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Reimagining the Past: A Bibliometric Analysis of Museum-Based VR in History Education (2021–2025)

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Abstract. Museum-based virtual reality (VR) is increasingly used to support immersive history and heritage learning, yet related studies remain scattered across education, computer science, tourism, and cultural heritage. This fragmentation obscures the field's intellectual structure, dominant themes, and pedagogical value for history education. To address this gap, this study maps the development, knowledge base, emerging topics, and practical contributions of museum-based VR in history education from 2021 to 2025. A bibliometric analysis was conducted on 116 peer-reviewed articles and review articles selected from 330 Web of Science records using VOSviewer, including performance, co-citation, and keyword co-occurrence analyses. The results show rapid growth after 2023, reflecting increased interest in immersive learning, digital heritage, remote cultural access, and VR-supported heritage education. Co-citation analysis identified four clusters related to immersive museum experience, educational VR and learning effectiveness, digital cultural heritage reconstruction, and foundational AR/VR theory. Keyword co-occurrence analysis identified seven clusters, highlighting themes such as AI-supported immersive

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learning, VR/MR design, heritage education, extended reality applications, cultural heritage visualization, digital storytelling, empathy, and gamified virtual museums. The findings suggest that museum-based VR should be understood not only as a technological innovation but also as a pedagogical and cultural environment that requires scaffolding, curriculum alignment, accessible design, and culturally responsive interpretation. Research output is concentrated mainly in China, Italy, and selected Asian and European countries, revealing a regional imbalance. This study contributes a structured knowledge map and practical guidance for designing inclusive, learner-centered, and pedagogically meaningful VR history learning experiences.

Keywords: museum-based virtual reality; history education; immersive learning; heritage access; bibliometric analysis

1. Introduction

Virtual reality (VR) is increasingly transforming how museums and heritage organizations present historical materials. However, the academic discussion on museum-based VR remains fragmented across education, computer science, tourism, and cultural heritage studies. In this study, museum-based VR refers specifically to VR experiences connected to museum collections, heritage sites, exhibition narratives, or curatorial interpretation, used to support historical learning. It differs from general educational VR applications, which may focus on simulation, training, gaming, or abstract visualization without a museum or heritage-based context. This study positions museum-based VR primarily as an educational and pedagogical issue, while treating technological design, visitor experience, and policy implications as supporting dimensions.

Over the past five years, researchers have moved beyond the novelty of VR displays to examine their educational, affective, and social implications (Zhou et al., 2022). The COVID-19 pandemic further accelerated interest in digital heritage experiences, including school field trips, remote museum portals, and mixed-reality tours (Trunfio et al., 2022; Wang et al., 2024). These developments show that VR can expand access to historical artifacts and cultural narratives, especially for learners who cannot easily visit museums in person. Nevertheless, increased access does not automatically lead to meaningful historical learning. The key issue is whether immersive museum experiences can support historical understanding, critical thinking, empathy, and learner engagement, particularly in curriculum-based and museum-supported history education contexts.

Existing studies reveal several tensions in the educational use of museum-based VR. Early classroom experiments suggest that students may be impressed by vivid historical reconstructions but still struggle with critical-thinking tasks when cognitive scaffolding is insufficient (Wu et al., 2023). Adoption studies also show that users evaluate VR platforms according to perceived usefulness, authenticity, and usability before deciding whether to use them (Wu et al., 2022). In addition, research on emotional and physiological responses indicates that strong audiovisual stimulation can generate both interest and anxiety, raising questions about the appropriate level of immersion for learning (Marín-Morales et al., 2021).

These findings suggest that the educational value of VR depends not only on technological immersion but also on instructional design, learner support, and contextual relevance.

A second concern relates to equity, representation, and cultural interpretation. Photorealistic reconstructions, such as virtual heritage sites, can democratise access to fragile or distant cultural locations (Liritzis et al., 2021). However, critical curriculum scholars warn that immersive environments may also reproduce dominant historical perspectives and marginalize certain cultural groups (Jones, 2022). Mixed-reality design studies further show that display modes, headset ergonomics, and sensory accessibility influence users' sense of presence and agency (Trunfio et al., 2022). Similarly, language-infused VR learning indicates that students' willingness to communicate improves only when tasks are embedded in culturally meaningful scenarios (Wu & Hung, 2022). These studies highlight the need for learner-centered and culturally responsive approaches to museum-based VR.

Museum-based VR is also connected to broader educational and institutional goals. For example, teacher-developed curriculum materials that integrate historical inquiry with STEM design problems create opportunities for interdisciplinary learning but also complicate curriculum alignment (Park & Cho, 2022). Museum tourism studies show that different display modes, such as head-mounted VR and large-screen projection, can influence post-experience behavior, including social sharing and return visits (Wang et al., 2024). These findings indicate that museum-based VR should be examined as a pedagogical tool that links historical learning, museum interpretation, learner experience, and institutional sustainability, rather than only as a technological innovation or visitor attraction.

Despite these developments, the research gap remains clear. Previous studies have often examined museum-based VR from distinct perspectives, including technological design, visitor experience, tourism behavior, classroom experimentation, and cultural heritage interpretation. However, limited bibliometric research has systematically mapped the connections among these perspectives within the specific field of museum-based VR for history education. In particular, the relationships among instructional design, adoption models, affective engagement, cultural representation, and curriculum relevance remain insufficiently synthesized. This gap is important because educators, museum practitioners, and policymakers need a clearer understanding of which research areas are well established, which themes are emerging, and how museum-based VR can be designed to support meaningful and inclusive history learning.

This study differs from previous studies in two main ways. First, it distinguishes museum-based VR from general VR applications by focusing on VR experiences connected with museum collections, heritage sites, exhibition narratives, and curatorial interpretation. Second, it focuses specifically on the educational role of museum-based VR in history learning rather than treating it solely as a technological innovation, a tourism product, or a visitor-experience tool. Using

bibliometric analysis, this study examines the development of museum-based VR research in history education from 2021 to 2025 by mapping publication patterns, co-citation networks, and keyword co-occurrence clusters to identify the field's intellectual foundations, emerging research directions, and pedagogical implications. In doing so, this study contributes a structured overview of the field and provides practical implications for designing pedagogically meaningful, culturally inclusive, and learner-centered VR history learning experiences.

Therefore, this study is guided by the following objectives:
1. To identify the major research patterns, influential studies, and dominant intellectual foundations in museum-based VR research through bibliometric and co-citation analysis.

2. To examine emerging themes and research frontiers in museum-based VR for history education through keyword co-occurrence analysis.

3. To clarify the pedagogical implications of museum-based VR for history learning, particularly in relation to learner engagement, historical understanding, cultural representation, and inclusive curriculum design.

2. Literature Review

This section reviews the existing literature on museum-based virtual reality (VR), museum learning, and history education. It first discusses how museum-based VR supports history learning through immersion, presence, and interaction. It then examines previous reviews and empirical studies on VR and museum learning before identifying the research gap and conceptual positioning of the present bibliometric study.

2.1 Museum-Based VR and History Learning

Previous studies on museum-based VR show that immersive technologies can increase access to historical artifacts, strengthen learners' sense of presence, and support more interactive forms of museum learning. However, immersion alone does not guarantee historical understanding. Without appropriate cognitive scaffolding, learners may be attracted by vivid reconstructions while still struggling with critical thinking and historical interpretation (Wu et al., 2023). Therefore, museum-based VR should be examined not only as a technological tool but also as a pedagogical environment that requires clear learning objectives, guided inquiry, and curriculum alignment.

2.2 Previous Reviews on VR and Museum Learning

Existing research has also examined user experience, technology adoption, and engagement in museum-based VR. Studies show that perceived usefulness, authenticity, usability, and display modes influence users' willingness to engage with VR platforms (Wang et al., 2024; Wu et al., 2022). Zhou et al. (2022) provided one of the closest related reviews by synthesizing virtual and augmented reality in museum learning. However, their scope was broader than the present study, which focused on museum learning generally rather than on museum-based VR specifically in history education. It also did not primarily map the co-citation

structure, keyword co-occurrence patterns, or intellectual development of museum-based VR research in history education from 2021 to 2025.

2.3 Research Gap and Conceptual Positioning

A further strand of research concerns cultural representation, equity, and inclusive design. Virtual heritage can democratise access to fragile or distant cultural sites (Liritzis et al., 2021), but immersive environments may also reproduce dominant historical narratives and marginalize certain cultural groups (Jones, 2022). Overall, existing studies have provided valuable insights into technological design, visitor experience, cultural interpretation, and learning engagement. However, limited bibliometric work has specifically mapped how museum-based VR connects pedagogical design, historical learning, learner experience, cultural representation, and curriculum relevance within history education.

Conceptually, this study understands museum-based VR history education as the interaction of four dimensions: museum and heritage context, pedagogical design, learner experience, and cultural inclusion. These dimensions guide the interpretation of the bibliometric patterns identified in this study. This positioning is also informed by embodied cognition and historical thinking, as learners' spatial movement, sensory engagement, evidence interpretation, perspective taking, and cultural memory may shape how they understand and connect with the past (Hine, 2025; Seixas, 2017).

3. Methodology

A bibliometric analysis examined the development, intellectual structure, and thematic patterns of museum-based virtual reality (VR) research in history education from 2021 to 2025. This method is appropriate for identifying publication growth, citation patterns, influential documents, co-citation relationships, and keyword co-occurrence networks within a defined body of literature (Zou et al., 2025). In the context of museum-based and immersive learning research, bibliometric mapping can help reveal how studies are distributed across education, technology, cultural heritage, and visitor-experience domains (Wu et al., 2022; Zhou et al., 2022). In this study, bibliometric analysis was used not only to describe research productivity but also to map the knowledge base and emerging research directions of museum-based VR in history education.

Three analytical procedures were applied. First, performance analysis was used to examine publication output, citation indicators, influential documents, leading journals, productive authors, institutions, and countries. Second, co-citation analysis was conducted to identify the intellectual foundations of the field by examining how frequently cited references appeared together in the same bibliographies. Third, keyword co-occurrence analysis was used to identify major themes and emerging topics based on the frequency and strength of keyword relationships. Together, these procedures provided a multi-layered understanding of how museum-based VR research in history education has

developed across educational, technological, cultural heritage, and visitor-experience contexts.

3.1 Search Strategy and Screening Criteria

This bibliometric analysis examined academic literature on VR and immersive technologies in museum-based history education. The Web of Science (WoS) Core Collection was selected as the primary data source because it provides structured bibliographic records, citation information, author keywords, institutional affiliations, and cited references, all suitable for bibliometric mapping and VOSviewer analysis.

The final dataset covered Web of Science records published between 2021 and 2025. The initial search was conducted in the WoS Topic Search (TS) field, followed by the application of publication year, document type, and language filters to refine the dataset. This period was selected because museum-based VR research expanded rapidly after 2021, particularly in relation to remote cultural access, immersive learning, digital heritage, and technology-enhanced education. The original WoS Boolean search query was reported in Table 1 to improve transparency and reproducibility. The query was designed around three search blocks: immersive technology terms, museum or heritage context terms, and history-oriented education terms.

The first search block captured VR-related and immersive technology terms, including "virtual reality," "VR," "mixed reality," and "immersive technolog*." The second block captured museum and heritage-related contexts, including "museum*," "heritage," and "cultural institution*." The third block used the NEAR/5 operator to ensure that history-related terms appeared close to education-related terms, thereby improving the relevance of the results to history education, historical learning, heritage education, and teaching contexts. The wildcard symbol * was used to capture word variants, such as "museum" and "museums," "technology" and "technologies," "education" and "educational," as well as "learning" and "teaching."

Clear inclusion and exclusion criteria were applied during the screening process. Records were included if they were published between 2021 and 2025, indexed in the Web of Science Core Collection, written in English, and classified as articles or review articles. Records were excluded if they were outside the selected publication period, were not articles or review articles, were not written in English, or did not match the combined focus on immersive technologies, museum or heritage contexts, and history-oriented education.

The initial search identified 330 records from the Web of Science Core Collection. After limiting the publication years to 2021–2025, 186 records remained. The dataset was then refined by document type, retaining only articles and review articles, which reduced the number of records to 121. After applying the English-language filter, 116 records were retained as the final dataset for bibliometric analysis. The screening process is presented in Figure 1.

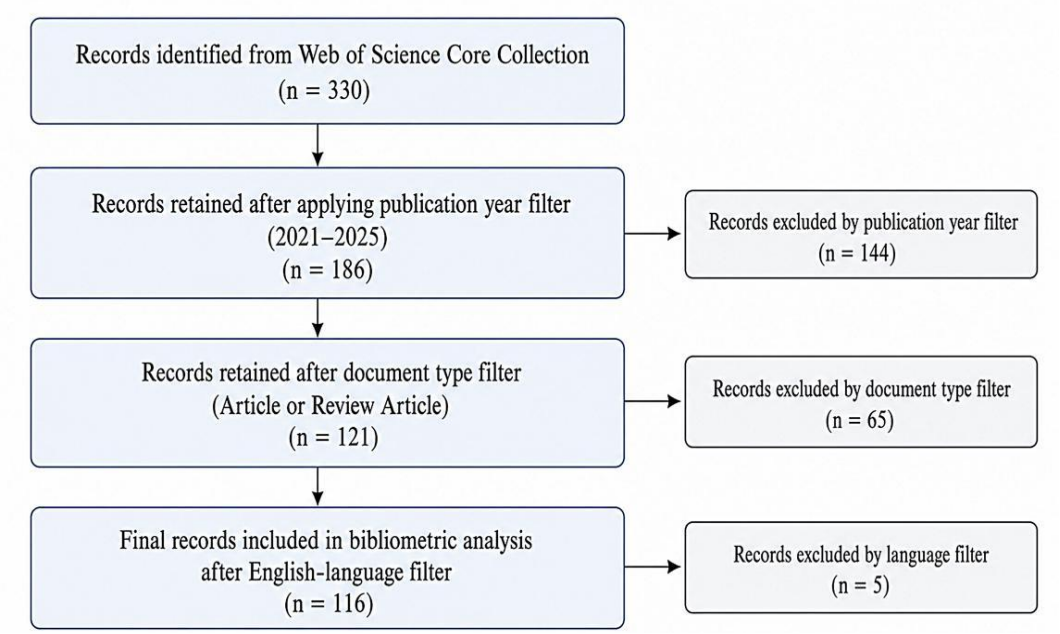

Figure 1: PRISMA-style flow diagram of Web of Science (WoS)-based literature screening

Table 1 summarises the search strategy, inclusion criteria, exclusion criteria, and final dataset used in the bibliometric analysis.

Table 1: Search and screening criteria for bibliometric analysis

Criteria	Details
Database	Web of Science Core Collection
Time period	2021 to 2025; records retrieved in May 2026
Search field	Topic Search field (TS)
Original search query	TS=(("virtual reality" OR VR OR "mixed reality" OR "immersive technolog*") AND (museum* OR heritage OR "cultural institution*") AND ((history OR historical OR heritage) NEAR/5 (educat* OR learn* OR teach*)))
Document type	Article or Review Article
Language	English
Screening criteria	Publication year, document type, language, and topic relevance based on the search query
Inclusion criteria	WoS-indexed articles and review articles published between 2021 and 2025, written in English, and related to immersive technologies, museum or heritage contexts, and history-oriented education, learning, or teaching
Exclusion criteria	Records outside 2021–2025, non-article or non-review document types, non-English records, and records not aligned with the VR/mixed reality–museum/heritage–history education focus
Screening outcome	330 records identified; 186 records remained after the year filter; 121 records remained after the document-type filter; 116 English-language articles and review articles retained as the final dataset

3.2 Data Export and Cleaning

After the final dataset was determined, bibliographic records were exported from the Web of Science Core Collection in plain-text format with full records and cited references. The exported data included titles, abstracts, authors, source titles, publication years, author keywords, Keywords Plus, affiliations, citation counts, and cited references.

The records were checked for bibliographic completeness and consistency of key metadata before VOSviewer analysis. Because all records were retrieved from a single Web of Science source, cross-database duplicate removal was not required. Keyword variations were also considered when interpreting the keyword co-occurrence results.

The bibliographic records were exported from Web of Science in May 2026, forming a fixed dataset for bibliometric analysis. Because WoS records, citation counts, indexing status, and early-access records may change over time, the exported dataset was retained consistently throughout the analysis to ensure alignment across the screening process, citation indicators, VOSviewer maps, and reported results.

3.3 Bibliometric Analysis Procedures

Bibliometric analysis was conducted using VOSviewer. Performance analysis was used to examine publication growth, citation patterns, influential documents, leading journals, productive authors, institutions, and countries. Co-citation analysis was used to identify the intellectual foundations of the field, while keyword co-occurrence analysis was used to identify dominant and emerging research themes.

For the co-citation analysis, cited references were analyzed directly from WoS-exported bibliographic records, without intermediary tools such as Bibliometrix. A minimum citation threshold of 5 was applied. Of the 6,048 cited references in the dataset, 43 met this threshold and were included in the final co-citation map, forming 4 clusters. VOSviewer's association strength normalization method and default clustering settings were used to calculate link strength and group closely related references. The resulting clusters were interpreted according to citation weight, link strength, and thematic coherence.

For the keyword co-occurrence analysis, author keywords and Keywords Plus were analyzed using VOSviewer. A minimum occurrence threshold of 3 was applied. Of the 553 keywords identified in the dataset, 54 met this threshold and were included in the final co-word map, forming 7 clusters. VOSviewer's association strength normalization method and default clustering settings were used to identify thematic keyword groups. Larger nodes indicate higher keyword frequency, stronger links indicate closer relationships between keywords, and clusters represent groups of terms with stronger internal connections.

The bibliometric maps were interpreted by combining quantitative indicators with qualitative reading of influential documents, representative keywords, and cluster labels. This approach helped move the analysis beyond descriptive

mapping and identify the intellectual structure, thematic development, and emerging research directions of museum-based VR in history education.

3.4 Methodological Scope and Limitations

Although the search string was expanded to include VR, mixed reality, immersive technologies, museum, heritage, cultural institutions, and history-oriented education terms, studies using only alternative labels such as "virtual museum," "augmented reality," "extended reality," "XR," "digital heritage," or "cultural heritage learning" may still have been missed. This limitation was accepted to maintain a focused, reproducible dataset centered on the intersection of immersive technologies, museum or heritage contexts, and history education.

This study used Web of Science as the sole database because it provides structured citation metadata, cited references, and bibliographic records suitable for VOSviewer analysis. However, this choice may have excluded relevant studies indexed in Scopus, ERIC, Google Scholar, regional databases, or non-English sources. The restriction to articles and review articles may also have excluded conference-based or locally published studies.

Therefore, the findings should be interpreted as a WoS-based bibliometric mapping of museum-based VR in history education rather than a complete representation of all existing research on the topic. In addition, bibliometric analysis can identify publication patterns, citation relationships, and thematic structures, but it cannot directly evaluate classroom effectiveness, learner achievement, or the quality of VR implementation in specific educational settings.

4. Results

The initial WoS Boolean search query reported in the Methods section identified 330 records from the Web of Science Core Collection. After applying the 2021–2025 publication-year filter, 186 records remained. The dataset was further refined by document type, retaining only articles and review articles, which reduced the number of records to 121. After applying the English-language filter, 116 peer-reviewed articles and review articles were retained as the final corpus for bibliometric analysis. This screening process strengthened the dataset's relevance by focusing on studies directly related to immersive technologies, museum or heritage contexts, and history-oriented education.

According to the Web of Science citation report, the final corpus received 1,341 citations in total, which decreased to 1,269 citations after self-citations were removed. The number of citing articles decreased from 1,103 to 1,065 after excluding self-citing articles. This difference suggests that self-citation accounted for only a limited proportion of the citation record. With an average of 11.56 citations per item, the corpus shows a growing level of scholarly attention, indicating that museum-based VR in history education has become an increasingly visible research area across education, cultural heritage, tourism, and technology-related fields.

The citation and publication distribution are shown in Figure 2. Publication output remained relatively modest from 2021 to 2023, with 13 publications in 2021, 13 in 2022, and 12 in 2023. A clear increase appeared in 2024, when the number of publications rose to 27, followed by a stronger rise in 2025, when output reached 51 publications. This pattern indicates that research on museum-based VR in history education expanded rapidly after 2023, reflecting growing interest in immersive learning, digital heritage, remote cultural access, and technology-enhanced museum education.

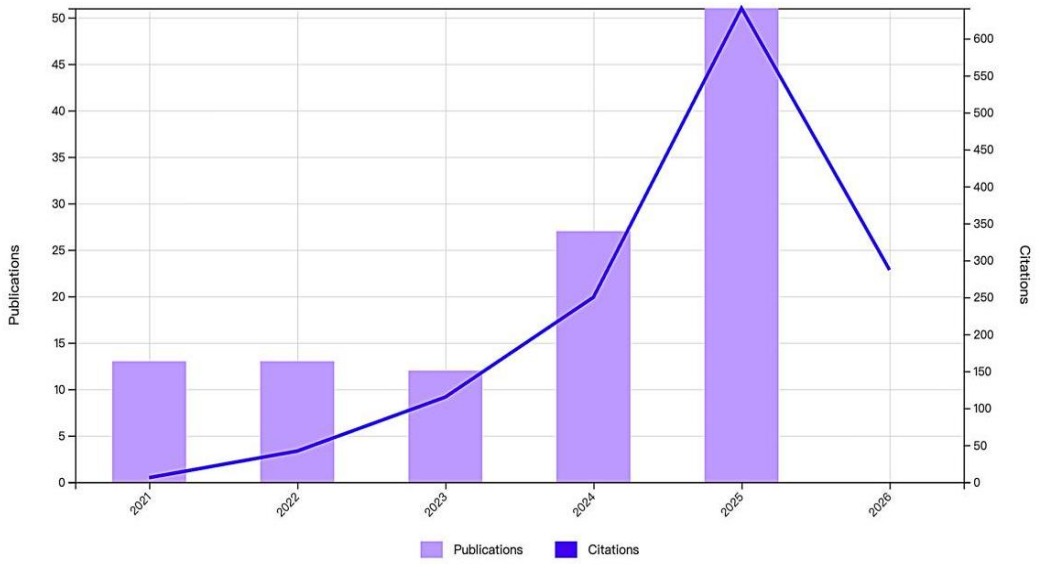

Figure 2: Quantity of publications and citations between 2021 and 2025

The citation trend also shows a marked increase over time. Citation volume rose gradually in the early years and increased substantially after 2023, reaching its highest level in 2025. This pattern suggests that the field has moved from early exploratory studies to a more visible research area focused on learning design, user experience, heritage interpretation, and the educational applications of immersive technologies. Highly cited studies such as Trunfio et al. (2022) and Zhou et al. (2022) further indicate that immersive functionality, visitor experience, and museum learning synthesis have become important reference points in the field.

The dataset recorded an H-index of 20, derived from the Web of Science citation report for the final corpus of 116 records. This means that 20 articles received at least 20 citations each. However, because the H-index is more commonly applied to authors, journals, or larger publication bodies, it should be interpreted here only as a descriptive indicator of citation concentration within this thematic corpus. Together with the citation counts and average citations per item, this result suggests that museum-based VR in history education is an emerging but rapidly developing field with growing relevance for future research, curriculum development, and immersive heritage learning.

4.1 Performance Analysis

A bibliometric performance analysis of museum-based VR in history education reveals important trends across documents, journals, authors, institutions, and countries. These indicators provide an overview of the field's publication output, citation influence, and international research distribution.

4.1.1 By Documents

Citation counts identified the most influential studies in the dataset. Zhou et al. (2022) ranked first with 98 citations, showing the importance of review-based evidence on virtual and augmented reality in museum learning. Trunfio et al. (2022) ranked second with 85 citations, highlighting the role of mixed reality in shaping museum visitors' immersive experiences and post-experience behaviors. Lian and Xie (2024) ranked third with 79 citations, indicating growing attention to digital cultural heritage trends. Other highly cited studies focused on phygital technologies, tangible interfaces, narrative engagement, metaverse and XR applications, traditional art learning, heritage digital twins, and VR-based archaeological reconstruction. Overall, the top-cited documents suggest that the field is shaped by both educational and technological concerns.

4.1.2 By Journals

The journal distribution confirms the field's interdisciplinary nature. Sustainability ranked first, with 9 documents and 173 citations, followed by the ACM Journal on Computing and Cultural Heritage, with 7 documents and 108 citations. Heritage also published 7 documents, while Applied Sciences-Basel contributed 5 documents and 76 citations. Other relevant journals included International Journal of Human-Computer Interaction, Virtual Reality, Multimodal Technologies and Interaction, Drones, Scientific Reports, and NPJ Heritage Science. These sources show that museum-based VR research is published across sustainability, computing, cultural heritage, human–computer interaction, and applied technology journals.

4.1.3 By Authorship

The author-level performance analysis shows that several scholars contributed repeatedly to this research area. Kitti Puritat ranked first with 5 documents and 81 citations, followed by Kannikar Intawong with 4 documents and 61 citations, and Natchaya Wongwan with 3 documents and 57 citations. Other productive authors included Miram Ali, Spyros Vosinakis, Pakinee Ariya, Pantelis Volonakis, Ioannis Liritzis, Pilar Merchan, and Maria Jose Merchan. These authors reflect the field's connection with educational technology, immersive learning, cultural heritage visualization, and digital reconstruction.

4.1.4 By Institutions

Institutional analysis shows that research output was distributed across Asian and European institutions. Chiang Mai University ranked first with 5 documents and 81 citations. The University of the Aegean also produced 5 documents, while Politecnico di Milano contributed 4 documents and 57 citations. Other contributing institutions included Beijing Institute of Graphic Communication, Communication University of China, Onaizah College, Henan University, University of Extremadura, National Yunlin University of Science and

Technology, and University of Macerata. These results indicate that museum-based VR research is supported by institutions with strengths in digital media, cultural heritage, design, education, and immersive technologies.

4.1.5 By Countries

Country-level results show that China was the leading contributor, with 34 documents and 516 citations. Italy ranked second with 14 documents and 258 citations, followed by South Korea, England, the USA, Spain, Greece, Thailand, Australia, and Saudi Arabia. These results suggest that the field has an international research base, but research output and citation influence remain concentrated in several countries. The strong contribution from China and selected European and Asian countries also indicates increasing global interest in museum-based VR, digital heritage, and immersive education.

Overall, the performance analysis shows that museum-based VR in history education has developed into an interdisciplinary, internationally connected field. Highly cited works mainly focus on museum learning, mixed reality experience, digital cultural heritage, immersive storytelling, user experience, and heritage reconstruction. However, the uneven distribution of countries and institutions suggests that future studies should include a broader range of regional, cultural, and educational contexts.

4.2 Co-Citation Analysis

The co-citation analysis of Web of Science records on museum-based virtual reality (VR) in history education identifies 10 influential works that were frequently cited together, thereby illuminating the conceptual backbone of the field. These works span museum learning, immersive experience, user interaction, digital heritage reconstruction, and educational applications, indicating that the field draws on multiple but interconnected research traditions.

Table 2: Top 10 co-cited articles on museum-based VR in history education

Rank	Authors	Title	Citations
1	Zhou et al. (2022)	A meta-analytic review on incorporating virtual and augmented reality in museum learning	98
2	Trunfio et al. (2022)	Mixed reality experiences in museums: Exploring the impact of functional elements of the devices on visitors' immersive experiences and post-experience behaviours	85
3	Lian and Xie (2024)	The evolution of digital cultural heritage research: Identifying key trends, hotspots, and challenges through bibliometric analysis	79
4	Del Vecchio et al. (2023)	Phygital technologies and environments for breakthrough innovation in customers' and citizens' journey: A critical literature review and future agenda	69
5	Hulusic et al. (2023)	Tangible User Interfaces for Enhancing User Experience of Virtual Reality Cultural Heritage Applications for Utilization in Educational Environment	46

6	Leow and Ch'ng (2021)	Analysing narrative engagement with immersive environments: Designing audience-centric experiences for cultural heritage learning	45
7	Anwar et al. (2025)	Metaverse and XR for cultural heritage education: applications, standards, architecture, and technological insights for enhanced immersive experience	44
8	Jin et al. (2022)	Immersive Spring Morning in the Han Palace: Learning Traditional Chinese Art Via Virtual Reality and Multi-Touch Tabletop	41
9	Pan et al. (2024)	Deep learning-based approaches from semantic point clouds to semantic BIM models for heritage digital twin	38
10	Stanga et al. (2023)	Enhancing Building Archaeology: Drawing, UAV Photogrammetry and Scan-to-BIM-to-VR Process of Ancient Roman Ruins	33

Zhou et al. (2022) ranked first with 98 citations, showing the importance of review-based evidence on the use of virtual and augmented reality in museum learning. Trunfio et al. (2022) ranked second with 85 citations, highlighting the role of mixed reality devices in shaping immersive museum experiences and post-experience behaviors. Lian and Xie (2024) ranked third with 79 citations, suggesting that digital cultural heritage research and trend-mapping studies have become important reference points in the field.

Several other highly co-cited studies reflect the technological and design-oriented development of museum-based VR research. Del Vecchio et al. (2023) and Hulusic et al. (2023) point to the importance of phygital technologies, tangible user interfaces, and user experience design. Leow and Ch'ng (2021) emphasize narrative engagement in immersive cultural heritage learning, while Anwar et al. (2025) reflect the increasing attention to metaverse and XR applications in cultural heritage education.

The remaining studies show the field's close relationship with digital reconstruction and heritage visualization. Jin et al. (2022) focus on learning traditional Chinese art through VR and multi-touch interaction, while Pan et al. (2024) and Stanga et al. (2023) highlight semantic point clouds, heritage digital twins, photogrammetry, Scan-to-BIM, and VR-based archaeological reconstruction. These works indicate that museum-based VR research is not limited to educational design alone, but also depends on advances in heritage documentation, digital modeling, and immersive visualization.

Together, the top co-cited works suggest that museum-based VR research is organized around three broad knowledge areas: museum learning and immersive education, user experience and interaction design, and digital cultural heritage reconstruction. This structure shows that the field is developing as an interdisciplinary area in which educational aims, technological affordances, and cultural heritage interpretation are increasingly interconnected.

4.3 Co-Citation Analysis by Clusters

The VOSviewer co-citation map identified 4 clusters among the 43 co-cited references that met the minimum citation threshold of 5 (see Figure 3). These clusters reveal the main intellectual foundations of museum-based VR research in history education, including immersive cultural experience, educational VR, virtual heritage reconstruction, and foundational AR/VR theory.

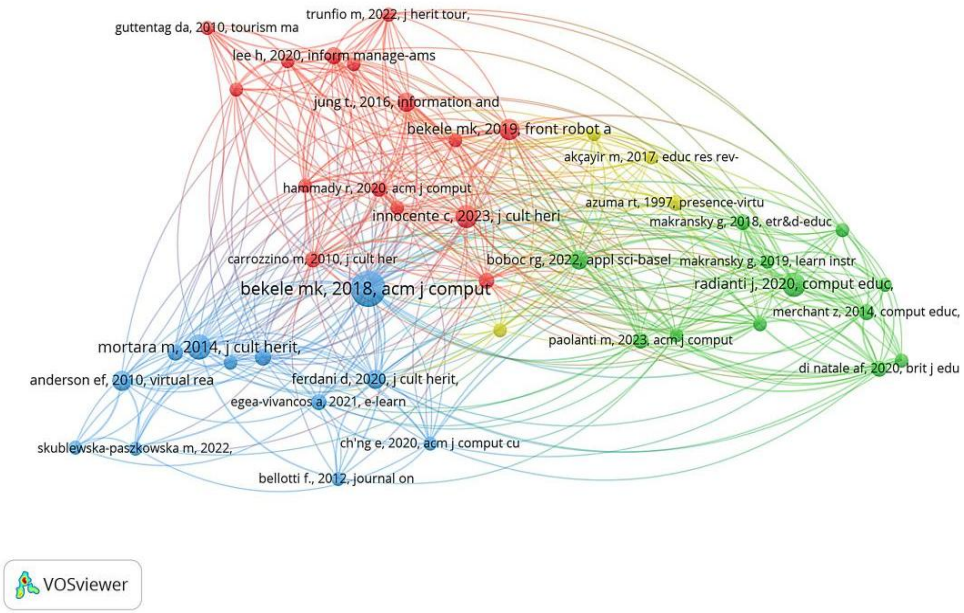

Figure 3: Co-citation Analysis (VOSviewer visualisation)

Cluster 1, labeled Museum VR, Heritage Tourism, and Immersive Cultural Experience, was the largest cluster, containing 15 co-cited references. Representative works in this cluster include Bekele and Champion (2019), Carrozzino and Bergamasco (2010), Guttentag (2010), Lee et al. (2020), Trunfio et al. (2022), Tussyadiah et al. (2018), and Innocente et al. (2023). These studies show that museum-based VR research is strongly connected to immersive visitor experience, heritage tourism, presence, cultural engagement, and the use of virtual environments to enhance museum and heritage interpretation. The frequent co-citation of these works suggests that visitor experience and immersive cultural participation form an important knowledge base for museum-based VR research.

Cluster 2, labeled Immersive Learning, Educational VR, and Learning Effectiveness, contained 12 co-cited references. Representative studies include Di Natale et al. (2020), Jensen and Konradsen (2018), Makransky and Lilleholt (2018), Makransky et al. (2019), Merchant et al. (2014), Radianti et al. (2020), and Slater and Sanchez-Vives (2016). This cluster highlights the educational dimension of VR, particularly learning effectiveness, learner engagement, presence, cognitive load, and the instructional design of immersive learning environments. The co-citation of these studies indicates that museum-based VR research is increasingly linked to broader debates on how immersive technologies support or constrain learning outcomes.

Cluster 3, labeled Virtual Heritage, Cultural Heritage Visualization, and Digital Reconstruction, also contained 12 co-cited references. Representative publications include Anderson et al. (2010), Bekele et al. (2018), Bellotti et al. (2012), Ch'ng et al. (2020), Egea-Vivancos and Arias-Ferrer (2021), Ferdani et al. (2020), and Mortara et al. (2014). This cluster shows that museum-based VR is closely related to virtual heritage, cultural heritage visualization, digital reconstruction, and the use of immersive technologies to represent historical and archaeological contexts. These works provide a technical and interpretive foundation for understanding how cultural artifacts, heritage sites, and historical environments can be reconstructed and experienced through VR.

Cluster 4, labeled Foundational AR/VR Theory, Presence, and Educational Applications, was smaller, containing 4 co-cited references. The co-cited references in this cluster include Akçayır and Akçayır (2017), Azuma (1997), Champion and Rahaman (2019), and Milgram and Kishino (1994). Although this cluster is smaller than the others, it provides an important theoretical and technological foundation for understanding augmented reality, mixed reality, presence, and the broader application of immersive technologies in educational and cultural heritage contexts.

Table 3: Co-citation by clusters

Cluster No and Colour	Cluster Labels	No. of Articles	Representative Publications
Cluster 1 (Red)	Museum VR, Heritage Tourism, and Immersive Cultural Experience	15	Bekele and Champion (2019); Carrozzino and Bergamasco (2010); Guttentag (2010); Lee et al. (2020); Trunfio et al. (2022); Tussyadiah et al. (2018); Innocente et al. (2023)
Cluster 2 (Green)	Immersive Learning, Educational VR, and Learning Effectiveness	12	Di Natale et al. (2020); Jensen and Konradsen (2018); Makransky and Lilleholt (2018); Makransky et al. (2019); Merchant et al. (2014); Radianti et al. (2020); Slater and Sanchez-Vives (2016)
Cluster 3 (Blue)	Virtual Heritage, Cultural Heritage Visualization, and Digital Reconstruction	12	Anderson et al. (2010); Bekele et al. (2018); Bellotti et al. (2012); Ch'ng et al. (2020); Egea-Vivancos and Arias-Ferrer (2021); Ferdani et al. (2020); Mortara et al. (2014)
Cluster 4 (Yellow)	Foundational AR/VR Theory, Presence, and Educational Applications	4	Akçayır and Akçayır (2017); Azuma (1997); Champion and Rahaman (2019); Milgram and Kishino (1994)

Taken together, the 4 co-citation clusters show that the intellectual structure of museum-based VR research is built around immersive museum experience, educational VR and learning effectiveness, digital cultural heritage reconstruction, and foundational AR/VR theory. This structure suggests that the field is not only technology-driven but also shaped by questions of learning design, visitor experience, cultural interpretation, and heritage visualization. Future research should therefore connect technical innovation more explicitly with historical learning goals, curriculum design, and inclusive museum education.

4.4 Co-Occurrence Analysis

The keyword co-occurrence analysis identified 553 keywords from the Web of Science dataset. After applying a minimum occurrence threshold of 3, 54 keywords met the threshold and were included in the final co-word map. These keywords formed 7 thematic clusters, indicating that museum-based VR research in history education is conceptually distributed across immersive technology, cultural heritage, education, user experience, design, gamification, and heritage learning.

Table 4: The 15 most frequent keywords in the co-occurrence analysis

Rank	Keyword	Occurrences	Total Link Strength
1	virtual reality	51	148
2	cultural heritage	37	129
3	augmented reality	24	93
4	virtual reality	21	82
5	education	16	82
6	design	13	58
7	gamification	13	55
8	experience	11	57
9	user experience	11	47
10	technology	10	43
11	cultural heritage	9	29
12	museum	8	34
13	mixed reality	8	32
14	framework	7	37
15	heritage education	7	32

Table 4 presents the 15 most frequent keywords in the co-occurrence analysis. “Virtual reality” ranked first, with 51 occurrences and a total link strength of 148, confirming that VR is the field's central technological focus. “Cultural heritage” ranked second, with 37 occurrences and a total link strength of 129, showing that heritage contexts provide the main cultural and interpretive setting for museum-based VR studies. “Augmented reality” ranked third, with 24 occurrences and a total link strength of 93, suggesting that the field is not limited to VR alone but also includes broader immersive and extended reality technologies.

The remaining high-frequency keywords further underscore the field's interdisciplinary nature. Terms such as “education,” “heritage education,” “museum,” and “framework” indicate that immersive technologies are

increasingly discussed in relation to learning design and educational application. Keywords such as "design," "experience," "user experience," and "technology" highlight the importance of interface design, usability, and learner or visitor experience. In addition, the presence of "gamification" and "mixed reality" suggests that researchers are also exploring interactive, motivational, and hybrid forms of museum-based heritage learning.

It is also important to note that some keyword variants appear separately in the VOSviewer output, such as "virtual reality" and "virtual-reality," as well as "cultural heritage" and "cultural-heritage." These variations reflect differences in keyword formatting across WoS records. Therefore, the results should be interpreted thematically rather than as isolated terms. Taken together, the keyword co-occurrence results suggest that museum-based VR research is moving beyond technological novelty toward a more integrated agenda involving immersive learning, cultural heritage interpretation, user experience, design frameworks, and heritage education.

Although "bibliometric analysis" appears as an author keyword in the present study, it does not appear among the top 15 keywords in the analyzed corpus. This is because the term primarily serves as a methodological descriptor rather than a substantive research theme in museum-based VR history education. Overall, the co-occurrence results reveal 3 major directions in the field: immersive technology development, cultural heritage and museum interpretation, and education-oriented design and user experience. These patterns suggest that museum-based VR history education is developing as an interdisciplinary area that connects technological design, heritage representation, and pedagogical application.

4.5 Co-Occurrence Analysis by Clusters

The keyword co-occurrence map generated in VOSviewer identified 7 thematic clusters among the 54 keywords that met the minimum occurrence threshold of 3 (see Figure 4). These clusters show that museum-based VR research in history education is organized around AI-supported immersive learning, VR/MR design, heritage education, extended reality applications, cultural heritage visualization, digital storytelling, empathy, and gamified virtual museums.

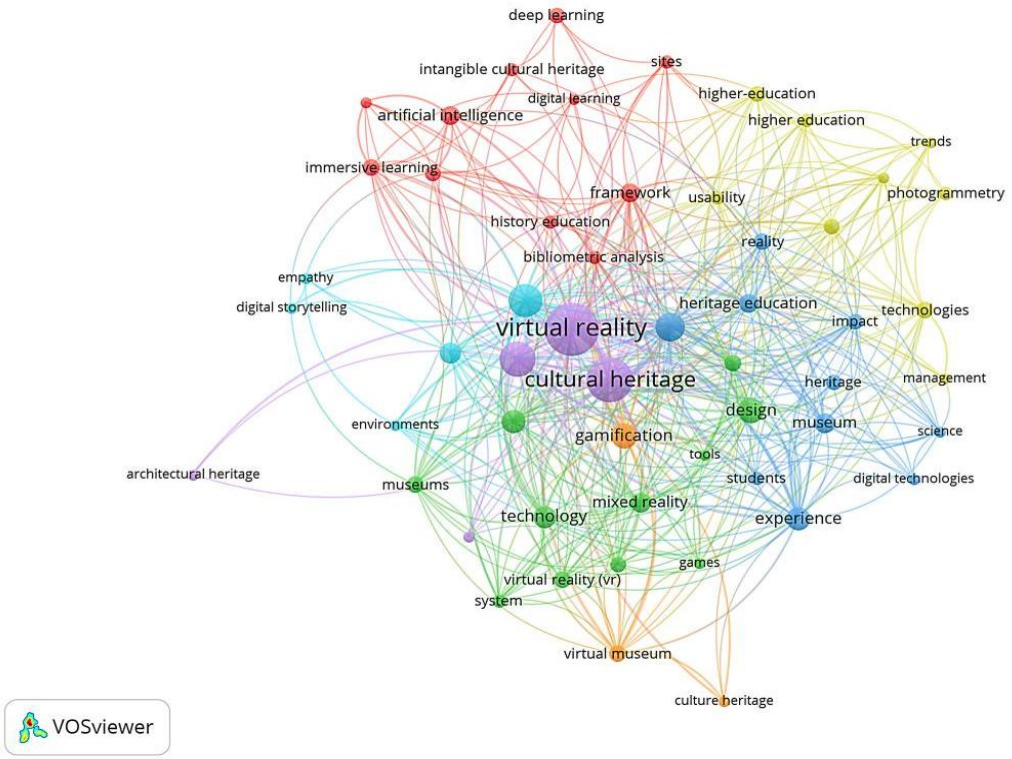

Figure 4: Co-word analysis of museum-VR scholarship in history education (VOSviewer visualisation)

Cluster 1, labeled AI-Supported Immersive Learning and History Education, contained 11 keywords, including "artificial intelligence," "bibliometric analysis," "cultural heritage education," "deep learning," "digital learning," "educational technology," "framework," "history education," "immersive learning," "intangible cultural heritage," and "sites." This cluster suggests that museum-based VR research is increasingly connected with AI-supported learning, digital education, and cultural heritage education. This direction is consistent with recent work on XR, metaverse technologies, and digital cultural heritage education, which highlights the role of advanced technologies in enhancing immersive cultural learning experiences (Anwar et al., 2025; Lian & Xie, 2024).

Cluster 2, labeled VR/MR Design, Museum Systems, and User Experience, also contained 11 keywords. Representative keywords include "design," "digital heritage," "games," "mixed reality," "motivation," "museums," "system," "technology," "tools," "user experience," and "virtual reality (VR)." This cluster highlights the importance of design, usability, motivation, and user experience in museum-based VR and mixed reality systems. These themes are closely related to studies showing that device functions, interface design, and user experience can influence visitors' immersion, satisfaction, and post-experience behaviors in museum contexts (Hulusic et al., 2023; Trunfio et al., 2022).

Cluster 3, labeled Heritage Education, Student Experience, and Learning Impact, contained 10 keywords, including "digital technologies," "education," "experience," "heritage," "heritage education," "impact," "museum," "reality,"

"science," and "students." This cluster shows that researchers are concerned not only with immersive technology itself but also with its educational impact, student experience, and relevance to heritage education. This pattern aligns with previous research suggesting that VR and AR can support museum learning when immersive activities are connected with clear pedagogical goals and learning outcomes (Zhou et al., 2022).

Cluster 4, labeled Extended Reality, Higher Education, and Usability in Heritage Applications, contained 9 keywords. Representative keywords include "archaeology," "extended reality," "higher education," "higher education," "management," "photogrammetry," "technologies," "trends," and "usability." This cluster indicates that extended reality is being explored in higher education and heritage-related applications, especially in relation to usability, archaeology, photogrammetry, and technology management. Such themes are reflected in research on digital reconstruction and VR-based heritage documentation, where photogrammetry and 3D modeling are used to support archaeological interpretation and heritage visualization (Pan et al., 2024; Stanga et al., 2023).

Cluster 5, labeled AR/VR Applications in Cultural and Architectural Heritage, contained 5 keywords: "architectural heritage," "augmented reality," "cultural heritage," "serious games," and "virtual reality." This cluster reflects the continued importance of AR/VR applications in cultural and architectural heritage, particularly through serious games and immersive visualization. Previous studies on 3D reconstruction and virtual heritage environments show that immersive visualization can help represent cultural sites, artifacts, and historical spaces in more accessible and interactive ways (Ferdani et al., 2020; Liritzis et al., 2021).

Cluster 6, labeled Digital Storytelling, Empathy, and Immersive Heritage Environments, also contained 5 keywords, including "cultural-heritage," "digital storytelling," "empathy," "environments," and "virtual-reality." This cluster suggests that museum-based VR is increasingly associated with narrative-based and affective forms of heritage learning, especially through storytelling, empathy, and immersive environments. Narrative engagement has been identified as an important element in cultural heritage learning, as immersive environments can foster emotional connection, perspective-taking, and audience-centered interpretation (Leow & Ch'ng, 2021; Patterson et al., 2022).

Cluster 7, labeled Virtual Museums and Gamified Heritage Learning, was the smallest cluster, containing 3 keywords: "culture heritage," "gamification," and "virtual museum." Although small, this cluster points to an emerging direction in which virtual museums and gamified learning are used to support cultural heritage engagement. This direction is consistent with studies suggesting that virtual museums and game-based interaction can enhance learners' motivation and participation in heritage-related learning activities (Arabacıoğlu & Okulu, 2021; Jin et al., 2022).

Table 5: Co-word analysis on museum-based VR in history education

Cluster No and Colour	Cluster Label	Number of Keywords	Representative Keywords
Cluster 1 (Red)	AI-Supported Immersive Learning and History Education	11	"Artificial intelligence" "bibliometric analysis" "cultural heritage education" "deep learning" "digital learning" "educational technology" "framework" "history education" "immersive learning" "intangible cultural heritage" "sites"
Cluster 2 (Green)	VR/MR Design, Museum Systems, and User Experience	11	"design" "digital heritage" "games" "mixed reality" "motivation" "museums" "system" "technology" "tools" "user experience" "virtual reality (VR)"
Cluster 3 (Blue)	Heritage Education, Student Experience, and Learning Impact	10	"Digital technologies" "education" "experience" "heritage" "heritage education" "impact" "museum" "reality" "science" "students"
Cluster 4 (Yellow)	Extended Reality, Higher Education, and Usability in Heritage Applications	9	"archaeology" "extended reality" "higher education" "higher education" "management" "photogrammetry" "technologies" "trends" "usability"
Cluster 5 (Purple)	AR/VR Applications in Cultural and Architectural Heritage	5	"Architectural heritage" "augmented reality" "cultural heritage" "serious games" "virtual reality"
Cluster 6 (Cyan)	Digital Storytelling, Empathy, and Immersive Heritage Environments	5	"Cultural-heritage" "digital storytelling" "empathy" "environments" "virtual-reality"
Cluster 7 (Orange)	Virtual Museums and Gamified Heritage Learning	3	"Culture heritage" "gamification" "virtual museum"

Across the 7 clusters, 3 broader directions can be identified: technology-supported immersive learning, heritage education and cultural visualization, and user-centered museum experience design. These relationships suggest that museum-based VR research is moving beyond technical experimentation toward a more integrated agenda that connects immersive technologies, heritage interpretation, learner experience, empathy, and educational design.

5. Discussion

The current bibliometric analysis of museum-based virtual reality (VR) research in history education provides recommendations for educators, museum practitioners, curriculum designers, and policymakers. This discussion is grounded in the analysis of 116 peer-reviewed and review articles selected from 330 records in the Web of Science published between 2021 and 2025. The co-citation and keyword co-occurrence results suggest that museum-based VR research has developed around 3 connected concerns: learning design and user experience, cultural heritage visualization and storytelling, and accessibility-oriented implementation. Therefore, the following discussion interprets the bibliometric patterns cautiously, rather than treating VR as inherently effective in all educational contexts.

5.1 Learning-Design Implications

The co-citation and keyword co-occurrence results indicate that learning design remains a central concern in museum-based VR history education. The co-citation clusters show strong links with immersive learning, educational VR, learning effectiveness, presence, and cognitive load. This suggests that VR-based history learning requires more than visual realism or technological novelty; it also requires clear learning objectives, scaffolding, inquiry tasks, reflection prompts, and curriculum alignment. This interpretation is consistent with the Cognitive Affective Model of Immersive Learning, which links presence, agency, embodiment, cognitive load, motivation, and self-regulation to learning in immersive VR environments (Makransky & Petersen, 2021).

The keyword clusters also show that terms such as “education,” “heritage education,” “framework,” “students,” “experience,” and “impact” are closely connected with immersive technologies. This indicates that museum-based VR is increasingly being evaluated for its educational relevance rather than solely for technical performance. Synthesized findings from museum-VR studies suggest that students benefit when immersive activities are connected to historical questions, guided exploration, and post-experience reflection rather than treated as isolated digital experiences (Zhou et al., 2022). Therefore, educators and curriculum designers may consider integrating storyboard templates, inquiry worksheets, guided debriefing, and VR authoring tasks into history education curricula.

5.2 Affective and Cultural Heritage Design

The findings further suggest that museum-based VR supports not only cognitive engagement but also effective and cultural forms of learning. In museum VR research, affective outcomes such as curiosity, empathy, wonder, and emotional arousal appear alongside cognitive outcomes (Zhou et al., 2022). Studies on emotional arousal and immersive presence indicate that immersive media can influence how learners feel connected to historical artifacts, places, and narratives (Marín-Morales et al., 2021; Somarathna et al., 2023). However, emotional engagement should be carefully designed, because excessive sensory stimulation may increase cognitive load or anxiety rather than deepen historical understanding.

Cultural heritage design also requires attention to authenticity, representation, user experience, and historical interpretation (Gong et al., 2024). Research on 3D reconstructions, such as the Sanctuary of Delphi, suggests that historically realistic aesthetics and accurate spatial modeling can enhance immersion and cultural authenticity (Liritzis et al., 2021). At the same time, VR reconstructions should avoid presenting history as a single fixed narrative. Studies on historical empathy and identity suggest that perspective-switching scenarios, local narratives, multilingual voice-over tracks, and culturally responsive storytelling can support more inclusive forms of heritage learning (Patterson et al., 2022). These findings indicate that museum-based VR should be designed not only to visualize the past, but also to help learners question whose histories are represented and how cultural memory is constructed.

5.3 Accessibility, Equity, and Policy Implications

The results also point to the importance of accessibility and equity in museum-based VR history education. Inclusive design principles suggest that VR learning environments should offer accessible modes, subtitle options, flexible pacing, and multilingual support, enabling learners with diverse language abilities, sensory preferences, and accessibility needs to participate more fully. This is consistent with recent bibliometric research on inclusive education for students with disabilities, which identifies accessibility, SDG 4, and reduced inequalities as important directions in educational research (Wider et al., 2025). These design choices are especially important in history education, where cultural interpretation, narrative complexity, and emotional engagement may create barriers for some learners if support mechanisms are not included.

At the institutional and policy levels, the findings suggest that museum-based VR may require sustained support rather than a one-time technological investment. Cloud-based content repositories, lower-cost VR kits, teacher training, and university–museum partnerships may help widen access to immersive heritage learning (Wu et al., 2023; Zhou et al., 2022). Policymakers and educational institutions may also consider quality-assurance criteria that evaluate not only technical performance, but also learning impact, cultural sensitivity, accessibility, and ethical representation (Han et al., 2022; Patterson et al., 2022). In addition, open-access archiving and inter-institutional sharing could help ensure that VR historical assets remain available for future teaching, research, and public heritage education.

5.4 Limitations of the Bibliometric Approach

The implications discussed above should be interpreted in light of the study's bibliometric scope. As noted in the methodology section, this analysis was based on Web of Science records and may not include relevant studies from Scopus, ERIC, Google Scholar, regional databases, or non-English sources. In addition, citation-based indicators reflect scholarly visibility rather than direct evidence of classroom effectiveness. Bibliometric analysis can map publication patterns, citation relationships, and thematic structures, but it cannot directly evaluate learner achievement, teacher readiness, classroom interaction, or the quality of VR implementation in specific museum and educational settings.

Future research should therefore combine bibliometric mapping with qualitative interviews, classroom observations, design-based research, or mixed-methods studies involving teachers, students, and museum educators. Such approaches would provide deeper evidence on the implementation and learning effects of museum-based VR in different cultural and institutional contexts.

6. Conclusion

This study mapped 116 peer-reviewed articles and review articles selected from 330 Web of Science records on museum-based virtual reality (VR) in history education from 2021 to 2025. Using performance analysis, co-citation analysis, and keyword co-occurrence analysis, it examined publication trends, citation patterns, intellectual foundations, and emerging themes in this developing field. The findings show that museum-based VR in history education has gained increasing scholarly visibility, especially after 2023, reflecting growing interest in immersive learning, digital heritage resources, remote cultural access, and VR-supported heritage education.

The analysis identified three core patterns. First, highly cited studies are concentrated around museum learning, mixed reality experience, digital cultural heritage, user experience, immersive storytelling, and heritage reconstruction. Second, the co-citation analysis identified 4 clusters, showing that the field's intellectual structure is built around immersive museum experience, educational VR and learning effectiveness, digital cultural heritage reconstruction, and foundational AR/VR theory. Third, the keyword co-occurrence analysis identified 7 clusters, indicating growing attention to AI-supported immersive learning, VR/MR design, heritage education, extended reality applications, cultural heritage visualization, digital storytelling, empathy, and gamified virtual museums.

Theoretically, this study clarifies how immersive technologies, museum and heritage contexts, learning design, user experience, and cultural representation are connected within museum-based VR history education. In practice, it highlights the need for scaffolded VR learning tasks, curriculum alignment, accessible design, culturally responsive storytelling, and stronger collaboration among schools, universities, and museums. Future research should examine non-Western heritage narratives, local cultural histories, longitudinal learning effects, historical empathy, accessibility for learners with disabilities, and classroom- or museum-based implementation. This study is limited by its reliance on Web of Science records and by the nature of bibliometric analysis, which maps publication patterns and intellectual structures but does not directly measure classroom effectiveness or learner outcomes.

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