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EDUCATION AND MUSEUMS IN THE DIGITAL AGE
A Systematic Review of Emerging Technological Trends in Learning Experiences

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ABSTRACT
The aim of this study is to analyze, synthesize, and categorize recent scientific evidence on emerging technologies in museum education. A PRISMA-compliant systematic review was conducted using Scopus and Web of Science, including 42 studies evaluated using CASP and GRADE. The results show that virtual museums and 2D and 3D digital museums are the most established technologies, particularly in terms of accessibility. Augmented reality and virtual reality stand out in immersive experiences and experiential learning, while artificial intelligence (AI), machine learning, and social robotics form an emerging trend linked to personalization. From a pedagogical standpoint, these technologies contribute to four key dimensions: accessibility, immersion, personalization, and engagement. Museum education is evolving toward an eco-pedagogical ecosystem in which technological, pedagogical, and institutional dimensions converge, bringing together AI, digital humanism, robotics, affective computing, and quantum computing to create an intelligent, affective, and quantum museum education.

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1. Introduction

The educational role of museums has undergone a significant transformation in recent decades. The focus has shifted from exhibition-centred models to approaches focused on experiential visitor learning and social impact. In this context, 21st-century museums must redesign their educational approaches, integrating digital technologies and responding to demands for accessibility, inclusion and educational relevance (Clover, 2015; Hooper-Greenhill, 2007). This evolution has established museums as spaces for non-formal learning with potential for cognitive, emotional and social development in diverse contexts (Todino & Campitiello, 2025).

The museum has been conceived as a space with high potential for identity and pedagogical transformation, in which educational experiences transcend the mere transmission of content (Adams, 2007). Within this framework, emphasis is placed on the need to promote sustainable educational practices, supported by organisational structures that foster teacher empowerment, pedagogical innovation and the effective integration of digital technologies, as well as the well-being of educational stakeholders (Galuban & Green, 2026; Kristinsdóttir, 2017; Tran et al., 2019).

From a teaching perspective, the design of meaningful learning experiences in museums requires a strong link between theory and practice, underpinned by robust educational frameworks (Mayer, 2005). Furthermore, museums are recognised as key infrastructures for public education, with the capacity to address global issues and generate relevant learning in contemporary contexts (Bakker et al., 2020). In this regard, museum education is conceptualised as a non-formal, inclusive learning process centred on the visitor's experience, with an impact on cognitive, emotional and social dimensions (Todino & Campitiello, 2025).

Concurrently, advancements in digital technologies have expedited a substantial transformation of museum education, particularly in the aftermath of the pandemic, which has precipitated the adoption of virtual and hybrid formats (Dumont et al., 2025). Technologies such as augmented reality (AR), virtual reality (VR), extended reality (XR), artificial intelligence (AI) and social robotics are transforming learning experiences in museums, promoting immersion, interactivity and personalisation (Cheng et al., 2025; Musicco & Berardinetti, 2025; Tan et al., 2026).

From a pedagogical perspective, these technologies enable the integration of approaches such as experiential learning and situated learning, facilitating the connection between abstract content and authentic learning contexts. Extended reality (XR) has demonstrated its ability to promote comprehensive educational experiences that integrate experimentation, reflection and conceptualisation, in line with models such as Kolb's learning cycle (Torre, 2026). Furthermore, recent studies have emphasised the potential of immersive environments to generate new methodologies for analysing and evaluating the interaction between users, content and museum objects (Huebner, 2026).

In terms of technological innovation, new avenues are emerging, such as virtual museums based on artificial intelligence. These museums integrate content generation systems and advanced interactive environments, with significant impacts on academic performance and the deepening of learning (Tan et al., 2026). Likewise, technologies such as telepresence robots and social robotics expand the possibilities for access, inclusion and the development of cross-curricular skills, such as communication and critical thinking (Laurits & Virkus, 2026; Musicco & Berardinetti, 2025). However, their implementation also poses challenges relating to teacher training, technological resources and access gaps (Berardinetti et al., 2025).

Despite this rapid growth, the literature is highly fragmented, characterised by a wide range of studies focusing on specific technologies, diverse methodological approaches, and limited integration of their pedagogical contributions. While there are reviews focusing on particular technologies, such as XR or augmented reality, there is still insufficient systematic evidence that comprehensively links emerging technologies with their educational contributions in the museum sector (Torre, 2026). It has been determined that there is a lack of literature on the subject of synthesising and categorising emerging technologies applied to museum education. This categorisation should be integrated and should also include the pedagogical contributions of these technologies and their future prospects.

1.1. Literature Review

Contemporary museum education is taking place against a backdrop of institutional, social and technological transformation. In this context, the museum is no longer conceived solely as an exhibition space, but is establishing itself as an environment for learning, participation and inclusion. In this transition, digitalisation evolves from a mere tool to a key medium for museums to share knowledge, enhance educational experiences and expand their reach to diverse audiences.

"In the history of museum education, three possible 'philosophies' or missions of museums can be identified: the educational museum, the aesthetic museum and the social museum" (Zeller, 1989, cited in Hein, 2007, p.342). Hein (2007) advances a similar argument when discussing education in modern museums, noting that:

> current definitions of museums—whether describing an institution containing precious objects, material of primarily historical or scientific value, natural environments designated as museums, or exhibitions specially constructed to illustrate ideas—tend to include some statement about public access and education. (Hein, 2007, p.342)

It can be argued that, based on these points, education should not be considered an ancillary function of the museum, but rather an intrinsic dimension that runs through and articulates its various historical missions. In this sense, museum education is one of the most authentic expressions of the raison d'être of museums. It links heritage conservation with the construction of meaning and democratic access to knowledge and establishes itself as an integrating axis in the evolution of the contemporary museum.

In the current context, this dynamic is expanded by the incorporation of digital technologies (Christ et al., 2021; Clark-Fookes, 2023), which constitutes a cross-cutting dimension that reconfigures the forms of access, interaction and learning within the museum. Therefore, technological mediation enhances and redefines educational, aesthetic and social functions, giving rise to new learning ecologies characterised by accessibility, immersion, personalisation and engagement. This is in line with the evolution towards a contemporary museum conceived as a techno-pedagogical ecosystem.

From this perspective, contemporary museum education is understood as a dynamic, interactive and situated process, in which learning emerges from the convergence of individuals, technologies and environments. Recent research indicates that educational experiences in museums are enhanced when they integrate multiple forms of interactivity—between visitors, with technologies and with the environment—with scaffolding being a key element in fostering meaningful learning (Andre et al., 2017).

Similarly, the growth of virtual museums and immersive environments is broadening educational opportunities beyond physical locations, facilitating experiences such as exploration, in-depth study and self-directed learning before, during and after a visit (Huebner, 2026; Kersten et al., 2017).

Concurrently, the integration of artificial intelligence and conversational agents is introducing new forms of educational mediation. However, this raises significant ethical and curatorial challenges regarding the relationship between humans and algorithmic systems (Brown, 2026). When considered as a whole, these advances underline the fact that museum education in the digital age is not only growing but also being redefined as a sophisticated field of pedagogical design, technological interaction and the construction of learning experiences.

This approach can be situated within the framework of digital humanism, understood as a perspective that seeks to integrate technological development with human values, needs and experiences, directing innovation towards well-being and the construction of meaning (Coeckelbergh, 2024; Prem, 2024). In this regard, technohumanism – a concept that emphasises the symbiotic relationship between humans and technology – plays a pivotal role. According to this philosophy, technology does not merely substitute for the individual; rather, it amplifies their potential for interaction, learning and cultural development.

Within this framework, the proposal aligns conceptually with the principles of Education 5.0, understood as a paradigm that places the human being at the centre of the educational process and integrates advanced technologies, such as artificial intelligence, to enhance personalised, interactive and meaningful learning experiences (Khang et al., 2023). However, while Education 5.0 is configured as a macro framework for educational transformation, the present eco-pedagogical model with technological mediation represents a contextualised application within the museum sector. Here, the interaction between individuals, technologies and cultural heritage gives rise to new learning ecologies.

In this sense, the integration of technology in museums is not only a response to the demands of digital innovation, but also a component of a humanistic and relational approach to learning. Technology plays a role in facilitating the creation of meaning, thereby shaping the dynamics of accessibility, immersion, personalisation and engagement.

1.2. Accessibility: Expanding Educational Access and Democratising Heritage

One of the most significant contributions of digital transformation in museums relates to accessibility. In pedagogical terms, this refers to the ability to increase access to heritage and reduce geographical, temporal, physical and cultural barriers. It also encourages the participation of traditionally under-represented audiences. From this perspective, museum education is linked to social inclusion, educational sustainability, and cultural democratisation. Hanson and Öhman (2022) propose public pedagogy geared towards sustainable development, while Clover (2015) emphasises that museums can challenge dominant narratives and become spaces for critical literacy and social transformation. Similarly, Llamazares de Prado and Arias-Gago (2023) emphasise the importance of ICT in promoting intercultural participation and equitable access, particularly for people with disabilities.

This focus has been significantly strengthened by the expansion of virtual museums, digitised collections, and online educational platforms. Various studies demonstrate that these resources enable museums to fulfil their educational role beyond in-person visits, establishing them as a second classroom or complementary learning environment (Geselowitz & Breitfelder, 2002; Ismaeel & Al-Abdullatif, 2016; Ulusoy, 2010). An ecosystemic perspective adds to this, suggesting that, in collaboration with their communities, museums can help reduce the educational and digital divides that have become more acute during times of crisis, such as the pandemic (Zollinger & DiCindio, 2021). Consequently, accessibility should be understood not only as technological availability, but also as a pedagogical and institutional condition that broadens opportunities for learning and cultural participation.

This perspective also necessitates organisational structures that promote educational sustainability, ensuring that inclusion is not solely dependent on technological accessibility, but also on broader institutional and pedagogical capabilities (Kristinsdóttir, 2017). Furthermore, the psycho-educational dimension of emotional well-being broadens the understanding of the museum as a safe, therapeutic and formative space (Wei et al., 2023).

1.3. Immersion: Situated Experiences and the Expansion of Experiential Learning

The second conceptual axis is immersion, which is defined as the ability of certain technologies to create multisensory, contextual, and emotionally significant experiences. This concept has become particularly well-established following the development of augmented reality, virtual reality, virtual worlds and three-dimensional modelling. From an educational perspective, immersion is linked to experiential and situated learning approaches as it enables visitors to engage with heritage artefacts, stories and contexts in a more active and contextualised way.

Augmented reality is emerging as one of the most promising technologies for enriching engagement with physical heritage by providing layers of information, visuals and narrative. Recent studies demonstrate that integrating it into educational programmes can improve heritage understanding, motivation and cultural appreciation, particularly among children and students (Lee et al., 2021; Yanar et al., 2026). Meanwhile, virtual reality and simulated environments extend the museum experience, offering navigable, immersive environments that can increase motivation, virtual presence, and awareness of heritage. However, the impact on deep cognitive learning is more mixed (Arayaphan et al., 2022; De Carolis et al., 2023; Ismaeel & Al-Abdullatif, 2016).

However, this area also calls for analytical caution. A highly immersive experience does not guarantee meaningful learning in itself. Mayer (2005) cautions that the educational value of multimedia resources hinges on their alignment with sound pedagogical principles. Therefore, immersion should be understood as a condition that enhances learning when integrated with well-defined educational objectives, narratives and mediations, rather than as an end in itself.

In specialised fields, three-dimensional platforms with educational value have been validated, suggesting the potential transfer of these technologies to various educational museum contexts (Sharma et al., 2026). Furthermore, the literature emphasises that a favourable attitude towards emerging

technologies and educational digitalisation is essential for effectively adopting these technologies for pedagogical purposes in museums (Menegaki, 2022).

1.4. Personalisation: Adapting Educational Mediation to the Visitor

The third pillar focuses on personalised learning, which is defined as the ability to adapt content, routes, mediation and interactions according to the characteristics, needs and responses of the visitor. This pillar has become particularly relevant in light of the development of artificial intelligence, social robotics, recommendation systems, virtual assistants and human-computer interaction.

Recent literature indicates that AI and robotics offer opportunities for more responsive and adaptive educational mediation. For example, some studies report that virtual assistants in immersive museums can improve access to information and facilitate interaction with the digital environment (De Carolis et al., 2023). Other studies have explored the use of humanoid robots with emotional recognition capabilities, which can adjust their responses according to the visitor's emotional state, thereby introducing a new dimension to pedagogical personalisation (Yang & Wang, 2023). Developments based on generative AI and machine learning also show potential for adapting content and offering experiences that are better tailored to individual learning trajectories.

However, this line of research is still in its early stages and faces significant challenges. Personalisation cannot be reduced to an algorithmic adjustment; it also depends on teacher mediation, curatorial design, and ethical criteria relating to data use, transparency, and the human–technology relationship. Berardinetti et al. (2025) and Dumont et al. (2025) emphasise that effectively incorporating advanced technologies requires professional training, institutional support, and pedagogical clarity. Personalisation is therefore one of the most promising and least empirically established horizons for digital museum education.

Nevertheless, digital transformation must be underpinned by critical reflection on the institutional narratives that shape these experiences, and the assumption that innovation is neutral or linear must be avoided (Adams, 2007).

1.5. Engagement: Motivation, Participation and a Meaningful Connection with the Museum

The fourth axis is engagement, understood as the degree of cognitive, emotional and participatory involvement that museum experiences generate among visitors. This component appears transversally in the literature and is typically reinforced through interactive, playful, immersive and co-creative experiences. At this level, social media, gamification, educational video games, interactive experiences and collaborative formats have significantly expanded museums' capacity to connect with younger audiences and foster more active participation.

Research on museum educommunication shows that platforms such as TikTok can bring art and heritage closer to new audiences through brief, expository and collaborative formats, although they also generate tensions in the relationship between educators, curatorial practices and audiences (Huebner, 2022, 2023). Complementarily, Rivero et al. (2023) argue that co-creation in museum contexts strengthens the links between museums, schools and communities, transforming the museum into a participatory space for shared cultural construction. In the same vein, Ferrer-Yulfo (2022) highlights its potential for teaching and preserving cultural expressions through active and contextualised approaches.

Likewise, the design of playful experiences and educational video games has demonstrated its capacity to increase visitor motivation, enjoyment and participation (Seale, 2023; Zhang & Hu, 2022). Even technologies such as 3D printing can reinforce this axis by making collections more accessible, encouraging hands-on educational engagement and linking heritage preservation with pedagogical innovation (Short, 2015). In sum, engagement should not be understood merely as momentary interest, but as a meaningful educational connection that strengthens motivation, participation and cultural appropriation.

1.6. Towards an Integrative Framework for Museum Education

Accordingly, technological developments in museum education can be seen to be organised around four key dimensions that structure the learning experience: accessibility, immersion, personalisation and engagement. Accessibility is associated with the democratisation of knowledge and the expansion of access to heritage through digital environments (Clover, 2015; Llamazares de Prado & Arias-Gago, 2023), while immersion is grounded in technologies such as augmented reality and virtual reality, which support multisensory experiences and situated learning (Lee et al., 2021; Mayer, 2005). Personalisation, in turn, emerges through the use of artificial intelligence and social robotics, enabling the adaptation of educational mediation to the characteristics of the visitor (De Carolis et al., 2023; Yang & Wang, 2023), and engagement is consolidated as a transversal dimension that enhances cognitive, emotional and participatory involvement through interactive and co-creative experiences (Rivero et al., 2023; Seale, 2023).

This articulation forms part of a broader transformation of the museum as an educational space, which has shifted from exhibition-centred models towards non-formal, experiential and socially relevant learning environments (Hooper-Greenhill, 2007; Todino & Campitiello, 2025). In this process, technological mediation reconfigures the dynamics of meaning-making, integrating approaches such as experiential and situated learning (Huebner, 2026; Torre, 2026). At the same time, the incorporation of advanced technologies is linked to the need for institutional and pedagogical structures that ensure their effective and sustainable implementation (Berardinetti et al., 2025; Kristinsdóttir, 2017), demonstrating that technological innovation in museums is inseparable from organisational conditions and educational intentionality.

In this context, museum education is evolving towards an ecopedagogical ecosystem of technological mediation, framed within digital humanism, in which technology is conceived as a facilitator of meaningful, learner-centred processes (Coeckelbergh, 2024; Prem, 2024). This approach, aligned with the principles of Education 5.0 (Khang et al., 2023), dynamically integrates technological, pedagogical and institutional dimensions, recognising the museum as a space of interaction between individuals, technologies and cultural heritage. However, despite these advances, the scientific evidence remains fragmented and dispersed across specific technologies and isolated contexts, lacking an integrative articulation that would enable a systematic understanding of how these dimensions converge in the configuration of educational experiences in museums.

Research question

How are emerging technological trends in museum education configured, and what are their main pedagogical contributions, gaps and future directions in learning experiences within museums?

Objective

In response to this gap, the objective of the present systematic review is to analyse, synthesise and categorise recent scientific evidence on the use of emerging technologies in museum education, with the aim of identifying the main technological trends, associated pedagogical approaches and emerging areas of development in learning experiences within museums.

Specifically, the review seeks to:

(a) classify the predominant emerging technologies
(b) examine their pedagogical contributions
(c) identify gaps, challenges and opportunities for future research

2. Method

The PRISMA methodology (Page et al., 2021) was employed, enabling improved traceability of the study through aspects such as eligibility criteria, sources of information, search strategy, study selection process, data extraction process, list of data items, assessment of the risk of bias in individual studies, synthesis methods, assessment of publication bias and evaluation of the certainty of the evidence.

2.1. Eligibility Criteria

The inclusion criteria were as follows: (a) peer-reviewed scientific publications; (b) publications indexed in Scopus and Web of Science; (c) studies explicitly addressing the relationship between

museums and education; (d) studies incorporating digital or emerging technologies applied to learning experiences; and (e) empirical, theoretical or review studies with an educational focus.

The exclusion criteria were: (a) non-peer-reviewed conference proceedings, editorials and technical notes; (b) studies focused exclusively on museum management or conservation without an educational dimension; (c) duplicate records across databases; (d) articles without access to the full text; and (e) publications that did not explicitly address digital technologies.

2.2. Search Strategy

The bibliographic search was conducted in Scopus and Web of Science, considering publications up to 28 January 2026. As a starting point, a generic query was applied: *TITLE-ABS-KEY ("museum" AND "education")*, yielding 8,830 documents. This dataset was subsequently downloaded in RIS and BIBTEX formats for bibliometric analysis in RStudio and for complementary analysis.

Subsequently, a preliminary semantic analysis of titles, abstracts and keywords was carried out, identifying terms with high conceptual density. Based on these terms, a refined search query was constructed, yielding 1,567 documents, which were incorporated into the PRISMA flow diagram.

The descriptors used in the search strategy included the terms *museum* and *education*, combined with a set of keywords associated with digital technologies and learning experiences, such as: *virtual reality, virtual museum, augmented reality, education computing, human–computer interaction, digital technologies, computer-aided instruction, digital museums, artificial intelligence, learning experiences, digital storage, 3D modelling, user interfaces, user experience, digital design and interactive design*.

2.3. Study Selection Process

The initial search in titles, abstracts and keywords (*TITLE-ABS-KEY*) yielded 8,830 records, enabling a broad mapping of the field. Subsequently, in order to increase specificity and focus on studies more directly related to the research object, the strategy was refined by restricting the search to the title field (*TITLE*), resulting in a refined corpus of 1,567 records. This transition reflects the shift from a broad, exploratory search to a more precise one aimed at identifying evidence directly relevant to emerging technologies and learning in museums.

From this refined dataset (n = 1,567), the selection process was initiated following the phases of the PRISMA methodology protocol. Prior to screening, records were removed based on automatic criteria and initial data cleaning (n = 567), including duplicates (n = 412), records flagged as ineligible by automated tools (n = 125) and other reasons (n = 30). The latter corresponded to documents without an identified author (n = 9), incomplete metadata (for example, abstracts without full text, editorial notes or bibliographic indexes) (n = 15), and publications in languages not accessible for analysis (with no translation available) (n = 6).

The screening phase then proceeded, in which the titles and abstracts of 1,000 records were assessed; 880 were excluded for not meeting the objectives of the study, primarily due to the absence of a direct relationship with museum education or the lack of integration of digital technologies in learning experiences.

In the subsequent phase, 120 documents were sought for full-text retrieval; of these, 18 could not be obtained, leaving 102 for eligibility assessment.

During the eligibility phase, the full texts were reviewed in detail, applying the inclusion and exclusion criteria rigorously. A total of 60 studies were excluded for the following reasons: lack of relevance to museum education (n = 24), absence of explicit technology (n = 18), lack of pedagogical contribution (n = 10), and low methodological quality (n = 8).

Finally, the process concluded with the inclusion of 42 studies, which constitute the final corpus for analysis. The full details of the selection process are presented in Figure 1 (PRISMA flow diagram).

2.4. Data Extraction Process

Data extraction was carried out systematically using a purpose-designed recording matrix. For each study, information was collected on authorship, year of publication, educational context, type of museum, emerging technology employed, methodological approach and main educational contributions.

Data Items

The extracted data included:

(a) type of emerging technology;
(b) educational level and museum context;
(c) pedagogical approach;
(d) contributions in terms of accessibility, immersion, personalisation and engagement;
(e) gaps, challenges and opportunities for future research.

2.5. Risk of Bias Assessment

Each study was assessed using judgements of "yes", "no" or "partial", on the basis of which an overall level of risk of bias was established: low, moderate or high (Purssell, 2020; Singh, 2013). The assessment of risk of bias was conducted using the Critical Appraisal Skills Programme (CASP), adapted to the context of systematic reviews with methodological diversity. For each study, an evaluation matrix structured around six dimensions was applied: clarity of objectives, appropriateness of the methodological design, coherence of sampling, validity of data collection, rigour of analysis and robustness of conclusions. Each criterion was assessed using judgements of "yes" (explicit fulfilment), "partial" (limited or ambiguous fulfilment) or "no" (absence of evidence), assigning scores of 2, 1 and 0, respectively.

Based on the total score, studies were classified into three levels of risk of bias: low (≥75% of the maximum score), moderate (50–74%) and high (<50%). For example, studies with clearly defined designs, data triangulation and coherence between results and conclusions were classified as low risk, whereas those with unspecified samples or insufficiently detailed analyses were considered to be at moderate or high risk.

2.6. Synthesis Methods

A thematic narrative synthesis was employed, complemented by categorical analysis, with the aim of integrating and organising evidence derived from methodologically heterogeneous studies. In an initial phase, the studies were coded using an inductive–deductive approach based on their main characteristics (type of technology, educational context, methodological approach and reported results). Subsequently, they were grouped into analytical categories that enabled the structuring of the evidence around three axes: predominant emerging technologies, pedagogical contributions, and research gaps and challenges.

2.7. Certainty of Evidence Assessment

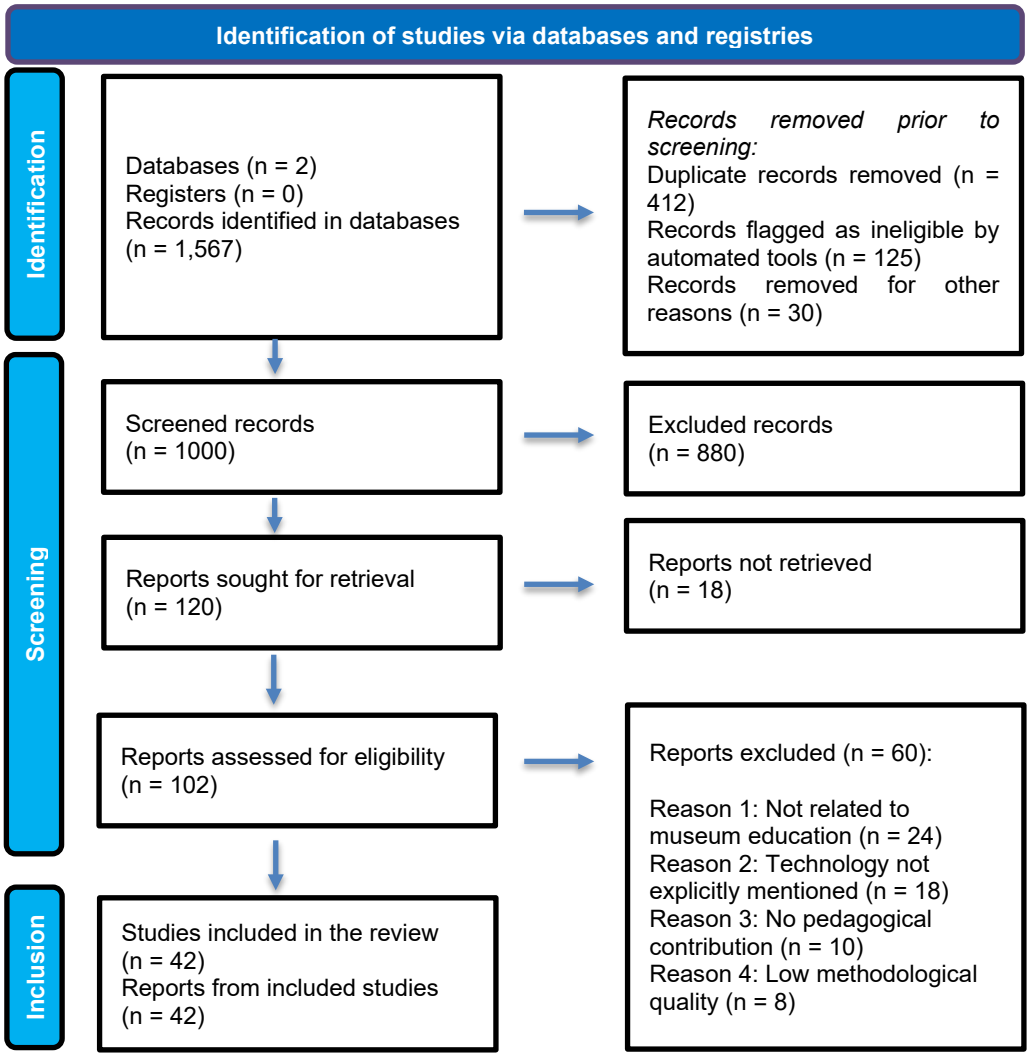
The certainty of the evidence was assessed using the GRADE approach (Grading of Recommendations, Assessment, Development and Evaluation), adapted to the predominantly qualitative and mixed-methods nature of the included studies (Balshem et al., 2011). Four main criteria were considered: methodological limitations (risk of bias), consistency of results across studies, precision of findings and applicability to the context of museum education. Based on these criteria, the evidence was classified into four levels: high, moderate, low and very low. The assessment was conducted iteratively, integrating the results of the CASP analysis and the thematic convergence of the studies.

In operational terms, evidence was considered of high certainty when multiple studies with a low risk of bias showed consistent results regarding the same phenomenon (for example, the impact of augmented reality on motivation and learning). Certainty was downgraded when inconsistencies, small samples or exploratory designs were identified, as is the case with emerging technologies such as artificial intelligence and social robotics, for which the evidence remains incipient.

3. Results

The results corresponding to item 16a of the PRISMA methodology (Page et al., 2021) are presented below, using a flow diagram to describe the outcomes of the search and selection processes, from the number of records identified in the search to the number of studies included in the review (Figure 1).

Figure 1. PRISMA flowchart



Source: Page et al. (2021).

3.1. Emerging Technologies

This section presents a synthesis of the technologies identified in the selected studies (see Table 1). To determine the quality of the included studies, an integrated evaluation was conducted combining the results of the risk of bias assessment (CASP) and the appraisal of the certainty of the evidence (GRADE). First, each study was assessed using CASP according to methodological rigour criteria, including clarity of design, validity of data collection, analytical coherence and robustness of conclusions, resulting in a classification of low, moderate or high risk of bias. These results were subsequently cross-checked against the GRADE assessment, which considered the consistency of findings across studies, sample size and type, precision of results and their applicability to the context of museum education.

Based on this triangulation, five levels of study quality were established: high, when low risk of bias (CASP) coincided with high or moderate certainty of evidence (GRADE); medium–high, when adequate methodological rigour was present alongside partial limitations (for example, small sample size or exploratory scope); medium, when acceptable methodological designs were observed with restrictions in validity or generalisability; medium–low, when exploratory studies with significant methodological limitations predominated; and low, when a high risk of bias or insufficient evidence was identified. It should be noted that, although the scale includes a low level, no study was classified in this category, as studies with critical methodological weaknesses were excluded during the eligibility phase. This criterion ensured a minimum standard of quality in the analysed evidence, thereby strengthening the validity of the synthesis.

Table 1. Selected studies and emerging technologies

No.	Authors and year	Technology identified	Methodology	Study quality
1	(Yanar et al., 2026)	Augmented reality (AR)	Three-phase educational programme (pre-visit, visit and post-visit), with data collection via pre- and post-visit evaluation forms and an evaluation of the application, and qualitative analysis of the results.	High
2	(Lin & Hu, 2025)	Generative artificial intelligence (GenAI)	Design and implementation of a creative learning platform based on five iterative stages, with preliminary evaluation of its effects on learning outcomes and creative self-efficacy	Medium
3	(Cheng et al., 2025)	Augmented reality (AR)	Quantitative approach using a survey and structural equation modelling with PLS-SEM (Partial Least Squares Structural Equation Modelling).	High
4	(Erol et al., 2025)	(Virtual Museum Education, VME).	A qualitative approach using action research, with data collection through pre- and post-interviews, observation, drawings and content analysis.	Media
5	(Kahveci, 2025)	Virtual museums.	Qualitative approach with a phenomenological design, aimed at exploring perceptions and experiences.	Media
6	(Dumont et al., 2025)	Educational digitisation/Digital Museum	Qualitative approach using semi-structured online interviews.	Medium-High
7	(Güler & Cengiz, 2025)	Virtual museums	Mixed-methods approach with an experimental design (experimental group and control group), using quantitative scales and semi-structured qualitative interviews.	High
8	(Gómez et al., 2025)	Immersive virtual reality (VR)	Design and implementation of immersive virtual environments through a three-phase process (development, implementation and evaluation), with analysis of preliminary results.	Medium-Low
9	(Musicco & Berardinetti, 2025)	Social robotics	Analysis of the literature and case studies (theoretical-analytical approach).	Medium-Low
10	(Berardinetti et al., 2025)	Virtual reality (VR) + NFC technology	Exploratory cross-sectional study; survey on attitudes and beliefs	Medium
11	(Yulifar et al., 2024)	Augmented reality (AR)	Development of AR-based digital content using a heuristic approach, comprising two phases: pre-production (information gathering and narrative design) and production (creation of virtual objects and real-time interaction).	Media
12	(Sun, 2024)	AR + Artificial Intelligence	Descriptive study with analysis of empirical cases; qualitative–interpretative approach	Media
13	(Zhang & Gao, 2024)	AI + Human-Computer Interaction (HCI)	Multi-criteria quantitative study; Analytic Hierarchy Process (AHP)	High
14	(Hernández Guzmán et al., 2024)	Augmented Reality (AR) + Makerspaces Museums	Design of an application based on student feedback and analysis using legal design techniques, with prototype development.	Medium-High

15	(Yang & Wang, 2023)	Humanoid robotics + emotional AI	Development and experimental validation of a sentiment analysis model based on multimodal data (voice and emotion), using multi-entity Bayesian networks (MEBN) and a Kalman filter.	High
16	(García et al., 2023)	Virtual museums (2D and 3D)	Research-creation approach with a theoretical-practical method based on artistic techniques and digital tools for museographic design.	Media
17	(De Carolis et al., 2023)	Virtual reality (VR) + AI virtual assistants	Development of a VR experience with virtual agents and preliminary evaluation of acceptance and learning effectiveness.	Medium
18	(Puspasari et al., 2023)	Machine learning	Development of an educational performance index model and sensitivity analysis using scenarios (Key Stage 1–Key Stage 4).	Medium-High
19	(Zhang & Hu, 2022)	Digital museums using *eye-tracking* technology	An experimental approach using visual analysis with *eye-tracking* to evaluate the learning experience in digital museum environments.	Top
20	(Arayaphan et al., 2022)	Immersive virtual reality (VR) (3D virtual museum environment).	Quasi-experimental approach with a control group (traditional learning) and an experimental group (VR), using pre-test/post-test, IMI and interviews; analysis using Student's t-test for paired samples.	High
21	(Piatkowska & Darecka, 2026)	Digital 3D reconstruction technologies (terrestrial laser scanning, digital photogrammetry and 3D modelling).	Integrated methodological approach combining archival documentation, laser scanning, photogrammetry, manual measurement and 3D modelling for historical reconstruction and chronological analysis.	High
22	(Elbay, 2022)	Virtual museums	Qualitative approach using a single, holistic case study, with semi-structured interviews and thematic analysis.	Medium-High
23	(Maipas et al., 2021)	Augmented reality (AR) and virtual reality (VR)	Theoretical analysis of trends and innovations in environmental health education.	Medium
24	(Fedotova et al., 2021)	Virtual museums	Content and cluster analysis applied to the museum's digital objects.	Media
25	(Butcher et al., 2021)	Digitised collections and digital visual media.	Conceptual analysis supported by case studies and the evaluation of educational experiences.	Medium-Low
26	(Fang, 2021)	Digital media technologies (including 3D holographic projection and human-computer interaction).	Quantitative approach using a survey to analyse the use of digital technologies in museum education.	Medium-High
27	(Carlini, 2021)	Digital technologies (digital video installations and prototyping using 3D printing).	Case studies on the architectural design and prototyping of educational kits in museum contexts.	Medium-Low
28	(Malyshev & Titova, 2020)	Digital technologies (video conferencing, teleconferencing and online educational resources).	Descriptive study based on the implementation and analysis of educational experiences and digital programmes in museums.	Medium-Low
29	(Puspasari et al., 2020)	Augmented reality (AR)	Development of an AR application and evaluation of usability using the SUS survey and learning measurement (pre- and post-tests, knowledge).	Medium-High

30	(Bolognesi & Aiello, 2020)	Virtual reality (VR) and ICT applied through a *serious game*.	Design and development of a *serious game* with a technical-engineering and psychological approach, applied to a museum setting.	Medium-High
31	(Dalari, 2019)	Virtual reality (VR)	Implementation of a VR application in arts education, with an assessment of students' attitudes and perceptions.	Medium
32	(Poce et al., 2019)	Augmented reality (AR)	Case study with a practical workshop and evaluation via questionnaire (open and closed questions).	Medium-High
33	(Guazzaroni & Pillai, 2019)	Artificial intelligence (AI), virtual reality (VR), augmented reality (AR) and *wearable* devices.	A theoretical review of approaches and applications of emerging technologies in education and museums.	Media
34	(Ying et al., 2019)	Educational digital museums	Design and development of a digital museum, with evaluation of the user experience via a survey.	Medium-High
35	(Ismaeel & Al-Abdullatif, 2016)	Interactive virtual museum	Quantitative approach using educational intervention and a questionnaire, with statistical analysis in SPSS.	Medium-High
36	(Fevgas et al., 2014)	ICT-based virtual museums (including RFID, web platforms and mobile applications).	Design and development of a technological platform (iMuse) integrating interactive components and evaluation of its application in museum education.	Medium-High
37	(Li, 2013)	Virtual museums based on Internet technologies (IT).	Theoretical and contextual analysis of the use of virtual museums in science education.	Medium
38	(Jun & Bin, 2011)	Virtual museums based on virtual reality (VR) and digital platforms.	Theoretical and conceptual analysis of the transformation of arts education in virtual museums.	Medium-Low
39	(Papadamou et al., 2010)	*Second Life* virtual world (virtual museum).	Development of a virtual educational environment with assessment via online questionnaires and virtual meetings.	Medium
40	(Ulusoy, 2010)	Virtual museums	Experimental design with pre- and post-tests; quantitative analysis using Student's t-test, supplemented with open-ended questions (mixed-methods approach).	Medium-High
41	(Vasilev et al., 2005)	University virtual museum	Description of the design and development of a virtual museum, with an analysis of its structure and future prospects.	Medium
42	(Geselowitz & Breitfelder, 2002)	Virtual museum (IEEE web platform).	Conceptual analysis and development of a digital educational resource for the integration of the humanities, science and technology.	Medium

Source: own work, 2026.

Beyond the description of technologies, methodologies and samples, the integrated CASP–GRADE analysis makes it possible to identify a clearly differentiated methodological pattern in the distribution of study quality. In particular, studies classified as high quality—including those based on augmented reality (Cheng et al., 2025; Puspasari et al., 2020; Yanar et al., 2026), virtual reality (Arayaphan et al., 2022), virtual museums with experimental design (Güler & Cengiz, 2025), as well as approaches involving artificial intelligence, advanced analytics and instrumental technologies (Fang, 2021; Piatkowska & Darecka, 2026; Yang & Wang, 2023; Zhang & Gao, 2024; Zhang & Hu, 2022)—share a common feature: the adoption of quantitative, quasi-experimental or mixed-methods designs with explicit strategies for empirical validation.

These studies incorporate techniques such as structural models (PLS-SEM), statistical tests (Student's *t*-test), controlled designs, multicriteria analysis (AHP) and instrumental measurements (eye-tracking), enabling an objective and replicable evaluation of learning outcomes. In this sense, high quality is not associated solely with the type of technology, but also with the capacity of the methodological design to generate verifiable evidence.

By contrast, studies classified at the medium, medium–high and medium–low levels are predominantly characterised by qualitative, descriptive, exploratory or conceptual approaches, including interviews, case studies, action research, content analysis, theoretical reviews and technological developments without robust empirical validation. This group largely comprises research on virtual museums, social robotics and emerging digital innovation proposals, where interpretative analysis or prototype development prevails over the systematic measurement of educational impact.

Thus, the identified pattern reveals a structural methodological divide: while quantitative and mixed-methods approaches concentrate the highest-quality evidence, qualitative and conceptual studies predominate at intermediate levels of quality. This asymmetry suggests that the field of digital museum education, although highly innovative in technological terms, still presents a gap in the consolidation of rigorous methodological designs, particularly in emerging lines of research where exploration precedes validation.

The results of the systematic review show a predominance of virtual museums and digital platforms as the most established emerging technologies in museum education, particularly in relation to accessibility and pedagogical continuity. At a second level are augmented reality (AR) and virtual reality (VR), associated with experiential and immersive learning approaches. Still incipient, but expanding, are technologies based on artificial intelligence, machine learning and social robotics, linked to processes of personalisation and adaptive educational mediation. In addition, mixed and supporting technologies are identified, such as Human–Computer Interaction (HCI), Radio-Frequency Identification (RFID), 3D printing, serious games and virtual worlds, which play a transversal role in the digital educational architecture of museums.

A synthesis of the studies organised by emerging technology is presented below, allowing for an integrated visualisation of the distribution and recurrence of the main technological strands identified (see Table 2).

Table 2. Summary of studies by emerging technology in museum education

Emerging technology	Grouped studies
Virtual museums / Digital museums	4, 5, 7, 16, 19, 22, 24, 34, 35, 36, 37, 38, 40, 41, 42
Augmented reality (AR)	1, 3, 11, 14, 23, 29, 32, 33
Virtual reality (VR)	8, 17, 20, 30, 31, 33, 39
Artificial intelligence (AI) / Machine learning / GenAI	2, 12, 13, 15, 17, 18
Social / humanoid robotics	9, 15
Educational digitisation / digitised collections / multimedia	6, 25, 26, 28, 41
Mixed technologies and others (HCI, RFID, 3D printing, serious games, Second Life)	10, 21, 27, 30, 33, 36, 39

Source: own work, 2026.

3.2. Pedagogical Contributions to Museum Education

Regarding pedagogical contributions, the analysed studies show that emerging technologies contribute in differentiated ways to the dimensions of accessibility, immersion, personalisation and engagement. Accessibility is primarily strengthened through virtual museums and the digitisation of collections, which make it possible to overcome geographical, temporal and contextual barriers and expand educational access to school, university and community audiences. Immersion is consistently associated with the use of AR and VR, which facilitate multisensory experiences, situated learning and greater cognitive and emotional involvement on the part of the visitor. The personalisation of learning is linked

to technologies based on artificial intelligence and educational robotics, enabling the adaptation of content, pathways and mediation according to users' characteristics and responses. Finally, engagement emerges as a transversal outcome, particularly reinforced by immersive, interactive and playful experiences, resulting in increased motivation, interest and participation.

Overall, the results suggest that pedagogical impact does not depend solely on the technology employed, but also on its coherent integration with educational approaches centred on the learner's experience. The greatest volume of pedagogical evidence is concentrated in engagement and immersion, while personalisation appears as an emerging line of research, strongly associated with AI and robotics, but still supported by a more limited number of empirical studies (Table 3).

Table 3. Pedagogical contributions to museum education

Pedagogical dimension	Studies	Summary rationale
Accessibility	4, 7, 19, 20, 22, 34, 35, 40, 42	Virtual and digital museums as an alternative to geographical, temporal or health-related barriers; distance learning and the virtual classroom.
Immersion	1, 3, 8, 14, 17, 20, 30, 31	Use of AR and VR to create multisensory experiences, virtual presence and experiential learning
Personalisation	2, 13, 15, 17, 18	AI, GenAI and emotional robotics to tailor content, pathways and educational mediation to the user
Engagement	1, 3, 7, 8, 14, 20, 30, 35	Increased intrinsic motivation, enjoyment, participation and positive attitudes towards learning

Source: own work, 2026.

The analysis reveals gaps that constrain the use of emerging technologies in museums, including a lack of pedagogical alignment, inequalities in adoption, and shortcomings in infrastructure and training. Ethical concerns also emerge regarding data management and human–technology interaction. Despite this, opportunities for future research are identified, particularly in relation to integrative pedagogical ecosystems (see Table 4).

Table 4. Gaps, challenges and opportunities for future research

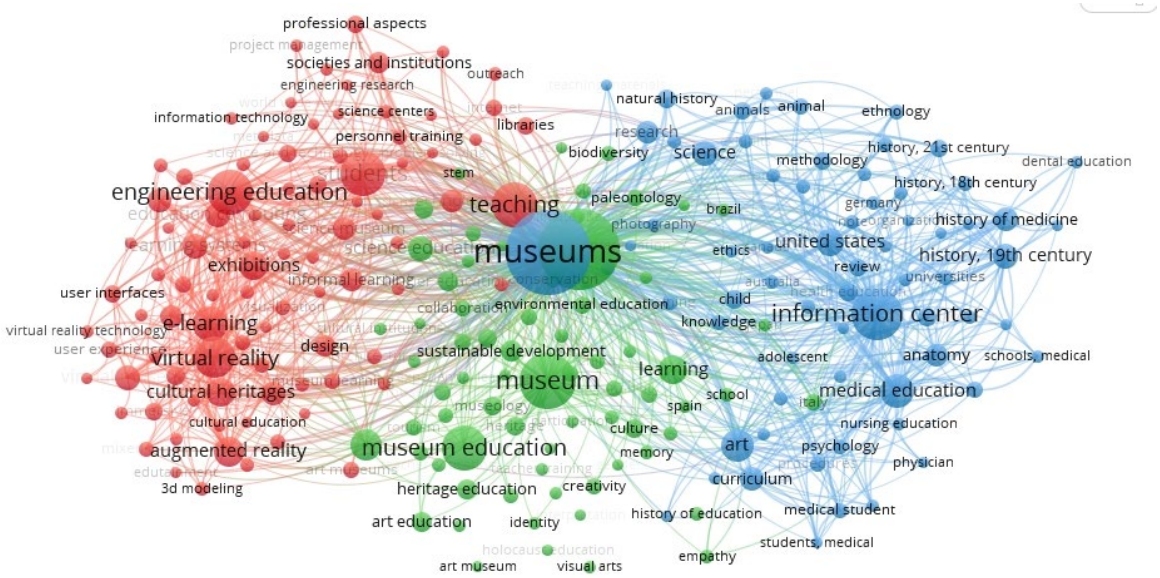
Type of contribution	Studies	Gaps and challenges
Pedagogical design gaps	8, 17, 22, 31	Use of technology without sufficient pedagogical alignment; immersive experiences without in-depth assessment of learning
Infrastructure and resource constraints	10, 27, 28, 30	Costs, equipment, technological sustainability and institutional dependency
Teacher and facilitator training	5, 6, 10, 25, 27	Shortcomings in digital skills, resistance to change and the need for continuous professional development
Ethical challenges and organisational-	6, 13, 15, 18	Data privacy, human- -machine interaction, cultural acceptance and AI-based decision-making
Opportunities for future research	2, 12, 15, 17, 18, 21, 39	Adaptive AI, social robotics, learning analytics, blended technologies, and inclusive and sustainable approaches

Source: own work, 2026.

3.3. Bibliometric Synthesis of Museum Education

Complementarily, a bibliometric package is presented to strengthen the findings of the systematic review. The analysis of the term co-occurrence network was based on 9,082 documents downloaded from Scopus (*TITLE-ABS-KEY: "museum" AND "education", updated to 14 April 2026*); this network reveals a clearly differentiated structure organised into three major thematic clusters.

Figure 2. Co-occurrence network



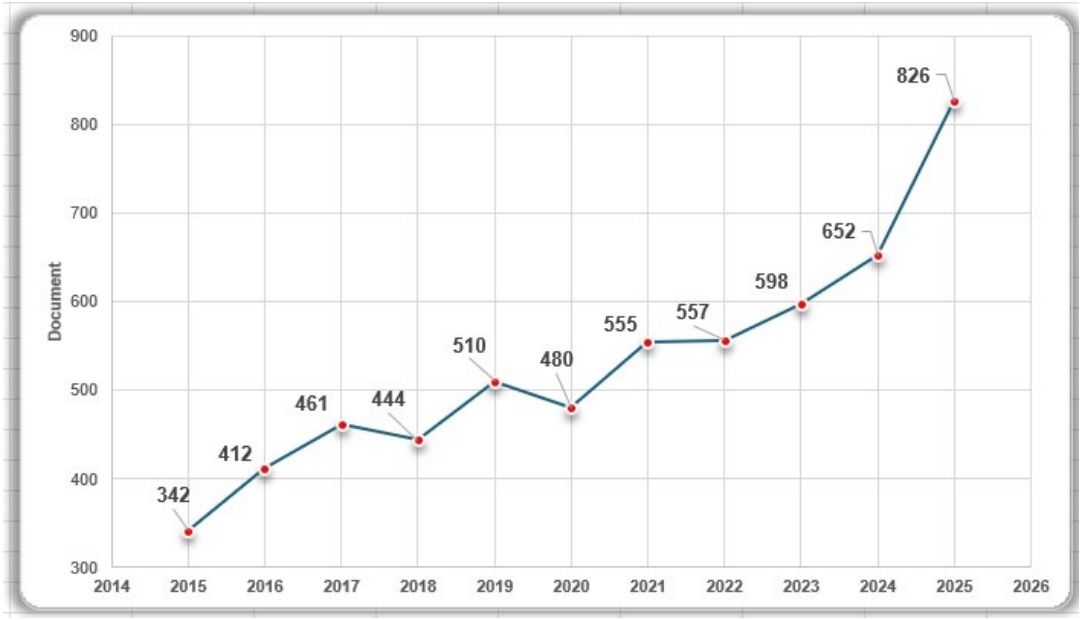
Source: Scopus. Created using VOSVIEWER

The red cluster concentrates terms associated with educational technologies and the design of experiences, such as virtual reality, augmented reality, e-learning, user interfaces, exhibitions and engineering education, indicating a high density of relationships linked to the technological dimension of the field. The green cluster groups concepts of a pedagogical and educational nature, including museum education, learning, creativity, identity, environmental education and sustainable development, reflecting the centrality of formative, cultural and educational approaches in the literature. The blue cluster brings together terms related to institutional and disciplinary contexts, such as information centre, medical education, history, science, curriculum and universities, highlighting the presence of museum-based educational applications in specialised domains. Taken together, the network reveals the coexistence and co-presence of technological, pedagogical and institutional dimensions in research on museum education, without the predominance of a single thematic line.

3.3.1. Annual production on museum education

The analysis of scientific production on museum education reveals a historical evolution marked by clearly differentiated stages. The earliest identified study dates back to 1888, with *The Bradshaw Lecture on Museums in Their Relation to Medical Education and the Progress of Knowledge* by Jonathan Hutchinson (1888). For more than a century, scientific output remained at very low levels and exhibited irregular growth. It was not until 2003 that the threshold of 100 annual publications was reached for the first time, signalling the beginning of a more consistent phase of expansion in the field. Subsequently, 2015 represents a significant turning point, with more than 300 articles published, reflecting a progressive consolidation of academic interest in museums, particularly in their educational, technological and sociocultural dimensions. From this milestone onwards, scientific production shows a sustained upward trend year after year, evidencing a process of maturation in the field. This trajectory culminates in a historical peak in 2025, when more than 800 articles were published annually, suggesting not only quantitative expansion but also thematic and methodological diversification in research (Figure 3).

Figure 3. Annual production on museum education

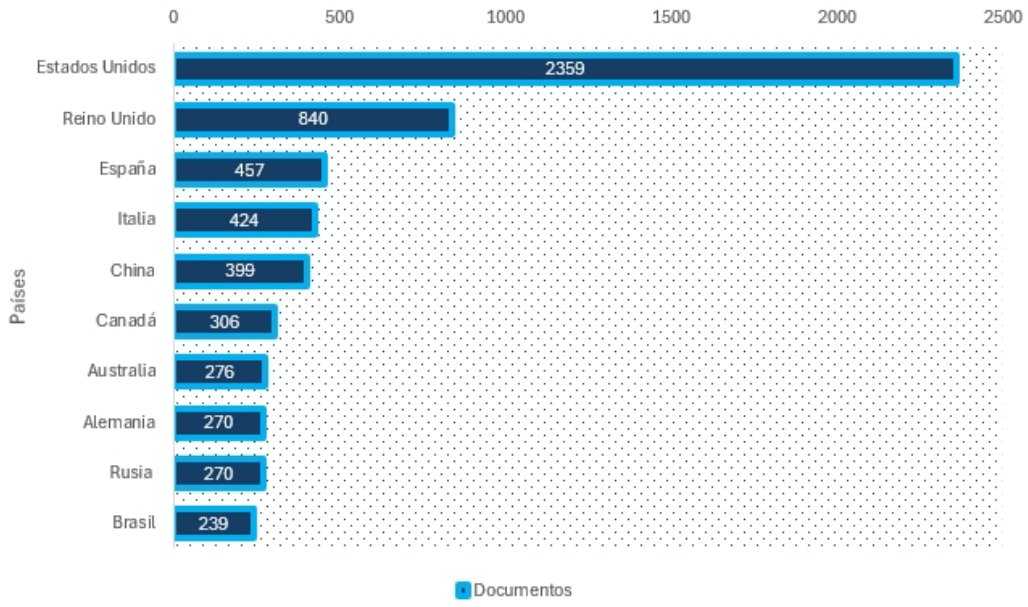


Source: Scopus. Date: 14 April 2026

3.3.2. Leading countries

Scientific production in museum education shows a clear geographical concentration, led by the United States (n = 2,359), followed at a considerable distance by the United Kingdom (n = 840). At a second level are Spain (n = 457), Italy (n = 424) and China (n = 399), indicating a predominantly Euro-North American distribution, alongside increasing participation from other international contexts, such as Canada, Australia, Germany, Russia and Brazil.

Figure 4. Leading countries in museum education



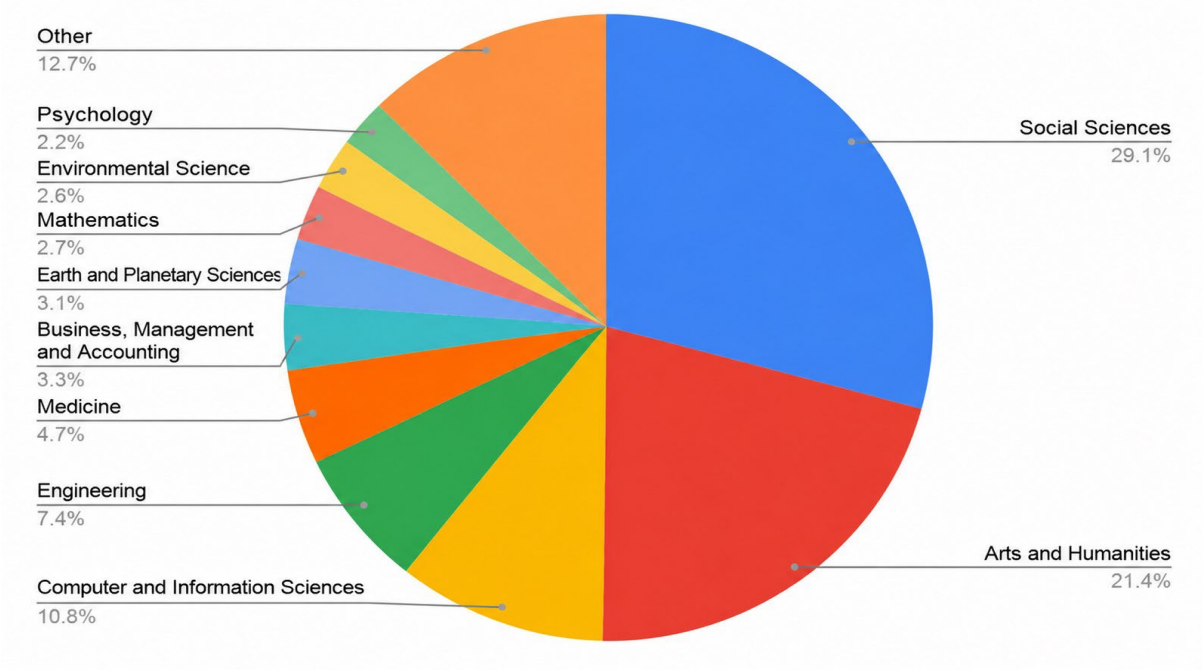
Source: Scopus. Date: 14 April 2026

3.3.3. Relevant subject areas in museum education

Among the ten most prominent thematic areas are: (1) Social Sciences, (2) Arts and Humanities, (3) Computer Science, (4) Engineering, (5) Medicine, (6) Business, Management and Accounting, (7) Earth and Planetary Sciences, (8) Mathematics, (9) Environmental Sciences and (10) Psychology. With lower representation, a second group of areas includes Agricultural and Biological Sciences, Physics and

Astronomy, Economics, Econometrics and Finance, Materials Science, Energy, Decision Sciences, Biochemistry, Genetics and Molecular Biology, Chemistry, Pharmacology and Neuroscience.

Figure 5. Relevant thematic areas in museum education



Sources: Scopus. Date: 14 April 2026

3.3.4. Most relevant sources

In terms of scientific impact, *Museum Management and Curatorship* ranks first, followed by *Journal of Museum Education* and *International Journal of Science Education*, consolidating their position as the leading journals in the field (Table 5).

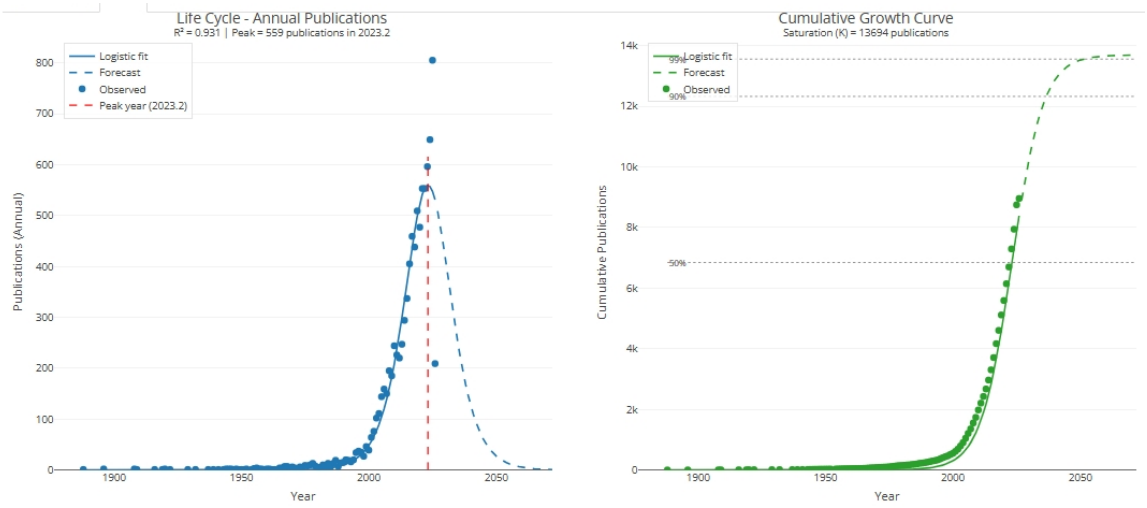
Table 5. Local impact of sources according to the H-index

Source	H_INDEX	G_INDEX	M_INDEX	TC	NP	PY_START
Museum Management and Curatorship	19	31	0.422	1205	80	1982
Journal of Museum Education	17	23	1,308	1336	284	2014
International Journal of Science Education	16	22	0.516	1066	22	1996
Journal of Research in Science Teaching	16	20	0.372	1428	20	1984
Sustainability (Switzerland)	16	23	1,778	600	43	2018
Lecture Notes in Computer Science	13	27	0.565	928	136	2004
International Journal of Art and Design Education	12	19	0.4	450	45	1997
International Journal of Science Education	12	19	0.857	375	23	2013
Science Education	12	19	0.255	984	19	1980
Computers and Education	11	13	0.344	1159	13	1995

Source: Scopus. Exported from Bibliometrix

Finally, the life cycle of scientific production reveals a process of maturation in the field of museum education, indicating that it is entering a phase of maximum expansion and suggesting a potential stabilisation in the near future. Furthermore, the cumulative growth curve, which follows a sigmoidal pattern, confirms this trajectory, moving from an initial slow phase to accelerated growth, and subsequently approaching a saturation point estimated at approximately 13,694 publications. This context opens a favourable scenario for theoretical deepening, thematic specialisation and the development of new emerging lines of research.

Figure 6. Life cycle of scientific production on museum education



Source: Scopus. Exported from Bibliometrix

4. Discussion

4.1. From Technological Fragmentation to an Ecopedagogical Model of Digital Museum Education

The main contribution of this review lies not only in identifying which technologies predominate in museum education, but in demonstrating that the field can no longer be adequately understood through isolated technological catalogues. Unlike previous reviews focused on specific technologies—such as XR or augmented reality—or on particular applications of digital innovation in museums (Guazzaroni & Pillai, 2019; Musicco & Berardinetti, 2025; Torre, 2026), this study shows that digital museum education is more coherently organised as an ecopedagogical ecosystem in which three interdependent dimensions converge: technological, pedagogical and institutional. Within this ecosystem, technology operates as a form of mediation whose value depends on its articulation with curatorial narratives, teaching sequences, the training of mediators, and the conditions of access and organisational sustainability (Berardinetti et al., 2025; Dumont et al., 2025; Hooper-Greenhill, 2007; Kristinsdóttir, 2017; Mayer, 2005).

From this perspective, the review offers a significant conceptual shift for the field and enables a reconsideration of how museum learning is reconfigured, under what conditions it produces educational value, and what tensions it introduces into the learning experience. This shift is particularly important because recent literature has tended to expand rapidly yet in a fragmented manner, with a predominance of exploratory studies, prototype developments and short-term evaluations, without an integrative synthesis linking pedagogical evidence, technological maturity and the institutional conditions of implementation (De Carolis et al., 2023; Gómez et al., 2025; Lin & Hu, 2025). Accordingly, the review analytically reconfigures the field by showing that accessibility, immersion, personalisation and engagement are dimensions traversed by epistemological, pedagogical and ethical tensions.

In this regard, the results suggest that contemporary digital museum education is in a transitional phase: virtual museums and educational digitisation constitute the most consolidated infrastructure; augmented reality and virtual reality represent the most rapidly expanding experiential layer; and artificial intelligence, machine learning and social robotics define an emerging frontier of personalisation and adaptive mediation that is still undergoing pedagogical validation (Arayaphan et al., 2022; Cheng et al., 2025; Güler & Cengiz, 2025; Lin & Hu, 2025; Yang & Wang, 2023). Consequently, the field does not advance as a succession of discrete technologies, but as a layered architecture of learning, in which each technology contributes distinct possibilities while simultaneously introducing new demands for educational design.

4.2. Pedagogical Dimensions as Structural Tensions in Museum Education

One of the most significant contributions of this review is to demonstrate that accessibility, immersion, personalisation and engagement are tension-laden dimensions whose pedagogical value depends on how they are designed, implemented and evaluated.

First, accessibility emerges as one of the most robust contributions of museum digitalisation. Virtual museums, digitised collections and online educational platforms have expanded access to heritage beyond physical visits, positioning the museum as a "second classroom", a complementary resource to formal education and a space for pedagogical continuity in times of crisis (Erol et al., 2025; Geselowitz & Breitfelder, 2002; Güler & Cengiz, 2025; Ismaeel & Al-Abdullatif, 2016; Ulusoy, 2010; Ying et al., 2019). This line of inquiry aligns with perspectives that conceive the museum as a form of public pedagogy, as a space of inclusion and as an agent of cultural democratisation (Clover, 2015; Hansson & Öhman, 2022; Llamazares de Prado & Arias-Gago, 2023). Moreover, the transformative potential of digitised collections to foster authentic learning experiences and expand equitable educational opportunities reinforces this interpretation (Butcher et al., 2021). However, the review shows that digital accessibility does not automatically translate into educational inclusion. Persistent gaps in connectivity, technological literacy, quality of visual design and social interaction limit the democratising potential of these tools, particularly in contexts with weaker infrastructure or limited institutional readiness (Dumont et al., 2025; Elbay, 2022; Zollinger & DiCindio, 2021). In other words, accessibility expands reach but does not in itself guarantee equity of participation or depth of learning.

Second, immersion concentrates a substantial portion of recent innovation, particularly through augmented reality, virtual reality, XR and three-dimensional modelling. The studies reviewed show that these technologies enhance presence, motivation, imagination and emotional engagement, while also facilitating situated and multisensory learning experiences (Arayaphan et al., 2022; Cheng et al., 2025; Dalari, 2019; Gómez et al., 2025; Lee et al., 2021; Poce et al., 2019; Yanar et al., 2026; Yulifar et al., 2024).

However, the review also confirms a central tension in the field: greater immersion does not necessarily imply greater learning. This finding aligns with Mayer's (2005) warning regarding the non-automatic nature of multimedia learning and with recent studies that distinguish between experiential intensity and cognitive depth (Ceccacci et al., 2026). The risk of the "wow effect" lies precisely in the possibility that technological spectacle generates strong emotional recall but only superficial conceptual understanding if it is not supported by a clear instructional sequence that integrates exploration, reflection and knowledge consolidation (Hernández Guzmán et al., 2024; Torre, 2026; Yanar et al., 2026). Thus, immersion is confirmed as a powerful yet pedagogically ambivalent condition.

Third, personalisation emerges as the most innovative dimension and, at the same time, one of the least empirically consolidated. Artificial intelligence, machine learning, human–computer interaction, virtual assistants and social robotics open up the possibility of adapting content, pathways and mediation to the characteristics, emotions or trajectories of the visitor (De Carolis et al., 2023; Lin & Hu, 2025; Puspasari et al., 2023; Yang & Wang, 2023; Zhang & Gao, 2024). This development shifts the museum model from homogeneous mediation to a more sensitive and responsive approach. However, the review shows that this promise coexists with a critical issue: personalisation may lead to algorithmic opacity if the criteria for adaptation, data usage and the curatorial and pedagogical decisions underpinning it are not made explicit. Here, the discussion is no longer purely technical, but also ethical and epistemological: who determines what content the visitor receives, for what purposes, what degree of human mediation is preserved, and how can algorithmic adaptation avoid simplifying the cultural experience or reproducing bias? These concerns appear implicitly in studies on teacher training, institutional adoption and educational digitalisation (Berardinetti et al., 2025; Dumont et al., 2025) and are reinforced by recent analyses on the ethics of AI in museums (Brown, 2026; Nguyen, 2026). Personalisation therefore represents a promising horizon, but one that requires more explicit pedagogical and ethical frameworks.

Fourth, engagement emerges as the most transversal outcome of emerging technologies. Immersive, interactive, playful and co-creative experiences increase visitor motivation, enjoyment and participation (Cheng et al., 2025; Güler & Cengiz, 2025; Seale, 2023; Zhang & Hu, 2022). Similarly, social media, gamification, educational video games and co-creation expand museums' capacity to engage with younger audiences and diverse communities (Ferrer-Yulfo, 2022; Huebner, 2022, 2023; Rivero et al., 2023). In addition, multitouch interactive systems and tangible environments designed for younger

audiences demonstrate clear improvements in engagement and active learning (Wang & Xie, 2026). However, the review allows this trend to be qualified: engagement should not be equated with deep learning. A highly participatory experience may generate momentary involvement without necessarily leading to historical understanding, critical thinking or sustained cultural appropriation. This finding calls for a shift in the discussion from merely "attracting visitors" to the more complex challenge of transforming participation into conceptual development and enduring educational experience. In this sense, the challenge is not to generate more interaction, but to design interactions with pedagogical depth.

4.3. Technology or Methodological Maturity?

Another significant finding of this review is that the strength of the evidence does not depend exclusively on the type of technology, but on the methodological design through which it is studied. The integrated CASP–GRADE analysis revealed a clear pattern: studies classified as higher quality tend to concentrate in quantitative, quasi-experimental or mixed-methods approaches, with explicit empirical validation, comparison groups, structural models, instrumental measurements or robust statistical tests (Arayaphan et al., 2022; Cheng et al., 2025; Güler & Cengiz, 2025; Piatkowska & Darecka, 2026; Yang & Wang, 2023; Zhang & Gao, 2024; Zhang & Hu, 2022). By contrast, a large proportion of studies classified at medium, medium–high or medium–low levels rely on qualitative, exploratory, descriptive, theoretical or conceptual designs, as well as technological developments with limited or short-term evaluation (Carlini, 2021; García et al., 2023; Kahveci, 2025; Musicco & Berardinetti, 2025; Sun, 2024).

This pattern does not invalidate exploratory studies, but it does suggest that the field still presents an asymmetry between technological innovation and educational validation. In other words, digital museum research rapidly produces new tools, prototypes and experiences, but shows less consistency in evaluating long-term impacts on learning, conceptual understanding, transfer or effective inclusion. This gap is particularly visible in emerging technologies such as artificial intelligence, social robotics and adaptive systems, where the novelty of the device often precedes the development of robust evaluative frameworks (Lin & Hu, 2025; Musicco & Berardinetti, 2025; Yang & Wang, 2023). Likewise, this distance between technological development and pedagogical grounding has already been noted in studies on digital processes and technologies in museum contexts, as well as in research on digital art and human–computer interaction, where the risk of instrumental or superficial uses of technology is highlighted when consistent didactic frameworks are lacking (Carlini, 2021; Fang, 2021). Therefore, one of the original contributions of this review is to demonstrate that the maturity of the field should not be measured solely by the level of technological sophistication achieved, but also by the capacity to articulate pedagogical design, institutional mediation and rigorous evaluation.

Furthermore, this perspective allows for a reinterpretation of recent bibliometric growth. The sustained increase in publications, particularly since 2015 and reaching a peak in 2025, should not be read solely as quantitative consolidation, but as the entry of the field into a phase in which producing more studies is no longer sufficient; rather, there is a need to develop stronger conceptual frameworks, cross-contextual comparisons and longitudinal evaluations. At this point, the review reframes the debate: the central issue is not whether technology has educational potential—the evidence shows that it does—but under what conditions that potential can be translated into meaningful learning, inclusion and institutional sustainability.

4.4. From the Digital Museum as a Device to the Museum as an Ecosystem of Mediation

The review suggests that the field is moving beyond an understanding of the digital museum as merely a technological extension of the physical museum. Instead, a conception is emerging of the museum as an ecosystem of mediation, in which heritage objects, interfaces, mediators, algorithms, narratives, communities and institutional policies converge. This reconfiguration is consistent with transformations of the twenty-first-century museum as a space of participation, identity, wellbeing and public learning (Adams, 2007; Hooper-Greenhill, 2007; Todino & Campitiello, 2025; Wei et al., 2023). It also resonates with studies that situate museum education within broader horizons of sustainability, transculturality, care and co-creation (Galuban & Green, 2026; Hansson & Öhman, 2022; Löseke, 2022; Rivero et al., 2023).

From this perspective, the principal novelty contributed by this review is not to assert that AR, VR, AI or virtual museums are important—an idea already established in previous research—but to demonstrate that the value of these technologies depends on their integration within an ecology of mediations. This implies that digital museum education can no longer be studied through isolated compartments: neither from engineering without pedagogy, nor from pedagogy without infrastructure, nor from institutional innovation without ethical criteria. What the review shows is that the future of the field lies in the simultaneous integration of these dimensions.

In this regard, the study implicitly proposes an ecopedagogical model of digital museum education based on four propositions: first, that emerging technologies should be analysed in terms of their pedagogical function rather than solely their technical novelty; second, that accessibility, immersion, personalisation and engagement are relational dimensions rather than automatic benefits; third, that the quality of evidence depends more on methodological maturity than on technological sophistication; and fourth, that the consolidation of the field requires an explicit articulation between technology, pedagogy, ethics and institutional frameworks.

4.5. Implications for the Future Agenda

Based on these findings, the future agenda should be oriented less towards the mere expansion of devices and more towards the development of evaluable and inclusive pedagogical models. This entails, first, strengthening longitudinal studies and mixed methods designs that allow for the distinction between immediate effects and long-term educational impacts. Second, it requires the development of metrics that go beyond motivation or satisfaction, incorporating conceptual understanding, critical thinking, cultural appropriation and learning transfer. Third, specific ethical frameworks are needed for artificial intelligence, learning analytics and algorithmic personalisation in museums, addressing issues of privacy, transparency, bias and the balance between human and automated mediation (Brown, 2026; Nguyen, 2026). Finally, it requires rethinking museum innovation in terms of institutional sustainability, continuous professional development and equity of access, in order to prevent digital transformation from amplifying pre-existing inequalities (Berardinetti et al., 2025; Dumont et al., 2025; Kristinsdóttir, 2017; Tran et al., 2019).

In addition, there is a need to further develop emerging lines of research related to sustainability, transcultural education and situated learning in hybrid contexts, as well as the potential of virtual environments for education for sustainable development and intercultural mediation (Löseke, 2022; Maipas et al., 2021; Papadamou et al., 2010). Similarly, XR applications based on the 3D digitisation of scientific collections open a promising pathway for the development of configurable, transferable and pedagogically more refined experiences across different types of museums (Richter et al., 2026).

Although it is still an emerging field, the future of museum education is projected to be shaped by the convergence of AI, affective computing, educational robotics, and quantum computing as key drivers of transformation. In this context, the integration of AI into museum education is already demonstrating significant improvements in engagement, satisfaction, and the educational experience (Song & Sarmiento, 2026). Furthermore, affective computing and AI hold promise in emotion recognition, revealing the emergence of museums that "read" emotions (Affective Museology), where learning is understood as a deeply emotional experience (Fominska et al., 2024; Varutti, 2023; Rojas Vistorte et al., 2024). At the same time, social robotics expands educational mediation, while quantum computing is emerging as a nascent frontier with the potential to redefine the management and analytics of digital cultural heritage (Trček, 2025), thereby shaping a future of intelligent, affective, and quantum museum education.

5. Conclusions

This systematic review shows that museum education in the digital era should be understood as the consolidation of a hybrid ecopedagogical ecosystem in which technological, pedagogical and institutional dimensions converge. Its main theoretical contribution lies in demonstrating that the educational value of technologies resides in their capacity to reconfigure—under specific conditions—accessibility, immersion, personalisation and engagement within learning experiences. Within this framework, virtual museums and digitisation constitute the most consolidated foundation, augmented

and virtual reality represent the experiential expansion, and artificial intelligence and robotics define a frontier that is still undergoing pedagogical validation.

From an applied perspective, the findings suggest that museum policies should be oriented towards selective, pedagogically grounded and sustainable strategies. This entails prioritising digital accessibility as a structural basis, incorporating immersive technologies only when there is didactic coherence, and proceeding with caution in the use of artificial intelligence, ensuring ethical frameworks, specialised training and institutional governance. Consequently, technological innovation cannot be dissociated from pedagogical capacity: educational impact depends more on institutional articulation—mediation, curatorial design, training and evaluation—than on technological sophistication. Digital transformation therefore requires a shift from a logic of technological acquisition to one of institutional pedagogical capacity.

In terms of research, four priorities are identified: (1) advancing towards longitudinal and mixed-methods designs that assess deep learning; (2) developing metrics that distinguish between immersion and meaningful learning; (3) strengthening ethical frameworks regarding artificial intelligence, personalisation and data use; and (4) consolidating emerging lines such as sustainability, transcultural education, digital humanism, wellbeing and co-creation.

These conclusions should be interpreted considering certain limitations: the restriction to Scopus and Web of Science, the potential for language bias and the overrepresentation of technological domains. Likewise, the inclusion of diverse literature (articles, book chapters and conference proceedings) introduces heterogeneity, although this was addressed through CASP–GRADE assessment and the exclusion of studies with critical methodological weaknesses.

The field of museum education is shifting from exhibition models to complex educational mediation ecosystems. The challenge is not to incorporate more technology, but to decide which technologies to use, for what purposes, and under what pedagogical and ethical conditions. The future agenda must be oriented toward critical, inclusive, and assessable digital innovation, capable of transforming digitization into rigorous and socially sustainable educational mediation. By exploring the potential of AI, digital humanism, robotics, affective computing, and quantum computing, we are moving toward an intelligent, affective, and quantum museum education.

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