

Emerging Technologies in Digital Museums: A Literature Review of Educational Application and Evaluation Methods

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Abstract. The rapid evolution of emerging technologies is fundamentally reshaping the educational landscape, with digital museums emerging as pivotal agents of educational innovation and progressively assuming vital roles in student learning. Through a systematic literature review, this study delves into the intricate relationship between new technologies and learning within digital museum contexts, along with the consequential impact of digital museums on student learning within the educational domain—an area of significant scholarly interest. The convergence of emerging technologies and the modernization of museum learning is increasingly ubiquitous, now integral to formal education. Initially, this paper scrutinizes the nexus between emerging technologies and the modernization of museum learning. Museums, revered as custodians of tradition and culture, are embracing digital media as conduits for transmitting cultural heritage and traditional knowledge to the younger generation. The application of emerging technologies heralds transformative possibilities for museum learning; for instance, Augmented Reality (AR) and Virtual Reality (VR) technologies afford students immersive experiences within historical settings or artifact displays, while big data analytics furnish museums with deeper insights into visitor behavior and enable personalized learning experiences. Furthermore, it expounds upon the tangible impacts of integrating digital museums with student learning activities. Technological innovations in digital museums not only enrich students' learning encounters but also cultivate their autonomy and spirit of inquiry. Through digital exhibits and interactive learning engagements, students gain profound insights into subjects such as historical cultures and scientific phenomena, thereby amplifying their engagement and efficacy in learning. This paper endeavors to meticulously screen literature, unraveling the emerging technological applications in digital museums and their integration with student learning activities.

Keywords: digital museum; museum learning; learning achievement.

1. Introduction

In recent decades, the fields of education and learning have undergone significant evolution, with the increasing integration of emerging technologies in instructional practices exerting a discernible impact on the approaches to museum-based learning.

A wealth of empirical studies has investigated the application of emerging technologies in museum-based learning, spanning various disciplinary domains such as science, arts, archaeology, medicine, and military studies. Additionally, emerging technologies have been extensively employed across diverse types of museums, including art museums, historical museums, and archaeological museums, to enrich or simulate artistic and cultural artifacts. Research indicates that the utilization of emerging technologies has inspired educators in designing pedagogical activities, such as digital learning modules and gamified learning. Many scholars have highlighted the novel characteristics brought about by the adoption of emerging technologies, which not only enhance the quality of student learning but also significantly augment learning motivation, thereby elevating learning efficiency to higher levels [1].

1.1. Technological Categories Utilized in Digital Museum Pedagogy

The continuous emergence of emerging technologies provides digital museums with abundant tools and extensive developmental opportunities. Among these, technologies such as Augmented Reality



(AR), Virtual Reality (VR), Artificial Intelligence (AI), Big Data analytics, and Web 2.0 are gradually being applied in the realms of exhibition, interaction, and education within digital museums, significantly enriching the forms and experiences of museum-based learning.

Museum learning has long been a focal point for numerous scholars, who have devoted considerable attention to various facets of museum education and its organizational dynamics. In contemporary times, the capabilities of digital technologies afford museum visitors manifold learning opportunities, notably characterized by interactive engagement tailored to individual interests and knowledge acquisition. Among these, VR and AR stand out as prominently discussed technological applications, frequently employed in science, art, and historical museums to facilitate conceptual knowledge acquisition. These technologies are commonly leveraged for purposes such as the integration of supplementary materials with physical exhibits, the animation of intricate events or concepts, and the simulation of virtual exhibitions and narrative scenarios [2].

Pavlovioc (2022) [3] proposed the application of VR technology in creating virtual museum environments, enabling visitors to remotely explore exhibits and immerse themselves in historical contexts, thereby stimulating visitors' interest in learning. Moorhouse (2018) [4] emphasized the experiential nature of VR, allowing children to engage dynamically and immerse themselves in museum content. On the other hand, AR technology overlays digital content onto the physical environment, providing visitors with interactive and contextualized learning experiences, thereby enhancing learning effectiveness.

Schweibenz (2004) [5] discusses the concept of utilizing digital narrative technology to present meticulously curated collections and thematic narratives to online audiences in virtual museums. The research posits that virtual museums, by amalgamating virtual displays and digital narratives, afford viewers a richer and more interactive visiting experience. This digitized presentation format not only extends the reach of museums to broader audiences but also provides viewers with more participatory and personalized learning experiences.

Furthermore, Web 2.0 tools offer museums opportunities to foster user-generated content creation, collaboration, and community engagement. For instance, Garibaldi (2015) [6] explores how museums leverage Web 2.0 tools to facilitate interactive experiences and user-generated content creation, thereby fostering participatory learning. Through Web 2.0 tools, museums establish closer connections with their audiences, stimulating creativity and engagement, and enriching educational activities within the museum context.

1.2. Utilization of Technology in Pedagogical Strategies within Digital Museums

As pivotal constituents of informal pedagogical settings, digital museums assume crucial roles within the pedagogical framework. Still, many scholars have contended that the opening up of once-private (often aristocratic) collections to the public in Europe marks the start of the modern museum. Seen in this way, the origin of the museum is inherently linked to educational goals, to the belief that the public should have access to works of art, even if eighteenth-century concepts of access and public differ from ours today [7].

In the field of museum education, educators employ various principles and methods to design teaching activities deeply integrated with technology, such as digital narratives, digital learning modules, and gamified learning, enhancing learners' educational experiences.

For instance, Pavlovioc (2022) [3] underscores the importance of integrating these activities with pedagogical frameworks such as constructivism and inquiry-based learning. By fully utilizing digital tools and resources, educators can create dynamic and immersive learning environments, thereby fostering critical thinking and knowledge construction among museum visitors. The integration of interactive elements stimulates active exploration and discovery, further deepening engagement with museum content.

Rosaria (2021) [8] emphasizes the efficacy of digital storytelling in fostering critical thinking skills among secondary school students. By interweaving narrative, multimedia elements, and interactive features into instructional materials, educators can create immersive learning experiences. These experiences prompt learners to reflect upon, analyze, and interpret museum content, thereby deepening their understanding and appreciation of exhibits.

Research indicates that digital learning tables incorporating sensory exploration design principles are most effective in enhancing learning motivation, particularly in the four dimensions of motivation: attention, relevance, confidence, and satisfaction. Chen et al. (2022) [9] delve into the impact of digital learning table design strategies on museum exhibition visitors' learning motivation and outcomes. By integrating formative assessment techniques and feedback mechanisms, educators can gauge learners' progress and adjust teaching strategies accordingly. This iterative process allows for personalized learning experiences to meet the diverse needs and preferences of museum visitors.

1.3. Study on the Pedagogical Effects of Technological Integration in Digital Museum

The diversity of learning outcomes in museum education aided by digital technologies is evaluated primarily from various perspectives including cognitive, emotional, and social aspects. These evaluations contribute to a comprehensive understanding of the impact of digital technologies in museum education, thereby providing crucial insights for future research and practice.

For instance, Hansson's (2022) [10] study demonstrates significant positive effects of digital technology application in museum education on adolescents' socio-emotional skills. Curricula focusing on facial expressions notably enhanced students' ability to recognize emotions, while courses emphasizing self-concept enhanced their self-awareness levels. Moreover, these curricula also fostered adolescents' understanding of social interactions, facilitating the development of their interpersonal skills and emotional intelligence.

Furthermore, Frykman (2014) [11] highlights that digital technologies not only enhance learning motivation and engagement but also support personalized needs for diverse learning styles and paces, thereby promoting social inclusivity. Moreover, the application of digital technologies aids in cultivating critical skills such as knowledge acquisition, creative expression, and social interaction. These findings underscore the significance of digital technologies in museum education and provide guidance for designing and implementing more engaging and effective educational activities.

From the emotional and social perspectives, researchers utilize technologies such as Web3D virtual reality and Java/HTML to immerse students in exploring museum exhibits, offering them rich learning experiences. Through interaction with virtual environments, exploration, and solving challenges within them, students not only enhance their cognitive abilities but also foster critical thinking and practical problem-solving skills [12].

1.4. Research Questions

The literature review underscores the considerable research effort devoted to integrating emerging technologies into digital museum education. Nonetheless, several issues necessitate further investigation.

Primarily, the relentless evolution of technology spawns new applications at a brisk pace, rendering existing research somewhat deficient in timeliness and comprehensiveness. For instance, while Pavlovioc (2022) [3] conducted a thorough review spanning from 2000 to 2020, the cutoff point omitted recent advancements. Consequently, there's a pressing need for a systematic review of emerging technologies employed in digital museum education over the past decade. Such an endeavor would address research lacunae and ensure a comprehensive grasp of the latest trends and accomplishments.

Secondarily, the strategic integration of emerging technologies into digital museum education must harmonize with teaching activities. Thoughtfully crafted teaching interventions can significantly

enhance learners' cognitive, affective, and social capacities. However, the plethora of design principles and methods for teaching activities leaves the academic community without a consensus on the most efficacious approaches. Thus, there's a call for meticulous research into the practical application effects of various design principles to delineate optimal methods for crafting teaching activities. This endeavor would furnish scholarly guidance and a robust foundation for future digital museum education activity design, thereby fostering the advancement of this domain.

Finally, some researchers argue that the effects of applying emerging technologies in digital museum education demonstrate a positive influence on learners' academic achievements and learning experiences. For instance, employing technologies such as augmented reality and virtual reality in digital museum education aids in enhancing student engagement, stimulating their learning interests, and fostering a deeper understanding of museum exhibits. Some scholars point out that these technologies contribute to improving students' cognitive abilities, such as academic performance and critical thinking skills. However, other researchers suggest that the impact of technological applications on learning performance is limited, with more emphasis on social-emotional aspects or motivation to learn. Consensus on these findings has yet to be reached.

Moreover, the majority of current research focuses on visitor experiences rather than concentrating on museum learning activities. Therefore, further research is needed to explore the effectiveness of these emerging technologies in various museum environments and understand their long-term effects on student learning outcomes. Such research endeavors will help uncover the true potential of digital technology in museum education, providing deeper insights for educational practices and policy formulation.

In order to provide a comprehensive and clear understanding for researchers in the relevant field regarding the application of technology in museum education, it is necessary to systematically review the literature to form an overall awareness of the deficiencies mentioned above. Building upon the literature review, this study presents the following research questions:

1. What emerging technologies have been applied to digital museum education in the past decade?
2. What design methods have been utilized in the application of emerging technologies to digital museum educational activities in the past decade?
3. What aspects of student learning in digital museum settings have been influenced by emerging technologies in the past decade?

By delving into these inquiries, this paper endeavors to offer profound insights and implications for the advancement and pedagogical practices of digital museums. In recent years, numerous scholars have delved extensively into the intersection of digital museums and emerging technologies. Subsequent sections will review and analyze select studies in this domain.

2. Research Design

2.1. Research Objectives

The overarching objective of this research is to investigate the influence of emerging technologies on museum learning. This is achieved through a comprehensive overview and analysis of pertinent research papers, aimed at systematically summarizing the current state, developmental trends, and key challenges within the research domain.

2.2. Methodology for Literature Acquisition (Inclusion and Exclusion Criteria)

Inclusion and exclusion criteria were rigorously established to ensure the selection of relevant literature. Multiple searches across various academic databases, including Web of Science, were conducted using targeted keywords such as "digital museum," "museum learning," and "learning achievement."(Table 1)

After iterative searches and refinements, an advanced search syntax was finalized for employment in the Web of Science database. This syntax, [(TS=digital museum) AND (TS=(education OR learn* OR student)) AND (ALL=(digital technology OR museum learning OR learning achievement))], yielded a substantial corpus of 664 articles.

Recognizing the variance in the quality of retrieved literature, it became imperative to evaluate and screen the original literature objects to ensure alignment with research objectives. The literature screening procedure adopted in this study mirrors the "evaluation of literature quality" step in a systematic literature review. This critical appraisal process is integral to maintaining the integrity and validity of the research findings. The literature screening procedure followed the PRISMA flow diagram [13], as illustrated in Figure 1.

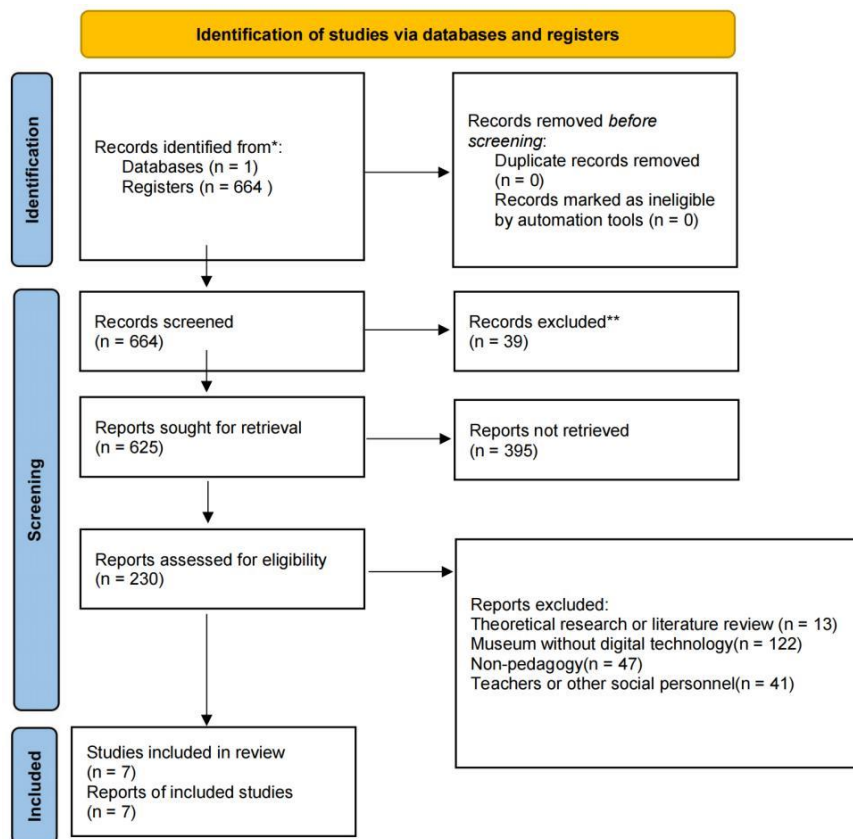


Figure 1. PRISMA Flowchart for Literature Selection

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria for Literature	Exclusion Criteria for Literature
1. The research is published in English	1. Non-English publications or duplicate publications
2. Full-text accessibility is available	2. Full-text accessibility is not available.
3. The study is empirical	3. The study is theoretical or a review study
4. The research belongs to the field of education	4. The research does not belong to the field of education
5. The research context is informal learning	5. The research context is entirely offline or entirely online teaching
6. The study participants are students from primary, secondary, and tertiary levels	6. The study participants are teachers or members of the community
7. The research environment is related to digital museums	7. The research environment is in other venues or locations
8. The research content involves specific plans for conducting teaching activities and evaluating their effectiveness	8. The research results focus on exploring scientific and technological aspects, without in-depth analysis of teaching activities

2.3. Coding Process

The design of the coding framework in this study was inspired by previous researchers [14], and the coding framework was formulated as shown in Table 2. In addition to the researchers themselves, an undergraduate student majoring in computer science and technology was invited to independently read the full text of 25% of the included literature and code the literature. The coding results of the two researchers were calculated, resulting in a consistency of 75%. The level of agreement was high.

Table 2. Coding Framework Table

Dimension	Descriptor Name	Literature Identification Code
	Publication Year	Publication Year
	Authors	First Authors
Basic Study Information	Journal	Title of the paper
	Country or Region	Country or Region of Study Implementation
	Sample Size	Sample Size of the Study
		Primary school
	Educational Level	Secondary School
Study Sample Information		University
	Application Scenario	Online/Offline
Methodology	Applied Technology	VR/AR/Mobile Devices
	Activity Design Methodology	Digital Learning Modules/Digital Narratives/Pre-visit Courses Learning
	Effectiveness Evaluation	Performance/Learning Interest/Critical Thinking

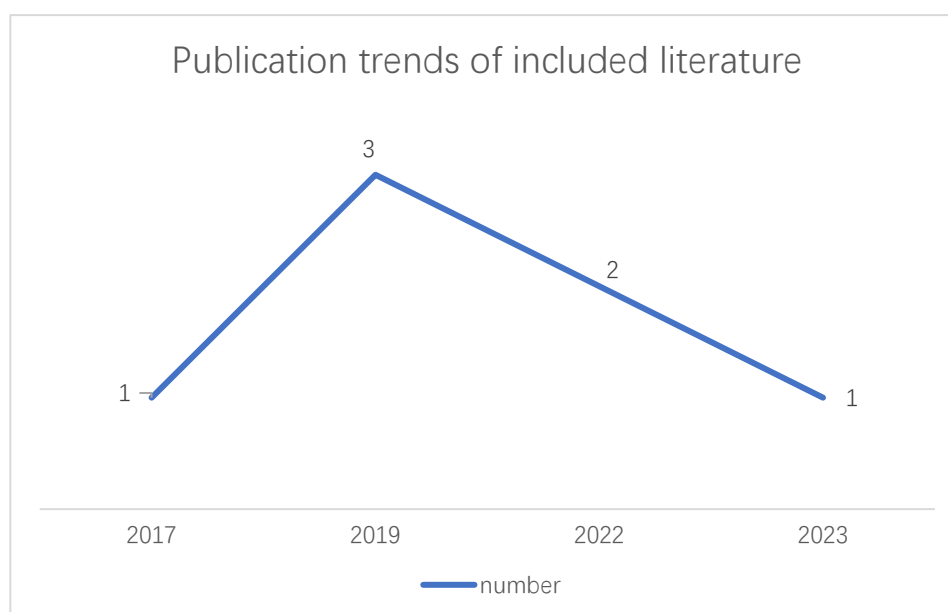
3. Result

3.1. Inclusion of Basic Information in the Study

This study incorporated a total of 7 English-language publications. The distribution of publication years was notably varied, with only 1 publication each in 2017 and 2023. In contrast, 2 publications were observed in 2022, and 3 in 2019. However, there were no publications meeting the inclusion criteria for this study in the years 2014, 2015, 2016, 2018, 2020, and 2021. This trend suggests a gradual increase in research focusing on educational design within the context of digital museums. Detailed information as shown in Figure 2. The research spanned multiple countries, including China, Thailand, the United Kingdom, Greece, Italy, and Portugal. China accounted for 2 publications, while other countries contributed 1 publication each. For detailed publication information, please refer to Supplementary Table 3.

Table 3. Including Basic Study Information and Sample Details

Literature Identification Code	Basic Information				Sample Information
	Title of the Literature	First Author	Year	Study Location	Section
Arayaphan (2022) [15]	Enhancing Intrinsic Motivation of Librarian Students using Virtual Reality for Education in the Context of Culture Heritage Museums	Watsaporn Arayaphan	2022	Thailand	University
Cesário (2022) [16]	Lessons Learned on Engaging Teenage Visitors in Museums with Story-Based and Game-Based Strategies	Vanessa Cesário	2023	Portugal	Secondary School
Chen (2023) [9]	A Study on the Effects of Digital Learning Sheet Design Strategy on the Learning Motivation and Learning Outcomes of Museum Exhibition Visitors	Tien-Li Chen	2022	China	Primary School
Poce (2022) [17]	Adopting Augmented Reality to Engage Higher Education Students in a Museum University Collection: the Experience at Roma Tre University	Antonell Poce	2019	Italy	University
Tsiviltidou (2019) [18]	Digital Storytelling as a Framework for Inquiry-Based Museum Learning	Zoi Tsiviltidou	2017	Greece	Secondary School
Zheng (2017) [12]	The Development and Performance Evaluation of Digital Museums towards Second Classroom of Primary and Secondary School - Taking Zhejiang Education Technology Digital Museum as an Example	Zheng Ying	2019	China	Primary and Secondary School
Moorhouse (2019) [4]	An experiential view to children learning in museums with Augmented Reality	Moorhouse	2019	England	Primary School

**Figure 2.** Publication trends of included literature

According to the statistical analysis, the literature included in this study consists of one study conducted in the primary school level in the United Kingdom, while two articles focus on the

university level. The remaining literature concentrates on the secondary school level. Across all studies, the sample size of the research subjects did not exceed 200 individuals. Detailed information as shown in Figure 3.

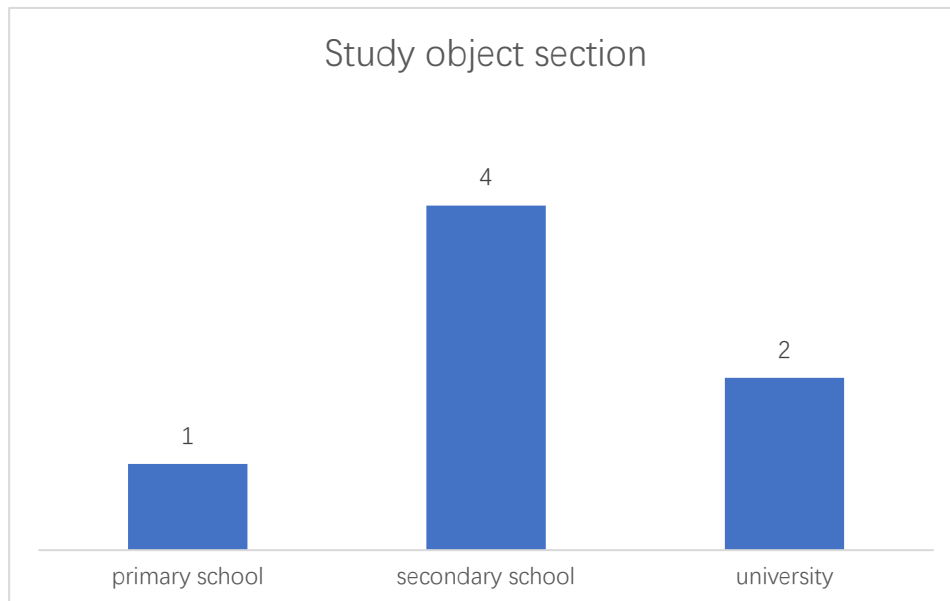


Figure 3. Educational Stages of Research Subjects

After reading the full text and conducting a statistical analysis, it was found that among the literature included in the study, one research article from the United Kingdom covers both VR and AR technologies, while another article from Portugal simultaneously addresses AR technology and mobile devices. It is worth noting that among the included literature, the number of articles involving these three emerging technologies is three each. Detailed information as shown in Figure 4.

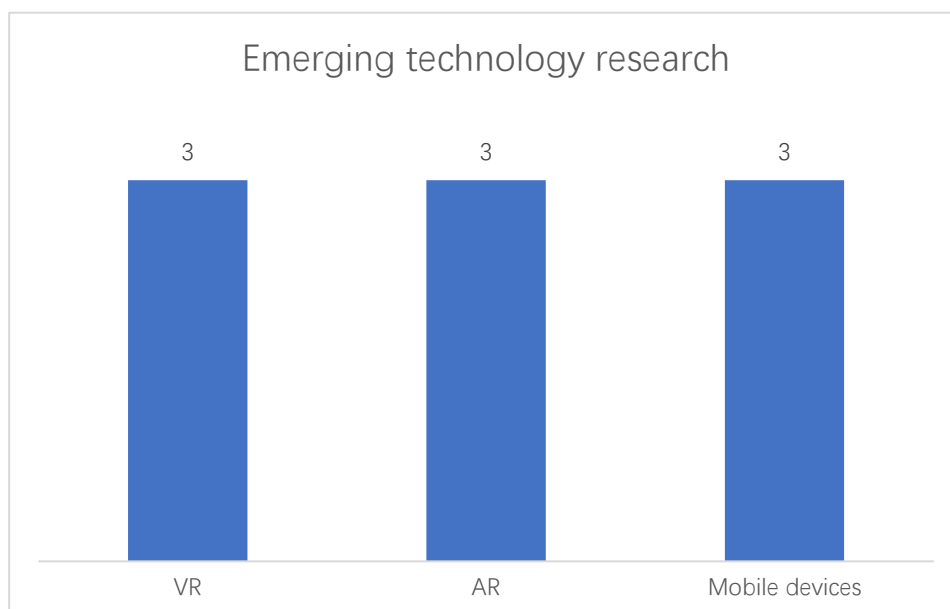


Figure 4. Emerging technology research

3.2. Types of Emerging Technologies

To address the first research question, this study systematically coded the selected literature. The findings revealed a widespread adoption of emerging technologies, including VR, AR, and mobile devices, across the 7 included articles. Specifically, three studies conducted in Thailand, China, and the United Kingdom utilized VR technology, while three studies from Portugal, Italy, and the United Kingdom utilized AR technology. Additionally, mobile device technology was adopted in three

studies from Portugal, China, and Greece. The distribution of technologies utilized is outlined as follows (refer to Table 4 for further details).

Table 4. Types of Emerging Technologies Applied

Literature Identification Code	VR	AR	Mobile Devices
Arayaphan (2022) [15]	√		
Cesário (2022) [16]		√	√
Chen (2023) [9]			√
Poce (2022) [17]		√	
Tsiviltidou (2019) [18]			√
Zheng (2017) [12]	√		
Moorhouse (2019) [4]	√	√	

3.3. Methods for Designing Instructional Activities

To address the second research question, this study systematically coded the included literature. The results revealed a variety of museum learning activity design methods across the seven covered articles. The specific distribution of methods employed is presented below (see Table 5 for details). Among the three articles discussing immersive learning teaching activity design approaches, two articles utilized AR or VR environments, with a focus on student engagement and the formation of abstract concepts in museum learning. The other article assessed students' levels of learning motivation through methods such as IMI (Intrinsic Motivation Inventory) interviews.

Table 5. Learning Activity Design Methods with Technological Applications

Literature Identification Code	Digital storytelling	Digital Learning Modules	Gamified Learning	Immersive Learning
Arayaphan (2022) [15]				√
Cesário (2022) [16]			√	
Chen (2023) [9]		√		
Poce (2022) [17]				√
Tsiviltidou (2019) [18]	√			
Zheng (2017) [12]		√		
Moorhouse (2019) [4]				√

3.4. Evaluation of Application Effectiveness

To address the third research question, this study systematically coded the covered literature and found that researchers have examined the effectiveness of emerging technologies in digital museum education (see Table 6 for details).

In terms of cognition, six articles indicated that emerging technologies play a positive role in enhancing students' abilities. On one hand, these technologies can facilitate students' academic performance and problem-solving skills (China). On the other hand, they can also foster and enhance students' critical thinking (Italy), promote the formation of abstract thinking (UK), and cultivate observational skills (Greece). However, some studies suggested that emerging technologies fail to improve learning outcomes (Thailand).

Regarding social-emotional aspects, three articles indicated that the application of technology has a positive impact on students' intrinsic motivation, learning motivation, and emotions. A study from Thailand demonstrated that technology use can enhance learning abilities. Meanwhile, research from

China indicated that technology can enhance students' cognition, emotions, and learning motivation in digital museum learning.

In academic writing, this information might be presented as a summary of findings related to the effectiveness of emerging technologies in digital museum education, highlighting both cognitive and socio-emotional impacts, as well as any discrepancies found in the literature.

Table 6. Evaluation of Technology Application Effectiveness

Literature Identification Code	Cognitive Enhancement	Socio-emotional Enhancement
Arayaphan (2022) [15]		√
Cesário (2022) [16]	√	√
Chen (2023) [9]	√	√
Poce (2022) [17]	√	
Tsiviltidou (2019) [18]	√	
Zheng (2017) [12]	√	
Moorhouse (2019) [4]	√	

4. Conclusion and Discussion

The discussion will first examine the current status and trends of the application of emerging technologies in digital museums, followed by an in-depth analysis of the effectiveness of different technologies and teaching methods. Finally, it will explore the significance and implications of these for educational practice and future research.

4.1. Emerging Technologies

The development of museum education benefits from the integration and application of various emerging technologies, particularly the widespread use of VR, AR, and mobile devices. Research indicates that these technologies play a significant role in digital museums by providing learners with opportunities for interaction with exhibits, thereby deepening their understanding and memory of exhibition content. For instance, VR technology creates a fully immersive museum experience, enabling students to remotely explore exhibits and experience historical backgrounds firsthand. AR technology cleverly blends digital information with the real environment, offering students a richer and more interactive learning experience. Additionally, as a medium for digital learning, mobile devices offer students immersive learning experiences.

Furthermore, the utilization of big data and analytics tools allows museums to gain a deeper understanding of students' behaviors and preferences, thus optimizing exhibition content and enhancing educational effectiveness. This integration of technology not only enhances the learning experience but also greatly improves educational accessibility through dynamic content presentation and personalized learning pathways. This ongoing technological innovation complements the development of museum education, opening up new perspectives and experiences for learners in the digital age.

4.2. Methods for Designing Instructional Activities

In the cited literature, researchers have utilized diverse design strategies to facilitate students' learning processes. These strategies encompass the utilization of augmented reality or virtual reality environments to achieve immersive learning, such as assessing students' levels of learning motivation through tools like the Intrinsic Motivation Inventory (IMI). The selection of these activity design methods closely correlates with the application of emerging technologies, aiming to enhance students' learning engagement and motivation, thereby further enhancing overall learning outcomes.

Of particular note, a study from Thailand proposed establishing control groups and experimental groups, focusing more on students' intrinsic motivation and experiences when exploring museums in virtual reality environments. Concurrently, literature from Italy emphasized students' active learning, with the aim of deepening their understanding of museum exhibits. Another study from the United Kingdom utilized Kolb's experiential learning cycle as a theoretical framework, emphasizing the stimulation of students' curiosity and the significance of concrete experiences and active experimentation. These three pieces of literature underscore the importance of students' experiences and engagement in the process of learning within digital museums. While the methods adopted by researchers may differ, they collectively indicate a shared focus among scholars on promoting student learning and engagement by providing rich and immersive experiences.

4.3. Evaluation of Application Effectiveness

Within the compiled literature, the widespread integration of emerging technologies within digital museums has the potential to offer students immersive learning experiences. Through simulated environments, students engage with historical scenarios or delve into abstract concepts, deepening their comprehension and proficiency while honing critical thinking skills. These immersive learning encounters not only kindle students' learning curiosity but also bolster their engagement and educational outcomes. Additionally, research suggests that emerging technologies positively impact students' engagement within digital museums and foster deeper emotional connections.

However, the influence of emerging technologies on students' learning outcomes is not consistently uniform across studies. While some research asserts that emerging technologies significantly enhance students' academic performance, problem-solving capabilities, and critical thinking skills, as well as positively influence their emotions and intrinsic motivation, others suggest that these technologies may not notably improve learning outcomes. Furthermore, the enriched learning experiences facilitated by emerging technologies do not always translate into enhanced individual abilities. Thus, further exploration of the effects of emerging technologies in educational contexts necessitates comprehensive consideration of these factors and rigorous research methodologies to yield more precise and reliable conclusions.

4.4. Limitations and Future Works

The literature review for this study was confined to the Web of Science database, potentially overlooking other high-quality English literature sources on the subject. During the literature selection process, it became apparent that certain studies exhibited non-random or non-representative sample selection, introducing the possibility of sample biases that could compromise the generalizability and applicability of research findings. Additionally, discrepancies and even contradictions were observed among certain research outcomes, likely attributable to various factors such as research methodologies and sample demographics, thus underscoring the intricate and challenging nature of the current research landscape. Furthermore, despite the literature review encompassing the application of various emerging technologies in digital museums, the assessment of their real-world effectiveness remains relatively underdeveloped, lacking comprehensive longitudinal tracking and qualitative as well as quantitative data analysis.

The rapid evolution of emerging technologies is reshaping the educational landscape, with digital museums emerging as pivotal components of educational innovation and progressively assuming significance as learning environments for students. The symbiotic relationship between new technologies and learning within digital museums, along with the tangible impact of digital museums on student learning in the educational domain, represents a critical area of scholarly inquiry garnering considerable attention.

This paper aims to thoroughly explore the application of emerging technologies in digital museums and the fusion of digital museum experiences with student learning activities through an exhaustive review and analysis of selected literature. It is hoped that this review will offer valuable insights and

avenues for the advancement of digital museums within the educational realm, fostering the convergence of technology and education to provide students with more enriching and effective learning experiences.

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