cognitive and social skills among learners [1–3]. For students with special needs, XR holds substantial potential in overcoming accessibility barriers, enhancing learning participation, and supporting the development of adaptive competencies within inclusive learning environments [4–6]. In line with the growing global emphasis on equitable and inclusive education, the application of XR in special education is gaining strategic relevance [7,8].

Theoretically, the integration of technology in special education has shifted from a compensatory paradigm toward more constructivist approaches, notably through the implementation of Universal Design for Learning (UDL) [9–11]. This framework underscores the importance of flexibility in instructional delivery, active learner engagement, and the provision of multiple means of representation and expression throughout the learning process. XR technologies, with their capacity to create interactive and adaptive learning environments, are considered highly compatible with UDL principles and are believed to facilitate the development of cognitive, affective, and social skills among students with diverse needs [12,13]. Recent studies have demonstrated a positive correlation between XR use and improvements in communication, collaboration, and problem-solving skills among students with disabilities [14–16].

Across various regions of the world, the adoption of XR in special education is showing increasing momentum. Studies from developed countries such as the United States, Australia, and South Korea have explored XR applications in supporting students with autism, sensory processing disorders, visual impairments, and intellectual disabilities [17–20]. Beyond empirical research, several bibliometric studies have been conducted to map the development of XR research, particularly within educational contexts. For example, some have examined XR implementation in health professional education [21], while others have analyzed XR's contribution to learning outcomes in general education settings [22]. Systematic reviews have also addressed the challenges of implementing XR in higher education [23], and additional studies have explored leadership perspectives in integrating XR into educational systems [24].

However, these bibliometric efforts remain fragmented: health-related mappings emphasize therapeutic outcomes, higher education reviews focus on adoption barriers, and leadership studies highlight policy-level concerns. None of them interrogates how XR scholarship can inform the *design* and *transformation* of inclusive learning environments in special education. This missing link is crucial for journals such as JELE, which center precisely on learning environment design and inclusivity.

Despite the growing body of literature on XR in education, to date, no bibliometric study has specifically mapped the structure, direction, and dynamics of XR research in the context of special education. This gap is particularly salient given the urgency of providing evidence-based insights to inform inclusive, technology-enhanced educational policies and practices. By situating XR research within the lens of learning environment transformation, this study extends beyond descriptive mapping to offer actionable insights into how XR trends can be harnessed for inclusive classroom design. Accordingly, this study is strategically positioned to address this critical gap in the literature.

Based on the aforementioned background, this study aims to conduct a quantitative exploration of scholarly publications on the application of XR in special education from 2015 to 2024. Employing a bibliometric approach, the study seeks to address the following research questions (RQs):

(i) What are the temporal patterns and geographical distribution of publications on XR in special education worldwide (RQ1)?

(ii) Who are the most influential authors, documents, and journals contributing to this field (RQ2)?

(iii) How have thematic focuses and topical trends in XR research within special education evolved over time (RQ3)?

The findings of this study are expected to offer valuable insights for policymakers, educators, and researchers in understanding the scholarly landscape and future directions of XR research in special education. Furthermore, the results may serve as a foundation for formulating collaborative strategies toward the development of inclusive, evidence-based educational technologies tailored to the needs of diverse learners.

2. Materials and Methods

This study conducted a bibliometric analysis of scholarly publications that investigate the application of Extended Reality (XR) technologies in the context of special education. The analysis focused on publication trends, key contributors, thematic contributions, and patterns of scientific collaboration during the period 2015–2024. Data were retrieved from two highly reputable academic databases, namely Scopus and Web of Science (WoS), both of which are widely utilized in bibliometric research due to the comprehensiveness of their bibliographic metadata [25,26]. The time period 2015–2024 was chosen because the exponential growth of XR technology occurred during this period, coinciding with the increasing availability of consumer-grade VR/AR devices and their gradual integration into educational environments.

Restricting the search to English-language publications may introduce database and language bias, potentially underrepresenting research published in regional journals or in other languages, particularly from the Global South. Nevertheless, this restriction was considered necessary to maintain consistency in data processing and comparability, as English serves as the dominant language of scientific communication and indexing in global academic literature [27]. Including multilingual sources without robust translation protocols could have introduced further bias and reduced the reproducibility of the study [28].

To enhance the precision of the search results, subject-specific filtering was applied [29]. In Scopus, only documents classified under the field of Social Sciences, specifically within the subject area of Education, were included. In WoS, the categories "Education Educational Research," "Education Special," "Education Scientific Disciplines," and "Psychology Educational" were selected. The search keywords were formulated using Boolean operators as follows: ("extended reality" OR "virtual reality" OR "augmented reality" OR "mixed reality" OR "virtual environment" OR "virtual world" OR "virtual system") AND ("special education" OR "inclusive education" OR "disability" OR "autism" OR "learning disabilities" OR "hearing impairment" OR "visual impairment" OR "developmental disorder" OR "intellectual disability"). These keywords were iteratively refined through pilot searches to ensure conceptual relevance and adequate coverage of both XR technologies and various categories of special educational needs. The selection of subject areas was informed by preliminary scoping reviews to align the retrieved documents with the interdisciplinary nature of XR implementation in special education contexts.

The initial search yielded 770 documents from Scopus and 410 from WoS (N = 1180). After deduplication, 324 records were removed, resulting in 856 unique records screened. Of these, 224 were excluded based on type (non-journal/proceedings), language, or pre-final publication status. At the eligibility stage, two records were excluded due to missing abstracts, leaving 630 records included in the analysis (see **Figure 1**). Deduplication was conducted using a semi-automated process via RStudio, employing a combination of DOI matching, article titles, and author metadata. The datasets from Scopus and WoS were first cleaned individually to remove inconsistencies, and then merged into a unified dataset for final validation. Manual verification was applied to a subset of records to ensure the accuracy of the deduplication process

The analysis was conducted using a combination of three tools: Biblioshiny (within the Bibliometrix R package), VOSviewer version 1.6.18, and RStudio. Biblioshiny was employed to evaluate temporal publication trends, author, country, and institutional productivity, as well as impact metrics such as citation counts and the h-index [30]. VOSviewer was used to visualize keyword co-occurrence networks and author collaboration patterns [31,32]. RStudio was utilized to integrate, clean, and validate data from the two sources, ensuring the removal of duplicates in the final dataset [33].

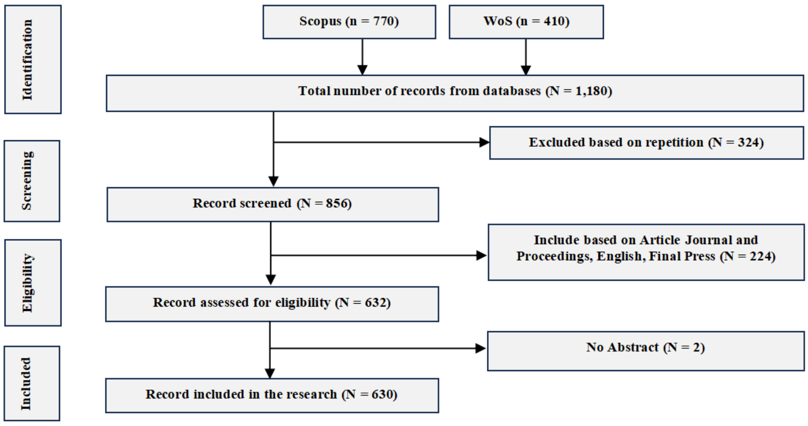

Figure 1. Prisma Flow [34].

This study followed a bibliometric analytical framework widely adopted in academic literature [35], comprising: (1) Performance Analysis, which measures scholarly productivity and impact based on publication volume, citation counts, and geographical contributions; and; (2) Science Mapping, which aims to uncover thematic structures and interrelationships among scientific entities through keyword analysis. To ensure thematic relevance and analytical significance, the keyword co-occurrence analysis applied a minimum threshold of eight occurrences, as recommended in previous studies [36]. The choice of a minimum threshold of eight co-occurrences was informed by a series of preliminary tests that evaluated network density, modularity, and thematic granularity. Thresholds lower than eight resulted in overly dense and less interpretable networks, while higher thresholds excluded emerging yet significant terms. The selected threshold thus reflects a balance between analytical depth and interpretability, consistent with best practices in the field.

3. Results and Discussion

3.1. Temporal Patterns and Geographical Distribution of XR Publications in Special Education

An analysis of 630 articles published between 2015 and 2024 reveals a significant upward trend in research on XR within the context of special education (see **Figure 2**). During the initial period (2015–2018), publication output remained relatively modest, averaging 26 articles per year. A noticeable increase began in 2019 with 57 articles, followed by a steady rise to 67 (2020) and 69 (2021). A sharp surge occurred in 2022 with 89 publications, reaching a peak in 2024 with 153 articles.

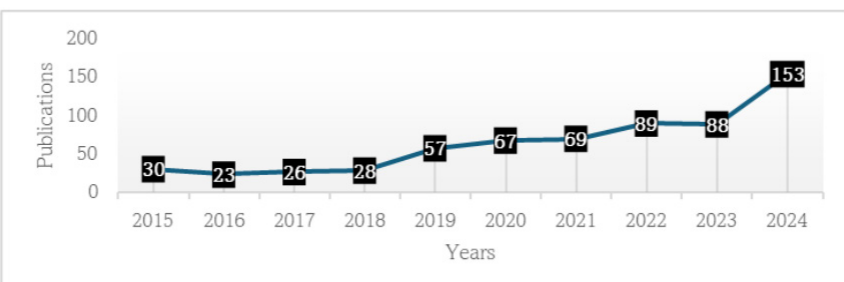

Figure 2. Annual Growth of Publications on Extended Reality in Special Education (2015–2024).

This progression reflects a growing scholarly interest in the role of XR in inclusive learning. The post-2020 surge may be attributed to the accelerated adoption of educational technologies during the COVID-19 pandemic, as well as heightened global attention to adaptive and equitable education systems. These findings support the notion that the integration of XR in special education has evolved from an experimental approach into a strategically recognized discourse within global educational scholarship. Beyond pandemic effects, growth likely reflects (i) falling hardware costs and better device availability, (ii) maturation of authoring tools lowering development barriers, and (iii) widening acceptance of UDL-aligned technology as part of school improvement agendas. These structural drivers suggest XR has shifted from pilot novelty toward an implementable component of inclusive learning-environment design.

Table 1 presents the distribution of publications by country, highlighting disparities between research productivity (Total Publications/TP) and scientific impact (Total Citations/TC). The top ten countries by publication output are the United States (TP = 148), China (126), the United Kingdom (89), Australia (74), Spain (57), South Korea (55), Germany (47), India (46), Canada (44), and Malaysia (39). The dominance of high-income countries underscores the correlation between robust research infrastructure and scholarly output.

Several structural conditions reinforce this dominance: first, XR research and development, as well as hardware supply chains, are heavily centered in the Global North. Second, these countries benefit from mature infrastructures, including ethics boards and established partnerships with schools and clinics, which facilitate intervention trials. Third, English-language indexation in Scopus and WoS amplifies their international visibility. Finally, better procurement capacity allows schools and universities to acquire XR devices and provide teacher training at scale. Taken together, these factors explain why both publication output and citation impact cluster in wealthier contexts.

The presence of India, Malaysia, and Brazil in the top producers indicates growing capacity in the Global South, yet citation shares remain lower, pointing to collaboration and venue-access gaps rather than topic irrelevance. Targeted North–South partnerships and open-access routes could rebalance visibility. Beyond collaboration, capacity-building initiatives should prioritize South-led research agendas, investment in local XR development, and multilingual indexing platforms to support greater inclusion. Regional hubs for XR in education could serve as anchors for localized innovation, ensuring that technology design and deployment reflect the linguistic, cultural, and infrastructural realities of underrepresented communities.

Table 1. Top ten countries by TP and TC XR research for special education (2015–2024).

Rank	Country	TC	Rank	Country	TP
1	USA	3357	1	USA	383
2	China	753	2	China	99
3	Spain	669	3	Spain	63
4	United Kingdom	575	4	Uk	53
5	Hong Kong	309	5	Italy	52
6	Turkey	278	6	Germany	40
7	Saudi Arabia	144	7	Turkey	36
8	Malaysia	111	8	Canada	33
9	Norway	108	9	India	31
10	France	83	10	Brazil	30

In terms of citation impact, the United States (TC = 2315) leads by a considerable margin, followed by the United Kingdom (1874), Australia (1596), China (1412), and Canada (1173). Countries such as Germany, Spain, and South Korea, although having lower publication counts, demonstrate competitive citation performance. In contrast, India (401) and Malaysia (398), despite being relatively productive, have not yet achieved proportional citation impact. This imbalance between quantity and influence is a common pattern also observed in other global bibliometric studies.

This quantity–influence gap reflects several systemic challenges: limited access to high-impact journals, lower levels of international collaboration, and language barriers in the publication process [37,38]. The tendency to publish in regional or non-indexed outlets further reduces visibility [39,40]. These dynamics highlight that building stronger collaborative networks and improving access to widely indexed journals are crucial for raising the global visibility of research from emerging contexts. Strategic investments in multi-site studies and open-access publishing could help rebalance the distribution of influence without necessarily inflating publication volume.

This asymmetry reflects broader structural dynamics in global knowledge production, often described as "epistemic North–South divides" [REF]. Such divides are perpetuated through linguistic hegemony, indexing preferences, and unequal access to infrastructure, resulting in a form of research dependency that limits local agenda-setting and theoretical innovation from the Global South.

3.2. Most Influential and Productive Authors

A total of 2,100 authors contributed to 453 publications on XR in special education, with an international collaboration rate of 14.6%. Based on total citations (TC), the most influential authors are Cihak D.F. (TC = 444), followed by McMahon D.D. (393), and Lorenzo G. (349). These authors' networks are anchored in institutions with lab infrastructure, school-district partnerships, and access to specialized populations (e.g., ASD programs)—a combination that accelerates trial-based evidence and, consequently, citations. These three scholars reflect dominant contributions from institutions in the United States and Europe, which generally benefit from extensive collaborative networks and access to high-impact journals. Detailed information on the top ten authors in terms of publication count and citation impact is presented in **Table 2**.

In terms of productivity (Total Publications/TP), F. Ke (Fengfeng Ke) from Florida State University ranks as the most productive author with 11 publications, followed by J. Moon and M. Schmidt, each with 10 articles. Notably, only two authors appear in both the top-TP and top-TC lists, underscoring that influence depends less on output volume and more on factors such as study design, journal prestige, and international collaboration. This pattern suggests that advancing the field may require prioritizing fewer but methodologically rigorous, theory-grounded studies, such as those explicitly aligned with UDL principles, over a larger number of small-scale pilots. Such findings are consistent with previous bibliometric evidence that impact arises from quality and collaboration rather than quantity alone [41].

Table 2. Top ten most influential and productive authors in XR research for special education (2015–2024).

Rank	Author	TC	Rank	Authors	TP
1	Cihak Df	444	1	Ke F	11
2	Mcmahon Dd	393	2	Moon J	10
3	Lorenzo G	349	3	Schmidt M	10
4	Lee Ij	322	4	Glaser N	9
5	Ip Hhs	267	5	Lee Ij	8
6	Li C	251	6	Sokolikj Z	8
7	Chan Dfy	248	7	Lorenzo-Lledo A	7
8	Lau Ksy	248	8	Newbutt N	7
9	Wong Swl	248	9	Cihak Df	6
10	Ke F	245	10	Ip Hhs	6

3.3. Most Influential Documents

Table 3 presents the five most influential articles in XR research for special education, based on total citations (TC). The top-cited article (TC = 187) developed a virtual reality (VR)-based approach to enhance emotional and social adaptation skills in children with Autism Spectrum Disorder (ASD) [42]. Conducted with 94 participants across 28 sessions in a half-CAVE immersive environment, the study reported significant improvements in emotional expression and social regulation, establishing it as a foundational reference for XR-based interventions in special education. The prominence of ASD in the top-cited works reflects structural and thematic factors. First, large, well-organized clinical and educational programs in high-income countries facilitate participant recruitment. Second, ASD-related outcomes, such as social communication and emotional regulation, align closely with XR affordances. controlled environments and safe rehearsal of social scenarios. Third, targeted funding streams and philanthropic initiatives have further fueled research in this area. While these conditions explain the concentration of high-impact studies on ASD, they also create a topic imbalance: sensory, motor, and other intellectual disabilities remain comparatively underexplored, particularly in longitudinal and cross-context designs.

Table 3. Top five most influential articles on XR in special education based on total citations (2015–2024).

Rank	Tittle	Author	TC	TC/Year	PY start	Scopus Rank	WoS Rank
1	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach	Ip et al.	187	23.38	2017	Q1	SCIE
2	Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders	Lorenzo et al.	181	18.10	2016	Q1	SCIE
3	Level of Immersion in Virtual Environments Impacts the Ability to Assess and Teach Social Skills in Autism Spectrum Disorder	Miller & Bugnariu	156	15.60	2016	Q1	SSCI
4	Augmented reality-based self-facial modeling to promote the emotional expression and social skills of adolescents with autism spectrum disorders	Chen et al.	149	13.55	2015	Q2	SSCI
5	Augmented Reality for Teaching Science Vocabulary to Postsecondary Education Students With Intellectual Disabilities and Autism	McMahon et al.	134	13.40	2015	Q1	ESCI

The second most cited article (TC = 181) integrated computer vision–based facial expression recognition into VR environments, enabling adaptive social scenarios. The study reported improved emotional competencies among students with ASD aged 7–12, marking a conceptual step toward emotionally responsive XR applications [43]. The third article (TC = 156) investigated the relationship between immersion levels and social skills training, showing that varying immersion (low, medium, high) produced differential outcomes and offering novel insights into the technical dimensions of XR-based learning design [44].

Two additional studies explored the potential of augmented reality (AR). One (TC = 149) applied AR to model self-facial expressions among adolescents with ASD, leading to greater emotional awareness and social responsiveness [45]. The other (TC = 134) examined AR for science vocabulary acquisition among students with intellectual disabilities and ASD, reporting significant academic gains across participants [46].

Taken together, these five articles highlight that the effectiveness of XR in special education depends less on technological novelty and more on how tools are integrated with evidence-based pedagogy and learner-centered design. Their success can be read through the lens of Universal Design for Learning (UDL): structured scaffolding supports multiple means of engagement, visual overlays provide multiple representations, and embodied or multimodal interfaces enable diverse forms of action and expression. This suggests that XR achieves broader and more sustainable impact when treated as a learning-environment intervention rather than as isolated hardware or software.

3.4. Leading Sources in XR Publications for Special Education

As shown in **Table 4**, XR research in special education is published across a range of high-impact journals, most indexed in WoS-SSCI and Scopus Q1–Q2. The Journal of Special Education Technology (Q2) emerges as the most prolific outlet, with 26 articles and 667 citations since 2015. Although its h-index is modest (43), its steady output makes it a central venue for scholarship on educational technologies for students with disabilities. The distribution of publications across journals illustrates the interdisciplinary character of XR research, drawing attention from fields such as educational technology, psychology, and human–computer interaction. At the same time, this dispersion risks fragmenting audiences and diluting practical impact. To strengthen translational value, scholars are encouraged to publish in outlets that explicitly foreground inclusive learning design and implementation, thereby aligning research outputs with the mission of journals like JELE.

Table 4. Top five influential Sources on XR in special education based on total citations (2015–2024).

Rank	Source	TC	NP	PY_start	Scopus Rank	WoS Rank	Scopus h_index
1	Journal of Special Education Technology	667	26	2015	Q2	SSCI	43
2	Education and Information Technologies	401	17	2019	Q1	SSCI	97
3	Cyberpsychology, Behavior, and Social Networking	428	10	2016	Q1	SSCI	190
4	International Journal of Human Computer Studies	210	8	2020	Q1	SSCI	152
5	Interactive Learning Environments	272	11	2016	Q1	SSCI	80

In contrast, Q1 journals such as Education and Information Technologies and Cyberpsychology, Behavior, and Social Networking demonstrate higher impact, with 401 and 428 citations respectively and h-indices of 97 and 190. Their prominence highlights how XR research resonates beyond special education, shaping broader conversations in educational technology and digital psychology. Other notable venues include the International Journal of Human-Computer Studies (TC = 210, h-index = 152) and Interactive Learning Environments (TC = 272, h-index = 80), which contribute to advances in interface design and immersive learning.

Taken together, these publication patterns confirm the interdisciplinary nature of XR scholarship in special education. While this diversity broadens reach across multiple academic communities, it also creates challenges for consolidating findings into coherent design guidance. For journals such as JELE, this underscores the importance of framing XR not only as a technological innovation but as a catalyst for rethinking inclusive learning-environment design.

3.5. Thematic Focus and Topic Evolution in XR Research for Special Education

A co-occurrence analysis was conducted to identify thematic linkages within the literature by examining the frequency with which keywords, authors, or citations appear together [32]. This technique generates network maps and thematic clusters that expose the intellectual structure and developmental trajectory of a field [47]. In this study, 3294 keywords from 453 journal articles on XR in disability and inclusive education were analyzed. Applying a minimum threshold of eight co-occurrences yielded 103 keywords grouped into five major clusters. As shown in **Figure 3**, resulting map revealed dense interconnections around "virtual reality," "autism," "education," and "special education," highlighting both the complexity of the field and its interdisciplinary scope. Beyond description, the network shows where evidence is concentrated and where gaps persist, information critical for guiding inclusive learning-environment design.

Cluster 1: Assistive technologies and inclusive learning. This foundational cluster emphasizes the integration of XR and assistive technologies in special education. Core terms include "virtual reality," "assistive technology," "e-learning," "inclusion," and "accessibility." C1 aligns with UDL's principle of multiple means of representation, for example, through visual overlays, captions, and adjustable complexity, as well as multiple means of engagement via scaffolded stimuli. These connections offer practical heuristics for classroom design, such as contrast controls and flexible task difficulty.

Cluster 2: Technological integration and psychological dimensions of learning. Keywords such as "education," "learning," "motivation," and "simulation" reflect a strong pedagogical orientation, while the inclusion of "hearing impairment," "disability," and "adult" points to diverse learner populations. This cluster highlights design considerations around feedback timing, immersion dosing, and motivational scaffolds. Read through UDL, these correspond to engagement checkpoints (optimizing relevance, minimizing distraction) and safe session design (duration, motion-sickness thresholds).

Cluster 3: Interventions for individuals with autism and intellectual disabilities. This cluster shows sustained attention to autism and intellectual disabilities, with keywords like "autism," "children," "adolescents," and "intellectual disability." ASD is overrepresented for three reasons: (1) well-established clinical–school pipelines and funding in the Global North, (2) strong fit between XR affordances and social-communication rehearsal, and (3) clearer, measurable outcomes for trials. The risk is topic skew: sensory/motor impairments and multiple-disability contexts remain underexplored. Extending ASD-derived design protocols, such as task analysis and social scripts, to mixed-ability classrooms would broaden relevance and reduce imbalance.

Cluster 4: Game-based and interactive rehabilitation strategies. This cluster highlights XR as a rehabilitative tool, with keywords like "rehabilitation," "serious games," and "human-computer interaction." Studies here often assess performance outcomes, reflecting a shift toward evidence-based evaluation. The design focus is on alternative response modes (gesture, haptics, switch access) and progress tracking, which can be directly aligned with Individualized Education Program (IEP) goals and support generalization across home, school, and therapy settings.

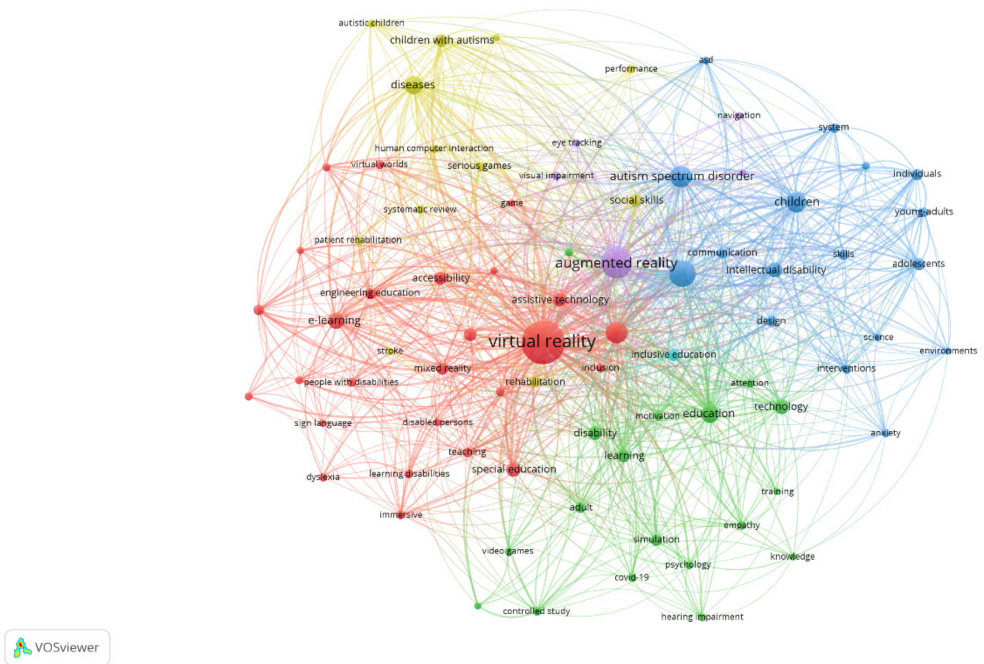

Figure 3. Keyword co-occurrence network in XR research for special education (2015–2024).

Cluster 5: Augmented Reality and Sensory Disabilities. This cluster centers on AR in contexts of intellectual and sensory impairments, with keywords such as "eye tracking," "visual impairment," "navigation," and "intellectual disabilities." AR supports engagement, cognitive training, and spatial orientation by adapting environments to individual learner profiles. However, evidence remains sparse and heavily device-dependent. To advance equity, future work must prioritize low-cost, offline-capable AR for bandwidth-constrained schools.

Taken together, the five clusters illustrate how XR research has matured into a multidimensional field spanning assistive technologies, vulnerable populations, pedagogical strategies, and rehabilitation. Connector nodes such as learning, education, and students reaffirm that learners remain central to XR development. Importantly, cluster insights translate into UDL checkpoints: multiple means of representation (captions, contrast), engagement (motivational scaffolds, immersion dosing), and action/expression (gesture, gaze, switch access). The map thus positions XR not merely as a supportive tool but as a design framework for responsive, personalized learning environments. Yet gaps persist: co-design with teachers and families is rare, longitudinal outcomes are scarce, cost-effectiveness is underreported, and Global South voices remain underrepresented due to language and database bias.

Addressing these persistent gaps requires systemic shifts in how XR research is conceptualized and funded. Funding agencies and academic institutions must support co-design approaches that meaningfully engage educators, learners, and caregivers from diverse socio-cultural contexts. Additionally, integrating cost–utility analysis and sustainability assessments into XR research design will enable schools, especially in resource-constrained settings, to make informed decisions about adoption and scaling.

Trend analysis (**Figure 4**) shows a conceptual shift from early themes, “virtual environments,” “inclusion,” “immersive”, to a stronger focus on “autism,” “intellectual disability,” and “augmented reality” after 2020. The rise of AR and eye-tracking reflects a move toward personalization (dynamic prompts, gaze-based inputs) and safety-by-design (fatigue detection). Schools can translate these signals into procurement criteria and classroom protocols. The steady recurrence of students, education, and virtual reality underscores thematic stability: enhancing student learning through XR remains the field’s core concern [13,48,49]. More recent terms, wearable technology, user-computer interface, indicate growing attention to technical sophistication for adaptive and sensor-driven learning [50–52]. Viewed through UDL, wearables and gaze inputs expand action/expression options, while adaptive interfaces diversify representation and sustain engagement through calibrated challenge.

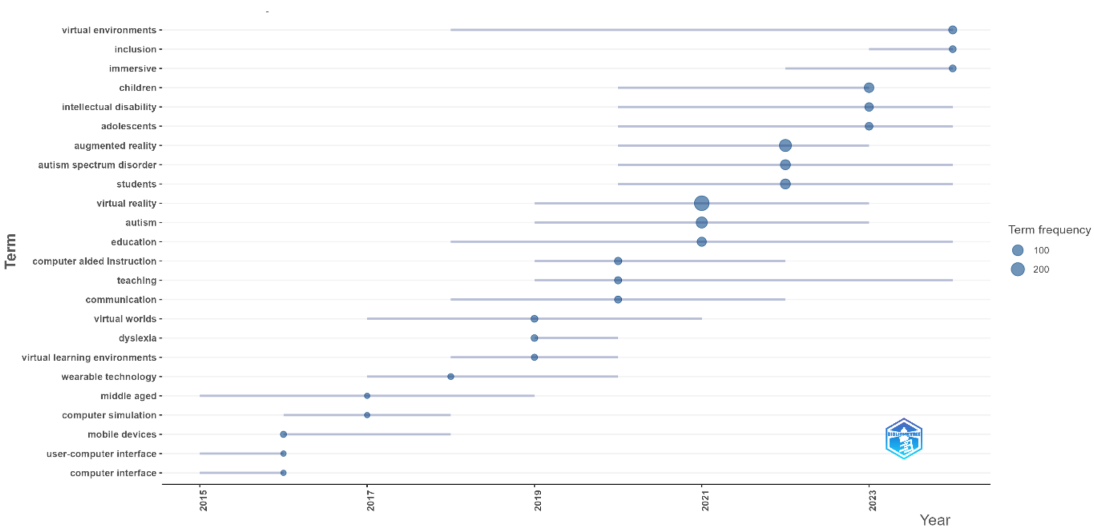

Figure 4. Trend topics in XR research for special education (2015–2023).

Overall, topic trends from 2015 to 2024 reveal both a steady expansion and conceptual maturation of XR research in special education. The field has shifted from early technological experimentation toward learner-centered instructional design [20,53]. The widening vocabulary, terms such as communication, computer simulation, and virtual learning environments, signals an interdisciplinary convergence of technological, pedagogical, and psychological perspectives [54–56]. This underscores the need for more integrated approaches that position XR as a learning tool capable of supporting diverse learner needs and potentials.

The findings also carry several implications for policy and practice. Institutions can benefit from adopting UDL-aligned XR design checklists, including features such as adequate contrast, captioning, and multimodal input options, to ensure accessibility. Teacher professional development on immersion dosing and safety is equally critical for successful classroom implementation. Widening access requires prioritizing affordable solutions, such as standalone devices or tablet-based AR, particularly in resource-constrained settings. In addition, supporting cross-regional research consortia is essential to address the current concentration of studies in the Global North and to test the portability of XR across different curricula, languages, and cultural contexts.

The trend analysis further indicates a shift toward context-sensitive applications, targeting specific learner populations and incorporating advanced technical features such as eye-tracking and adaptive interfaces. This evolution reflects not only greater theoretical maturity but also increasing responsiveness to diverse educational needs, reinforcing the potential of XR as a catalyst for inclusive learning-environment design.

Thematic and trend analyses presented above reveal that XR has evolved from a speculative innovation into a credible tool for inclusive education, particularly when aligned with Universal Design for Learning (UDL) principles. Translating these insights into practice requires actionable strategies across classroom, institutional, and policy levels. At the classroom level, teachers should be supported with XR integration frameworks that emphasize multimodal content delivery (e.g., captions, gesture input, gaze control), personalization features (e.g., adjustable immersion), and accessibility tools (e.g., contrast settings, narration). Professional development programs must include modules on XR ethics, safety protocols, and pedagogical adaptation.

Institutionally, decision-makers can adopt UDL-aligned XR checklists during procurement processes to ensure technologies are inclusive and adaptable. Policies should incentivize low-cost XR solutions (e.g., standalone headsets, tablet-based AR) and content that is culturally relevant and available in local languages. From a systems perspective, cross-regional research consortia, especially those led by institutions in the Global South, should be funded to test XR implementation across diverse educational ecosystems. These efforts will help dismantle the dominance of Global North perspectives and ensure that XR research outcomes reflect a pluralistic understanding of inclusion.

Future research priorities include longitudinal, multi-site trials that track maintenance and generalization outcomes, embedding cost–utility metrics, extending studies to underrepresented disabilities and Global South contexts, and institutionalizing co-design with educators, therapists, and families. Together, these strategies will help ensure that XR research balances theoretical development with practical implementation, sustaining its role as a learner-centered innovation for inclusive education. This study also has limitations. Reliance on Scopus and WoS, while ensuring coverage of high-quality peer-reviewed literature, may underrepresent regionally indexed journals, non-English publications, and grey literature, particularly from the Global South. As such, the results should be interpreted as representative but not exhaustive of global XR research activity.

4. Conclusions

This bibliometric study aimed to map and analyze the trends, thematic foci, and scholarly contributions in research on Extended Reality (XR) in special education from 2015 to 2024, as outlined in the Introduction. Drawing upon 630 publications retrieved from the Scopus and Web of Science (WoS) databases, the study employed co-occurrence analysis, network visualization, and topic evolution mapping to identify the developmental trajectory of the field. The analysis revealed five major thematic clusters: (1) assistive technologies and inclusive learning, (2) technological integration and psychological dimensions of learning, (3) interventions for individuals with autism and intellectual disabilities, (4) game-based and interactive rehabilitation strategies, and (5) the application of Augmented Reality in the context of sensory disabilities. Dominant keyword nodes such as "virtual reality," "education," and "students" reaffirm the initial finding that XR research is consistently directed toward fostering inclusive, personalized, and adaptive learning environments. These clusters provide a conceptual roadmap for future XR-enabled learning environments, underscoring the potential of XR to operationalize Universal Design for Learning (UDL) principles and advance more inclusive and adaptive classrooms.

The findings highlight a conceptual shift from early technological exploration toward evidence-based and learner-centered applications, with growing interest in sophisticated features such as eye-tracking, wearable technology, and adaptive interfaces. Despite this progress, challenges remain, particularly the lack of longitudinal evaluation, limited cross-disciplinary integration, and uneven geographical representation. Research remains concentrated in the Global North, leaving contributions from the Global South and regionally indexed journals underrepresented. Future research should therefore prioritize longitudinal, multi-site studies that track sustained outcomes, expand coverage beyond English-language databases to capture Global South perspectives, and conduct cross-regional comparisons to assess portability across educational systems. By addressing these gaps, XR scholarship can move toward a more equitable, evidence-driven, and globally representative knowledge base. In this regard, the present study establishes a critical foundation by mapping the existing terrain and identifying thematic directions to guide both researchers and practitioners in designing XR-based inclusive learning environments.

Author Contributions

Conceptualization, G.R.; methodology, G.R. and R.T.; software, R.T.; validation, G.R.; formal analysis, G.R. and R.T.; writing—original draft preparation, G.R.; writing—review and editing, G.R. and T.R.; visualization, RT.; supervision, G.R. Both authors have read and agreed to the published version of the manuscript.

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The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Radianti, J., Majchrzak, T.A., Fromm, J., et al., 2020. A Systematic Review of Immersive Virtual Reality Applications for Higher Education: Design Elements, Lessons Learned, and Research Agenda. Computers & Education. 147, 103778. DOI: https://doi.org/10.1016/j.compedu.2019.103778

[2] Pressley, G. M, 2002. Editorial. Journal of Educational Psychology. 94(4), 659. DOI: https://doi.org/10.1037//0022-0663.94.4.659

[3] Bordegoni, M., Carulli, M., Spadoni, E., 2023. Multisensory Interaction in eXtended Reality. In Prototyping User eXperience in eXtended Reality, Part F1280. Springer: Cham, Switzerland. pp. 49–63. DOI: https://doi.org/10.1007/978-3-031-39683-0_4

[4] Lorenzo, G., Gilabert Cerdá, A., Lorenzo-Lledó, A., et al., 2022. The Application of Augmented Reality in the Learning of Autistic Students: A Systematic and Thematic Review in 1996–2020. Journal of Enabling Technologies. 16(2), 75–90. DOI: https://doi.org/10.1108/JET-12-2021-0068

[5] Barbu, M., Iordache, D.-D., Petre, I., et al., 2025. Framework Design for Reinforcing the Potential of XR Technologies in Transforming Inclusive Education. Applied Sciences. 15(3), 1–20. DOI: https://doi.org/10.3390/app15031484

[6] Shaaban, T.S., Mohamed, A.M., 2024. Exploring the Effectiveness of Augmented Reality Technology on Reading Comprehension Skills Among Early Childhood Pupils with Learning Disabilities. Journal of Computer Education. 11(2), 423–444. DOI: https://doi.org/10.1007/s40692-023-00269-9

[7] Global Education Monitoring Report Team, 2020. Global Education Monitoring Report 2020: Inclusion and Education: All Means All. UNSCO: Paris, France. DOI: https://doi.org/10.54676/jjnk6989

[8] Peterson-Ahmad, M.B., Keeley, R., Frazier, A., 2023. Using Mixed Reality to Support Inclusive Teaching Strategies in General and Special Education Preparation Programs. Social Sciences. 12(11), 596. DOI: https://doi.org/10.3390/socsci12110596

[9] Basham, J.D., Smith, S.J., Satter, A.L., 2016. Universal Design for Learning: Scanning for Alignment in K–12 Blended and Fully Online Learning Materials. Journal of Special Education Technology. 31(3), 147–155. DOI: https://doi.org/10.1177/0162643416660836

[10] Kennedy, M.J., Boyle, J.R., 2019. The Promise and Problem with Technology in Special Education: Implications for Academic Learning. In Handbook of Special Education, 2nd ed. pp. 606–614. Routledge: New York, NY, USA. DOI: https://doi.org/10.4324/9781315517698-46

[11] Coy, K., Marino, M.T., Serianni, B., 2014. Using Universal Design for Learning in Synchronous Online Instruction. Journal of Special Education Technology. 29(1), 63–74. DOI: https://doi.org/10.1177/016264341402900105

[12] Lalotra, G.S., Kumar, V., 2024. The Impact of Virtual Reality and Augmented Reality in Inclusive Education. In: Kaluri, R., Mahmud, M., Gadekallu, T.R.

(Eds.). Applied Assistive Technologies and Informatics for Students with Disabilities. Springer: Singapore. pp. 71–94. DOI: https://doi.org/10.1007/978-981-97-0914-4_5

[13] Vairamani, A.D., 2024. Enhancing Social Skills Development Through Augmented Reality (AR) and Virtual Reality (VR) in Special Education. In: Devi, V.A., Singh, W., Kumar, Y. (Eds.). Augmented Reality and Virtual Reality in Special Education. Wiley Online Library. pp. 65–89. DOI: https://doi.org/10.1002/9781394167586.ch3

[14] Baragash, R.S., Al-Samarraie, H., Moody, L., et al., 2022. Augmented Reality and Functional Skills Acquisition Among Individuals With Special Needs: A Meta-Analysis of Group Design Studies. Journal of Special Education Technology. 37(1), 74–81. DOI: https://doi.org/10.1177/0162643420910413

[15] Mitsea, E., Drigas, A., Skianis, C., 2023. VR Gaming for Meta-Skills Training in Special Education: The Role of Metacognition, Motivations, and Emotional Intelligence. Educational Sciences. 13(7), 639. DOI: https://doi.org/10.3390/educsci13070639

[16] Algerafi, M.A.M., Zhou, Y., Oubibi, M., et al., 2023. Unlocking the Potential: A Comprehensive Evaluation of Augmented Reality and Virtual Reality in Education. Electronics. 12(18), 3953. DOI: https://doi.org/10.3390/electronics12183953

[17] Roberts-Yates, C., Silvera-Tawil, D., 2019. Better Education Opportunities for Students with Autism and Intellectual Disabilities Through Digital Technology. International Journal of Special Education. 34(1), 197–210.

[18] Michalski, S.C., Szpak, A., Ellison, C., et al., 2022. Using Virtual Reality to Improve Classroom Behavior in People With Down Syndrome: Within-Subjects Experimental Design. JMIR Serious Games. 10(2), e34373. DOI: https://games.jmir.org/2022/2/e34373

[19] Ahn, S.-N., 2021. Combined Effects of Virtual Reality and Computer Game-Based Cognitive Therapy on the Development of Visual-Motor Integration in Children with Intellectual Disabilities: A Pilot Study. Occupational Therapy International. 2021(1), 1–8. DOI: https://doi.org/10.1155/2021/6696779

[20] Yakubova, G., Kellems, R.O., Chen, B.B., et al., 2022. Practitioners' Attitudes and Perceptions Toward the Use of Augmented and Virtual Reality Technologies in the Education of Students With Disabilities. Journal of Special Education Technology. 37(2), 286–296. DOI: https://doi.org/10.1177/01626434211004445

[21] Li, S., 2024. Immersive Technologies in Health Professions Education: A Bibliometric Analysis. Computers & Education: X Reality. 4, 100051. DOI: https://doi.org/10.1016/j.cexr.2024.100051

[22] Zhang, Y., Mohamed, H.B., Rosli, M.S., et al., 2024. Understanding Social Presence in Extended Reality: A Bibliometric Analysis Based on Web of Science Database Using Bibliometrix RStudio and Citespace. In Proceedings of the 2024 4th International Conference on Educational Technology (ICET), Wuhan, China, 13–15 September 2024; pp. 603–608. DOI: https://doi.org/10.1109/ICET62460.2024.10869048

[23] Qawaqneh, H., Al Ahmad, A., Qutishat, D., 2023. Challenges of Extended Reality Technology in Higher Education: A Review. International Journal of Emerging Technologies in Learning. 18(24), 133–148. DOI: https://doi.org/10.3991/ijet.v18i14.39871

[24] Zhao, X., Ren, Y., Cheah, K.S.L., 2023. Leading Virtual Reality (VR) and Augmented Reality (AR) in Education: Bibliometric and Content Analysis From the Web of Science (2018–2022). SAGE Open. 13(3), 1–23. DOI: https://doi.org/10.1177/21582440231190821

[25] Pranckutė, R., 2021. Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World. Publications. 9(1), 12. DOI: https://doi.org/10.3390/publications9010012

[26] Chapman, K., Ellinger, A.E., 2019. An Evaluation of Web of Science, Scopus and Google Scholar Citations in Operations Management. International Journal of Logistics Management. 30(4), 1039–1053. DOI: https://doi.org/10.1108/IJLM-04-2019-0110

[27] Yu, Z., Ma, Z., Wang, H., et al., 2020. Communication Value of English-Language S&T Academic Journals in Non-Native English Language Countries. Scientometrics. 125(2), 1389–1402. DOI: https://doi.org/10.1007/s11192-020-03594-3

[28] Bolibaugh, C., Vanek, N., Marsden, E.J., 2021. Towards a Credibility Revolution in Bilingualism Research: Open Data and Materials as Stepping Stones to More Reproducible and Replicable Research. Bilingualism: Language and Cognition. 24(5), 801–806. DOI: https://doi.org/10.1017/S1366728921000535

[29] Pessin, V.Z., Yamane, L.H., Siman, R.R., 2022. Smart Bibliometrics: An Integrated Method of Science Mapping and Bibliometric Analysis. Scientometrics. 127(6), 3695–3718. DOI: https://doi.org/10.1007/s11192-022-04406-6

[30] Ghorbani, B.D., 2024. Bibliometrix: Science Mapping Analysis with R Biblioshiny Based on Web of Science in Applied Linguistics. In: Meihami, H., Esfandiari, R. (Eds). A Scientometrics Research Perspective in Applied Linguistics. Springer: Cham, Switzerland.

pp. 197–234. DOI: https://doi.org/10.1007/978-3-031-51726-6_8

[31] Wang, Y., Huo, X., Li, W., et al., 2022. Knowledge Atlas of the Co-Occurrence of Epilepsy and Autism: A Bibliometric Analysis and Visualization Using VOSviewer and CiteSpace. Neuropsychiatric Disease and Treatment. 18, 2107–2119. DOI: https://doi.org/10.2147/NDT.S378372

[32] van Eck, N.J., Waltman, L., 2014. Visualizing Bibliometric Networks. In: Ding, Y., Rousseau, R., Wolfram, D. (Eds). Measuring Scholarly Impact: Methods and Practice. Springer: Cham, Switzerland. pp. 285–320. DOI: https://doi.org/10.1007/978-3-319-10377-8_13

[33] Nikolić, D., Ivanović, D., Ivanović, L., 2024. An Open-Source Tool for Merging Data from Multiple Citation Databases. Scientometrics. 129(7), 4573–4595. DOI: https://doi.org/10.1007/s11192-024-05076-2

[34] Page, M.J., McKenzie, J.E., Bossuyt, P.M., et al., 2021. The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. BMJ. 372, n71. DOI: https://doi.org/10.1136/bmj.n71

[35] Donthu, N., Kumar, S., Mukherjee, D., et al., 2021. How to Conduct a Bibliometric Analysis: An Overview and Guidelines. Journal of Business Research. 133, 285–296. DOI: https://doi.org/10.1016/j.jbusres.2021.04.070

[36] Klarin, A., 2024. How to Conduct a Bibliometric Content Analysis: Guidelines and Contributions of Content Co-Occurrence or Co-Word Literature Reviews. International Journal of Consumer Studies. 48(2), e13031. DOI: https://doi.org/10.1111/ijcs.13031

[37] Ayala-Orozco, B., Rosell, J.A., Merçon, J., et al., 2018. Challenges and Strategies in Place-Based Multi-Stakeholder Collaboration for Sustainability: Learning from Experiences in the Global South. Sustainability. 10(9), 3217. DOI: https://doi.org/10.3390/su10093217

[38] Al-Worafi, Y.M., 2024. Research Publication in Developing Countries: Achievements and Challenges. In: Al-Worafi, Y.M. (Ed). Handbook of Medical and Health Sciences in Developing Countries. Springer: Cham, Switzerland. pp. 1–21. DOI: https://doi.org/10.1007/978-3-030-74786-2_388-1

[39] Guan, J., Yan, Y., Zhang, J.J., 2017. The Impact of Collaboration and Knowledge Networks on Citations. Journal of Informetrics. 11(2), 407–422. DOI: https://doi.org/10.1016/j.joi.2017.02.007

[40] Ellegaard, O., Wallin, J.A., 2015. The Bibliometric Analysis of Scholarly Production: How Great is the Impact? Scientometrics. 105(3), 1809–1831. DOI: https://doi.org/10.1007/s11192-015-1645-z

[41] Jokić, M., 2020. Productivity, Visibility, Authorship, and Collaboration in Library and Information Science Journals: Central and Eastern European Authors. Scientometrics. 122(2), 1189–1219. DOI: https://doi.org/10.1007/s11192-019-03308-4

[42] Ip, H.H.S., Wong, S.W.L., Chan, D.F.Y., et al., 2018. Enhance Emotional and Social Adaptation Skills for Children with Autism Spectrum Disorder: A Virtual Reality Enabled Approach. Computers & Education. 117, 1–15. DOI: https://doi.org/10.1016/j.compedu.2017.09.010

[43] Lorenzo, G., Lledó, A., Pomares, J., et al., 2016. Design and Application of an Immersive Virtual Reality System to Enhance Emotional Skills for Children with Autism Spectrum Disorders. Computers & Education. 98, 192–205. DOI: https://doi.org/10.1016/j.compedu.2016.03.018

[44] Miller, H.L., Bugnariu, N.L., 2016. Level of Immersion in Virtual Environments Impacts the Ability to Assess and Teach Social Skills in Autism Spectrum Disorder. Cyberpsychology, Behavior, and Social Networking. 19(4), 246–256. DOI: https://doi.org/10.1089/cyber.2014.0682

[45] Chen, C.H., Lee, I.-J., Lin, L.-Y., 2015. Augmented Reality-Based Self-Facial Modeling to Promote the Emotional Expression and Social Skills of Adolescents with Autism Spectrum Disorders. Research in Developmental Disabilities. 36, 396–403. DOI: https://doi.org/10.1016/j.ridd.2014.10.015

[46] McMahon, D.D., Cihak, D.F., Wright, R.E., et al., 2016. Augmented Reality for Teaching Science Vocabulary to Postsecondary Education Students with Intellectual Disabilities and Autism. Journal of Research on Technology in Education. 48(1), 38–56. DOI: https://doi.org/10.1080/15391523.2015.1103149

[47] Sedighi, M., 2016. Application of Word Co-Occurrence Analysis Method in Mapping of the Scientific Fields (Case Study: The Field of Informetrics). Library Review. 65(1–2), 52–64. DOI: https://doi.org/10.1108/LR-07-2015-0075

[48] Luo, Y., Grimaldi, N.S., Lu, X., et al., 2022. Repurposing Design in Bedrooms to Improve Home Accessibility: Task and Motion Analysis Using the Virtual Reality Environment. Proceedings of the Human Factors and Ergonomics Society. 66(1), 368–372. DOI: https://doi.org/10.1177/1071181322661133

[49] Saudagar, A.K.J., Kumar, A., Khan, M.B., 2024. Mediverse Beyond Boundaries: A Comprehensive Analysis of AR and VR Integration in Medical Education

for Diverse Abilities. Journal of Disability Research. 3(1), 1–15. DOI: https://doi.org/10.57197/JDR-2023-0066

[50] Li, W.-A., Chiu, F.-Y., 2024. Using VR Eye-Tracking Technology to Explore the Perceptiveness of Preschool Teachers in Observing Students with Special Needs in Teaching Environments. In Proceedings of the 2024 6th International Workshop on Artificial Intelligence and Education, Tokyo, Japan, 28–30 September 2024; pp. 177–181. DOI: https://doi.org/10.1109/WAIE63876.2024.00039

[51] Naves, E.L.M., Bastos, T.F., Bourhis, G., et al., 2016. Virtual and Augmented Reality Environment for Remote Training of Wheelchair Users. In Proceedings of the 2016 IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom), Munich, Germany, 14–16 September 2016; pp. 1–4. DOI: https://doi.org/10.1109/HealthCom.2016.7749418

[52] Budziszewski, P., Grabowski, A., Milanowicz, M., et al., 2016. Workstations for People with Disabilities: An Example of a Virtual Reality Approach. International Journal of Occupational Safety and Ergonomics. 22(3), 367–373. DOI: https://doi.org/10.1080/10803548.2015.1131069

[53] Iatraki, G., Delimitros, M., Vrellis, I., et al., 2021. Augmented and Virtual Environments for Students with Intellectual Disability: Design Issues in Science Education. In Proceedings of the 2021 International Conference on Advanced Learning Technologies (ICALT), Tartu, Estonia, 12–15 July 2021; pp. 381–385. DOI: https://doi.org/10.1109/ICALT52272.2021.00122

[54] Silva, R.M., Martins, P., Rocha, T., 2025. Virtual Reality Educational Scenarios for Students with ASD: Instruments Validation and Design of STEM Programmatic Contents. Research in Autism Spectrum Disorders. 119, 102521. DOI: https://doi.org/10.1016/j.rasd.2024.102521

[55] Ancis, J.R., 2020. The Age of Cyberpsychology: An Overview. Technology, Mind, and Behavior. 1(1), 1–15. DOI: https://doi.org/10.1037/tmb0000009

[56] Di Mascio, T., Tarantino, L., 2020. The Structured Methodological Framework 'Deejay': Foundation and Its Application to the Design of an ASD-Oriented AAC Tool. In: Rehm, M., Saldien, J., Manca, S. (Eds). Project and Design Literacy as Cornerstones of Smart Education. Smart Innovation, Systems and Technologies, vol 158. Springer: Singapore. pp. 247–259. DOI: https://doi.org/10.1007/978-981-13-9652-6_22