Systematic Literature Review on Interaction Design used for Museum Learning

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Museums bear the responsibility of collecting and communicating knowledge to their visitors, and in recent decades, the emergence of interaction design has proved to be a valuable means of communication. This literature review explores the current state of interaction design in relation to museum learning, focusing on its demonstrated benefits for engagement and learning outcomes. The results show that engagement is essential in elevating the quality of museum learning, as it reinforces the acquired information to the visitor. Emphasizing the influence of learning domains and contexts on design patterns, the review advocates tailoring design elements to align with specific learning domains and contexts to enhance the effectiveness of museum learning. Future research directions underscore the importance of intuitiveness and adaptability in design, which is crucial for ensuring usability across diverse museum settings. Additionally, a focus on technological aspects is recommended to foster broader applicability and reproducibility of interaction design used for museum learning.

Additional Key Words and Phrases: Interaction Design, Museum Learning, Cultural Heritage, Learner Engagement

1 INTRODUCTION

Interaction design within museum exhibitions has been increasingly prevalent over the past decades [14, 19, 20]. The incorporation of interaction design creates an engaging and enriching experience for visitors, allowing them to learn from and immerse themselves in the exhibition. Museums employ a diverse array of designs, ranging from interactive mobile applications that challenge visitors with puzzles or quizzes [36] to creating immersive 3D environments that the user can explore with virtual reality [23].

One of the fundamental goals of museums is to enhance visitors' understanding of the world through their exhibitions [20]. One effective way to achieve this goal is through museum learning, which encompasses the educational experiences and knowledge acquisition within the museum setting. The nature of knowledge acquired varies based on the museum's focus and the type of interactive application employed. Existing research underscores the positive impact of interaction designs on learning outcomes within the museum context [27]

This literature review aims to consolidate existing research, delving into various interaction designs and their unique elements to discern the factors contributing to a practical design. Given the broad spectrum of design elements in use, a comprehensive overview becomes evident, and this review attempts to fulfill that need.

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1.1 Research Questions

To comprehensively understand the impact of interaction design on museum learning, we intend to address the following research questions:

- RQ1: How can museums effectively integrate interaction design into their exhibitions to enhance their learning experience?
  - RQ1.1: What interaction design elements have been successfully employed by museums?
  - RQ1.2: How can these elements be applied effectively for different museums?
- RQ2: What are the future directions for research on using interaction design for museum learning?

2 RELATED WORKS

Several literature reviews have explored the integration of technology within museum settings using interaction design. To identify the related works, we performed searches on multiple digital libraries using search terms like 'Interaction Design', 'Museum Learning', and 'Education'. Furthermore, some of these works were recommended by my supervisor.

Zhou et al.'s literature review [41] delves into the contexts of the use of AR and VR technologies in museum learning, highlighting their impact and applications. They found a slight positive effect on knowledge and skills due to the use of AR and VR with museum learning and found that AR and VR applications are most often applied in art and history museums.

In contrast, the literature review by Marto et al. [19] focuses less on learning but more on the multi-sensory aspects of VR and AR applications. Their findings show that sight and touch are the dominant senses used within these applications. It found that most applications use sight and touch as the primary senses but identified a lack of user evaluations and a data mismatch across studies.

The paper by Zou et al. [42] is a literature review that summarizes the trends of VR, AR, and MR research from 2009 to 2020 and proposes a value-based model of user interaction design for virtual museums based on the literature. Their findings show that haptic senses are essential to the quality of visual and auditory experiences. The final suggestion in their paper is that their findings could be used for other virtual applications as well.

Pavlović [28] performed a literature review on museum learning by dividing papers into four time periods. It provides a chronological overview of digital tools used for museum learning, and it highlights how digital tools have expanded and enhanced the museum experience for visitors. Overall, the paper suggests that more research should be done on the impact of these digital technologies on changes in museum learning.

Lastly, the systematic mapping study on Serious Games in museums by Paliokas and Sylaiou [27] focuses mainly on serious games.

Still, it does examine the impact of interaction designs as a whole on museum learning. The study's results indicate that while there is a positive effect on learning, the quality of the design is crucial in motivating visitors to engage with educational games in museums.

Many of the literature reviews discussed here only encompass parts of interaction designs. Some only consider VR and AR, while others only consider games, and they all only consider studies at most until July 2021. Considering the reopening of museums after the COVID-19 pandemic, it is reasonable to assume that more studies have been conducted since then, so completing a new literature review would be sensible. This literature review will also consider more than just VR and AR interaction designs, which ensures that different papers will be found and compared.

3 METHODOLOGY

3.1 Planning

3.1.1 Study collection. The initial planning step involves formulating advanced search queries based on the research questions, specifically the PICO (Population, Intervention, Comparison, and Outcome) criteria. These criteria aid with deconstructing the research objectives into keywords and identifying synonyms [29], which will later be used to create the search strings for the digital libraries.

- Population
  - The population, in this case, will refer to the museum visitors who are interacting with the digital systems.
  - They will be the visitors who are actively trying to learn
- Intervention
  - The intervention is the use of interaction design for museum exhibitions. The design could be VR, AR, or just a kiosk which visitors can interact with.
- Comparison
  - Different types of interaction designs will be compared based on their effectiveness for museum learning. This comparison will be done based on the results of user evaluations, quantitative or qualitative.
- Outcome
  - The desired outcome of the research will be the effectiveness of types of interaction design and analyzing how tools contribute to knowledge acquisition.

The final search query based on these criteria used for Scopus [1], one of the digital libraries, is as follows:

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1 ( TITLE-ABS-KEY ( "Interacti* Design" ) OR TITLE-ABS-KEY ( "User-Centered Design" ) OR TITLE-ABS-KEY ( "Interacti* Devices" ) OR TITLE-ABS-KEY ( "Interactive Digital Storytelling" ) OR TITLE-ABS-KEY ( "Interacti* Technologies" ) OR TITLE-ABS-KEY ( "Application Design" ) ) AND
2 ( TITLE-ABS-KEY ( museum ) OR TITLE-ABS-KEY ( exhibition ) OR TITLE-ABS-KEY ( "Science center" ) ) AND
3 ( TITLE-ABS-KEY ( "Application" ) OR TITLE-ABS-KEY ( "App" ) OR TITLE-ABS-KEY ( "Program" ) OR TITLE-ABS-KEY ( "VR" ) OR TITLE-ABS-KEY ( "MR" ) OR TITLE-ABS-KEY("AR") OR TITLE-ABS-KEY("Virtual Reality") OR TITLE-ABS-KEY("Mixed Reality") OR TITLE-ABS-KEY("Augmented Reality") OR TITLE-ABS-KEY ( "Web" ) OR TITLE-ABS-KEY ( "Virtual" ) OR TITLE-ABS-KEY ( "Digital" ) ) AND
4 ( TITLE-ABS-KEY ( "Learn*" ) OR TITLE-ABS-KEY ( "Educat*" ) OR TITLE-ABS-KEY ( "Teach*" ) OR TITLE-ABS-KEY ( "Train*" ) OR TITLE-ABS-KEY ( "Instruct*" ) )
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It consists of four main sections and requires a paper to feature at least one keyword from each line in the title, abstract, or keywords. The first line focuses on interaction design keywords, which are directly related to the intervention aspect of PICO. The second line pertains to the population criteria and ensures that all papers include a museum aspect. The third line encompasses many systems to align with the comparison criteria. Lastly, the fourth line specifies keywords related to teaching and learning to ensure the papers are related to museum learning, which is vital to the population and outcome criteria.

All the search terms were derived from the keywords identified in previously discovered papers related to studies, systems, and interaction designs within the scope of museum learning. This ensured that those papers and those closely related to them would also be retrieved during the search.

This search was then performed on three digital libraries: Scopus, ACM Digital Library[2] and Web of Science[3]. These libraries were chosen because of their large databases of papers, especially those related to computer science. They also can do advanced queries, which makes it possible to perform the same query on all databases.

Appendix A shows the specific search query used in each digital library

3.2 Study selection

The search with the final search queries was conducted on December 12th 2023 and included papers up until that date. Afterward, two rounds of selecting were conducted, for which the parsif.al[4] tool was used. The first round removed duplicates and excluded papers based on the predefined criteria, and this round was only based on the title and abstract and a quick skim of the paper if necessary.

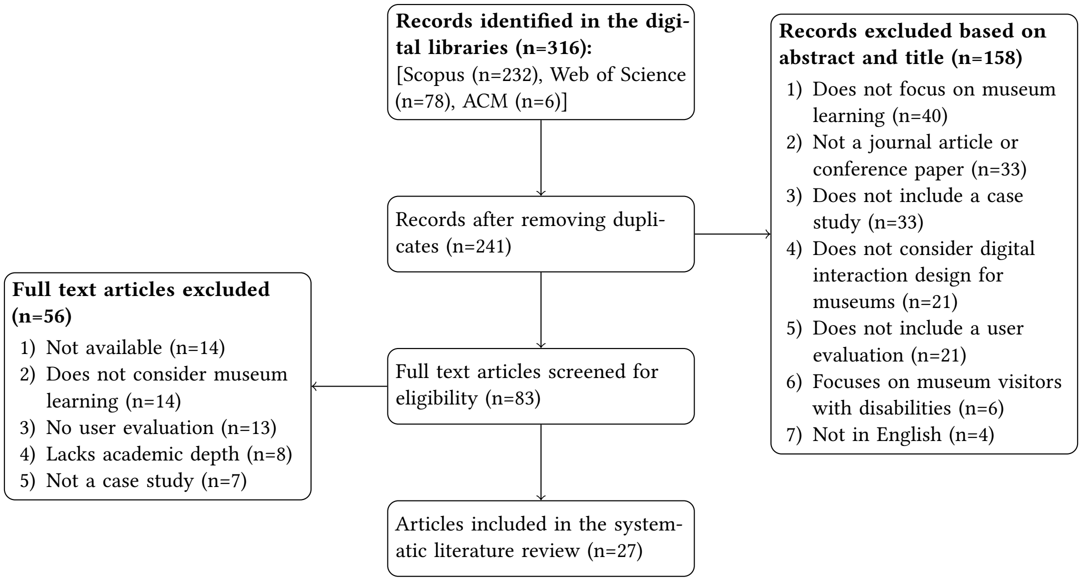
(1) The paper must be written in English
(2) The paper must be a conference paper or a journal article
(3) The paper must consider the use of interaction design for an interactive installation in a museum
(4) The paper must consider museum learning
(5) The paper must include a user evaluation of the learning
(6) The paper must not focus on museum visitors with disabilities
(7) The paper must include a case study

The first two criteria ensured that the papers met academic standards and would be written in a language we could understand. Criteria 3 and 4 ensured that the paper addresses interaction design and museum learning. Additionally, user evaluations will be used to assess the learning effectiveness and overall engagement of a

[1] https://www.scopus.com

[2] https://dl.acm.org/
[3] https://www.webofscience.com/
[4] https://parsif.al/about/

Fig. 1. Flowchart depicting study selection process



design, so all papers without a user evaluation have been excluded. Criterion 6 excluded papers that focus on visitors with disabilities, as those papers usually emphasize inclusive design, which goes beyond the scope of this study. Finally, criterion 7 ensured that only papers with an actual implementation have been included to avoid theoretical discussions on interaction design.

After this, the selected papers were thoroughly screened and excluded or included based on a quality assessment. This is also where papers for which no full text was available were excluded. As seen in figure 1, most articles were excluded because they did not focus on learning or they had no evaluation of the design by the intended users. Several articles focused primarily on engagement or the learnability of the application itself, not museum learning. The eight papers that were excluded based on a lack of academic depth were those where there was no transparent data on the user evaluation, primarily if they used a survey, or the studies were the users that did do the evaluation were not general museum visitors but only researchers or students who are not representative of the actual audience.

3.3 Data extraction

A coding framework was established and partly adapted from Zhou et al. [41] to describe and categorize the extracted studies.

3.3.1 Codes for museum types, learner types, and learning domains. This coding has been copied from Zhou et al. [41] as the museum types, learner types, and learning domains are also generally relevant to interaction design. Museum types and learning domains not found within the final papers were excluded. The museum types are divided into science, art, history, natural history, archaeological, and exhibitions that did not occur in museums. Learner types are divided into five categories: K-12 learners, who are between 5 and 18 years old, higher education learners, adults, families, and the general public. Lastly, the codes for the learning domains are mathematics, physics, botany, art, history, archaeology, and politics.

3.3.2 Codes for learning context. Table 1 shows the codes for the learning context adapted from Zhou et al. [41]. The only changes that have been made are that the explanations of the learning contexts were more general to interaction design elements rather than VR and AR, which is what is focused on in the original paper.

3.3.3 Codes for design elements and devices. Table 2 describes the coding framework for the design elements and affordances for museum learning, for which the technologies section has been adapted to include technologies outside of VR and AR. Similarly, table 3 categorizes possible devices and has adapted the explanations and technologies to be more general to interaction design.

3.3.4 Additional Characteristics. In addition to the established coding framework, additional characteristics were extracted from the studies. First of all, each museum's exact museum and country of origin were collected for more contextualization. Secondly, the number of participants and whether the study showed a significant increase in learning outcomes were also extracted to judge the validity of the results. Lastly, notes were made for each paper with a general description of the design and the suggestions the authors made for future research.

4 RESULTS

4.1 General characteristics of the selected articles

A total of 27 papers were collected, with 26 unique interaction designs. The studies and their extracted data from the codings defined in section 3.3 can be found in appendix B. All papers were published between 2010 and 2023, as is shown in figure 2. It also shows that

Table 1. Coding framework for the learning context

Category	Explanation
Declarative knowledge	The use of interaction design intend to help learners remember factual knowledge and develop conceptual understanding (e.g., theoretical concepts and physical principles).
Analytical and problem-solving skills	The use of interaction design intend to improve learners' analytical skills (e.g., analyze the factors affecting weather changes).
Emotional experience	The use of interaction design can provide learners with empathic experience (e.g., experiencing reconstructed historical battles of ancient Egypt).
Behavioral impacts	The use of interaction design aims to change the behavior of visitors (e.g., presenting harmful impacts of smoking).
Procedural-practical knowledge	The use of interaction design provides learners with interactions or animations to acquire procedural or practical knowledge (e.g., sculpturing).
Others	Articles that could not be classified into the alternative concepts above
Not specified	There is no statement or implicit information about the learning content of interaction design

Table 2. Coding framework for the design elements and affordances of interaction design for museum learning.

Categories	Explanation	Examples	Technologies
Object Manipulation	Users interact with digital objects to change their position or state.	Rearranging items in a digital environment.	VR, AR, Interactive Websites/Apps
User-Generated Content	Users create and share new content within digital applications or platforms.	Creating digital artworks or interactive stories.	Social Media, Creative Apps/Platforms
Interactive Learning Tasks	Users engage in interactive tasks or quizzes related to educational content.	Completing digital quizzes or puzzles.	Educational Apps, Gamified Learning Platforms
Simulated Environments	Creating digital replicas or simulations of real or imaginary environments.	Simulating historical places or creating virtual landscapes.	Simulation Software, VR, AR
Visualization of Abstract Concepts	Presenting visual representations to explain complex or abstract ideas.	Displaying simulations of scientific concepts or data.	Data Visualization Tools, AR
Narrative Reconstruction	Recreating historical or fictional scenarios in a digital format.	Creating digital reconstructions of past events or stories.	Storytelling Apps, Virtual Tours
Augmented Information Overlay	Providing additional information or context through digital augmentation.	Overlaying information on real-world objects through an app.	AR, Informational Apps

Table 3. Devices for interaction design elements

Categories	Explanation	Technologies
Mobile Devices	Portable, handheld computing devices enabling digital interactions.	Smartphones, Tablets, Wearable Tech
Head-Mounted Displays	Devices worn on the head enabling immersive digital experiences.	VR Headsets, AR Glasses
Desktop Devices	Stationary computers facilitating digital interactions and experiences.	Computers, Laptops
Projectors	Devices projecting digital content onto screens or surfaces.	Projectors, Interactive Displays
Not Specified	No specific device is mentioned or required for the interaction.	N/A (Depends on the digital platform/application)

two-thirds of the documents were published after 2016, which suggests a growing interest in utilizing interaction design for museum learning.

Fig. 2. Year distribution

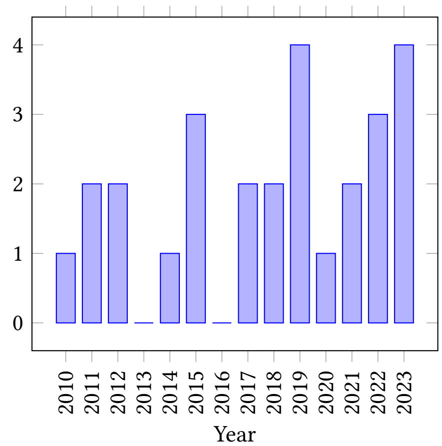


Fig. 3. Distribution by Country

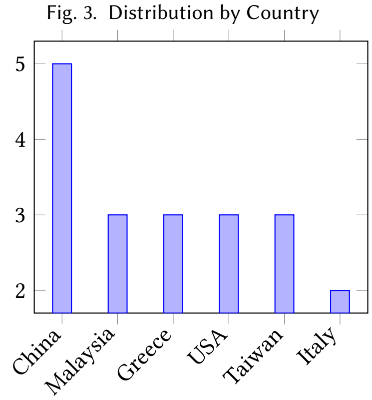
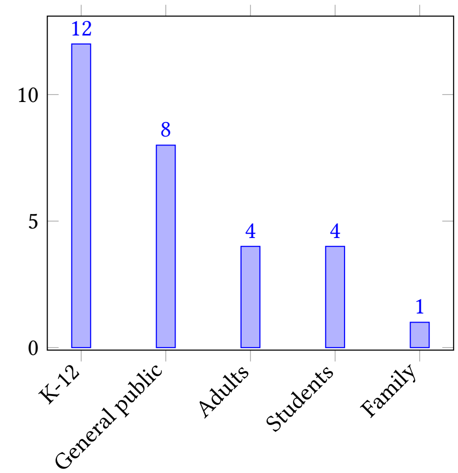


Figure 3 depicts the geographical distribution of the studies, excluding the countries in which only one study was performed. This shows that five of the six most common countries are in Europe and Asia, with China being the predominant country. This prevalence aligns with expectations, as many focus on history and cultural heritage, which is emphasized in China [32].

4.2 Learner types and learning domains in museum contexts

The distribution of learner types across the selected literature reveals a focus on K-12 learners followed closely by the general public, as illustrated in figure 4. The prominence of K-12 learners aligns with the importance of cognitive development in children. Amran and Admodisastro [1] suggest that children's engagement with museum exhibitions is hindered by a lack of active participation, which is helped by good interaction design. Additionally, the focus on the general public reflects the museum's aim to communicate and interpret knowledge to society as a whole [3]. For example, Kuching Orchid Garden had visitors use their smartphones to avoid the added barrier of learning a new device. Furthermore, the app avoided features only on more expensive smartphones to cater to as many visitors as possible [25]. This emphasis on K-12 and general public learners in the literature indicates a commitment to children's education and ensuring widespread access when implementing interaction designs within museum contexts.

Fig. 4. Learner types



An evident overlap emerges in the distributions of museum types in figure 5 and learning domains in figure 6, with most studies taking place in a history museum, focusing on history as the primary learning domain. Notably, a discernible pattern within these studies emerges, wherein the objective is to facilitate direct interaction between the user and the past. Some instances involve the simulation of historical environments, exemplified by the China Agricultural Digital Museum, where visitors engaged in virtual agricultural tasks from the past in VR [38]. Similarly, the Ancient House of Thetford reconstructs and shows historical sites that no longer exist at the actual location on their phone [15]. The predominant approach to teaching history through interaction design involves the utilization of applications to either function as immersive tour guides [18, 24] or providing the user the option to digitally interact with the artifacts [10, 12, 26].

Fig. 5. Museum types

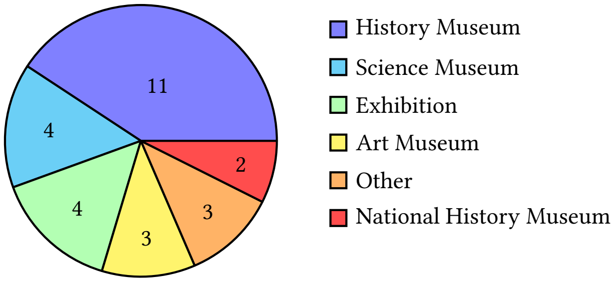
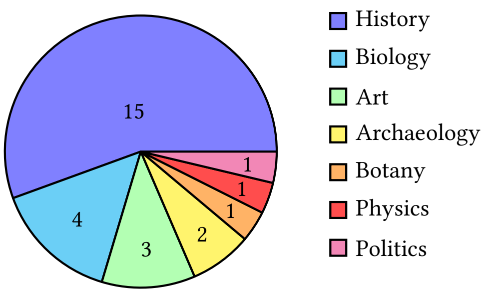


Fig. 6. Learning domains



Another pattern surfaces within art as a learning domain, where an effort is made to actively involve visitors in engaging with the art in a freeform way. For instance, Vayanou et al. facilitated visitor interaction by designing a game that has the visitor create a story for artwork and have other visitors connect the story with the artwork [35]. Likewise, at the National Palace Museum, users experienced a tale associated with artwork through that artwork. They could also engage and manipulate artworks using various interactive devices directly [11]. Moreover, the Liaoning Provincial Museum extends this trend by creating an interactive exhibition where users can manipulate the artworks through gestures [17].

This pattern is distinct from the pattern emerging in history, emphasizing a more personal interaction with the artworks. Rather than only presenting declarative knowledge, the visitors can explore the artistic concepts and create, fostering a more immersive connection to the content. Despite these differing patterns, there does not seem to be a significant difference between domains on how it affects museum learning, with the papers within both domains either not concluding anything on the learning quality or concluding that it improves museum learning.

4.3 Designs of applications in a museum context

Figure 7 and 8 show the data collected on the devices and design elements used for all the unique implementations of interaction design. Notable is that almost half of the designs have an augmented information overlay. For example, in the paper by [6], they created an app where users walk around a historical area and find points to trigger an information overlay. Similarly, in the Museum of Solomos and Eminent Zakynthians, children went around with handheld devices and scanned exhibits to get more information on the exhibition and to play a game [33]. The augmented information overlay is likely so standard because it can function as a replacement for traditional signs.

One of the more innovative applications of interaction design is the visualization of abstract concepts. Three papers exploring this approach employ projects to convey these concepts and focus specifically on science education. For example, the CosmoCaixa Science Museum utilized projectors to provide children with a tangible understanding of the nanoscale [21], while Baranauskas et al. [2] engaged children with a project table and tangible objects to immerse them in the main eras of world history, to give them an understanding of deep time. Remarkably, all papers assert that their applications impacted learning. Tokuno et al. [34] attributes their success to the engaging and user-friendly nature of their installation, while Yoon et al. [39] conducted a comparative analysis with a control group and revealed that participants spent more time interacting with the interactive design and enhanced their conceptual gains.

Fig. 7. Devices for interaction designs

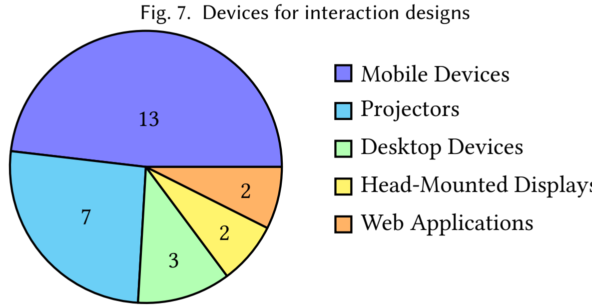
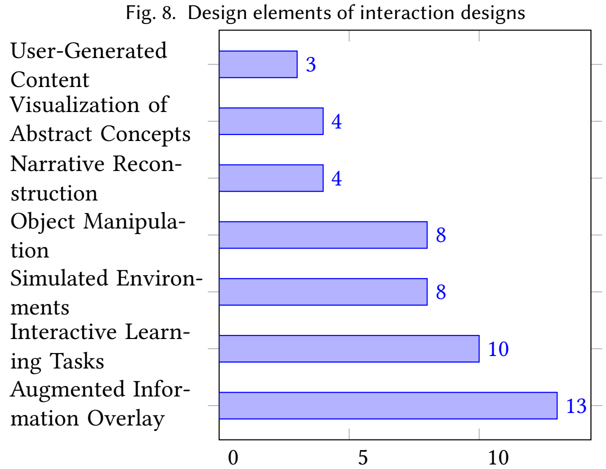


Fig. 8. Design elements of interaction designs



In the examined papers, mobile devices emerged as the most common tool. As mentioned in section 4.2, they are frequently employed as tour guides, guiding users through museum exhibits while offering additional information at some parts of exhibitions. The appeal of mobile devices lies in their versatility; unlike desktop devices or projectors, which are often limited in number and fixed in place, mobile devices are more plentiful and cost-effective. Visitors can still communicate with other visitors and show others what they are looking at, ensuring the possibility of social interaction. For instance, Cordova-Rangel and Caro [9] developed *Aventura Marina*, a serious game in the form of a mobile app that guided the visitors through an exhibition, immersing them in a storyline where puzzles had to be solved for progression. They had a point system and a shared leaderboard, and this social interaction motivated the players to continue playing.

On the other hand, the head-mounted display (HDM) is a less commonly employed device. Despite the significant growth of VR and AR in recent years [28], challenges persist with HDMs. In a study detailed by Karnchanapayap [13], users experienced a 5-minute story using an HDM at an exposition, and they encountered issues such as waiting times due to only having one headset and instances of virtual reality sickness among participants. Museum professionals echo concerns about these issues and the lack of social interaction with HDMs, the associated costs, and the need for training and staffing to manage VR exhibits [31]. Given the expense and resource-intensive nature of HDMs, their infrequent usage in these studies is to be expected.

Similarly, another uncommon device is the web application, categorized separately from the desktop device, as these were not interaction designs inside a museum but for the user to experience at home. The two studies are the digitization of The Museum of Ancient High-Imitative Calligraphy and Painting [37] and The Sarajevo Survival Tools project [30], which are both virtual museums. Although these studies were done in 2011 and 2012, respectively, the increased relevance of virtual museums during the COVID-19 pandemic has brought attention to their potential [40]. However, the broader adoption of these web applications was likely hindered due to funding losses during the pandemic.

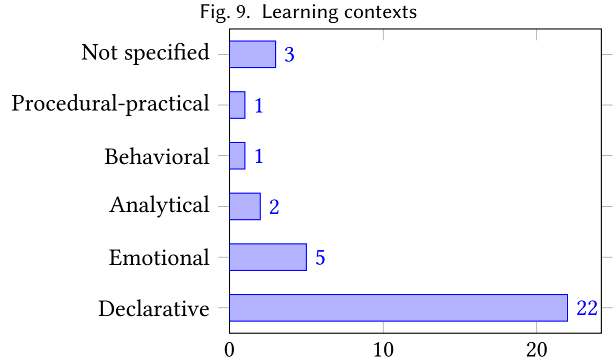
4.4 Learning contexts

Figure 9 illustrates that interaction design often imparts declarative knowledge. Museums often seek to convey essential facts about their exhibitions to their visitors, to give them a sound basis of knowledge on a topic. This means that acquiring factual information is emphasized and a goal for museum interactive installations. Currently, museums often use textual displays to communicate these facts and interactive installations with declarative knowledge to make this information more engaging.

An example of an engaging interaction design like this is the design created by Condado et al. [8], where visitors' experiences were enriched through audio clips and augmented reality renderings of significant landmarks. Participants noted that this approach gave them access to new information and engaged them. However, the most common method of delivering declarative knowledge we identified in these papers is the creation of mobile application feature quizzes or treasure hunts, allowing users to immediately apply and reinforce their acquired knowledge playfully.

For instance, Cesário et al. [5] created three different tours where the visitors would get hints on their next point of interest, and once there, they would get some info on that point and be directed to the next point. Similarly, at The Muzium Haiwan dan Mamalia, children engaged in an animal treasure hunt on mobile devices, answering questions to enhance their understanding [1]. In the Sarawak Cultural Village, visitors embarked on a tablet-guided tour featuring educational games, combining entertainment with learning experiences [24]. This trend shows an approach to interactive designs that are both engaging and cost-effective, especially when compared to resource-intensive setups like virtual reality or large-scale projector installations.

Fig. 9. Learning contexts



There is also a noticeable pattern within the emotional experience learning context. Most interaction designs attempt to convey an emotional experience by creating an immersive storyline in which the user partakes. They either affect the storyline and directly change outcomes or are more passive observers.

For example, in the Robert C. Williams Museum of Papermaking, visitors were given the chance to use a storytelling device, the Lukasa, used in pre-colonial Central Africa, to create stories and tell them to each other in a similar manner to how they were used in history [7]. They are not told a story from the past, but they gain a personal and emotional understanding of the Lukasa by making up their own. This is contrasted by the Sarajevo Survival Tools exhibit, which leads the user through an immersive digital exhibit and tells the stories of Sarajevo citizens who lived through the siege the exhibit is about [30].

Neither of these approaches seems superior to the other; their effectiveness depends on the specific circumstances and topics discussed within the exhibition. The Sarajevo Survival Tools exhibition narrates an intense story of a siege. It might be perceived as insensitive if transformed into a more interactive experience, as it tells the story of real people. On the other hand, the storytelling device has no pre-set stories. It allows the creators to allow the user to create their narrative as a vital component entirely. Both approaches have unique qualities and should be chosen based on the particular context of the museums.

4.5 Gaps in Museum Interaction Design Research

As mentioned in section 3.3.4, notes were made on suggestions made for future research. The suggestions depend on the design elements used within the study, but there are also some more general notes to be made. For example, in the study performed by Nikolakopoulou et al. [22], the discussion brings up the point of identifying an intuitive interface for all users. The innate diversity in the group of museum visitors makes this problematic, but they recommend extensive evaluations to determine where the interface issues lie. Othman et al. [25] state that their concept of users bringing their devices should also be implemented in future works, as they found that it eliminated issues with the learnability of the designs.

The study performed on the Museum of Ancient High-Imitative Calligraphy and Paintings replicated the museum, emphasizing aesthetics and realistic replications [16]. The paper underlines the significance of developing new technologies and techniques to meet the requirements, as the project necessitated innovation in techniques to be feasible. Similarly, Jiang et al. [12] faced the challenges of advanced scanning and image tracking algorithms to realize their interaction design. Only a few papers delve into the technical aspects of creating such applications despite the pivotal role these aspects play in creating an innovative and engaging design.

The application developed for the Caracol Museum was intentionally designed to be modifiable, enabling museum staff to adapt it for potential new exhibits. However, Cordova-Rangel and Caro [9] observed that the tools used for modifying the application posed usability challenges for users without technological backgrounds, leading them to recommend creating intuitive tools for content modification. Similarly, the game MuseumScrabble prioritized modifiability by incorporating game scenarios that could be adjusted to cater to different age groups for enhanced engagement [33]. Still, many papers overlook modifiability in their design processes, emphasizing the potential for future research to include adaptability within their designs.

5 CONCLUSION

This systematic literature review addressed the overarching research question of how museums can effectively integrate interaction design into their exhibitions to enhance the museum learning experience. The study delved into specific aspects by exploring the successful applications of interaction design elements in museums and recognizing patterns in how these elements are deployed.

The study found a wide array of design elements used for museum learning, as described in section 4. The most common elements were mobile applications the visitor could use as tour guides, providing extra knowledge, with education games following closely behind. Notable about these design elements is that one of the most critical factors, especially when communicating factual knowledge, is ensuring that it is engaging. That way, the user will reinforce their learned knowledge and remember it better than simply reading it on a textual display.

One of the most influential factors influencing the application of design elements is the learning domain and context. Distinct design patterns emerge when considering history compared to art, yet their effectiveness is comparable when applied correctly. Moreover, the nature of the knowledge sought to be imparted greatly affects the specific design elements employed. Emotional experiences, for instance, are often experienced through stories told in various ways, whereas declarative knowledge is best conveyed with quizzes or serious games. The design elements should be tailored to consider the learning domain and context carefully, as it is integral to their overall effectiveness.

Finally, the future directions for research on the use of interaction design for museum learning were explored. An essential factor of effective interaction design lies in its intuitiveness, which is a challenging feat considering the diversity of museum audiences. Future research should examine what intuitiveness entails for individual museums and their visitors. Furthermore, a shift towards prioritizing the technological aspects of the designs, rather than merely focusing on the application contents or the study outcome, could result in broader applicability. Focusing on technological aspects makes it possible to replicate and adapt the designs for other museums. Lastly, it is also essential to consider the adaptability of the created designs to ensure their relevance and utility across different museum settings while being cost-effective.

6 DISCUSSION

A defined limitation in this research paper was the exclusion of papers focusing on museum visitors with disabilities. While this limitation was necessary to contain the scope of this research, it should be acknowledged that inclusive design should be addressed in future research. Museums have the responsibility of communicating knowledge to society at large and should thus ensure accessibility to all groups. Future research should delve into how interaction design can be tailored to accommodate diverse disabilities.

Furthermore, the broader concept of accessibility did not receive a lot of attention within the reviewed literature. Interaction design often incorporates new or uncommon technologies, such as Virtual Reality headsets and gesture-based controls. However, these technologies have drawbacks for many users, such as VR-induced discomfort and nausea or unintuitiveness of gesture-based controls, and were not thoroughly considered in the literature. A future literature review should look critically at the use of cutting-edge technology if it neglects to take accessibility into account as well.

Lastly, a recurring observation in the literature is the absence of critical testing in assessing learning outcomes. Nearly half of the examined papers relied on self-assessments obtained through questionnaires to gauge visitors' learning rather than employing more rigorous measures like comparisons to control groups or pre- and post-tests. Future research should emphasize determining what the most effective means of knowledge testing could be and exploring alternatives beyond the traditional tests. For example, while biometric data can be used to provide insights into visitor engagement [4], its impact on education outcomes remains unexplored in the existing literature.

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A SEARCH QUERIES

A.1 Scopus

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( TITLE-ABS-KEY ( "Interacti* Design" ) OR TITLE-ABS-KEY ( "User-Centered Design" ) OR TITLE-ABS-KEY ( "Interacti* Devices" ) OR TITLE-ABS-KEY ( "Interactive Digital Storytelling" ) OR TITLE-ABS-KEY ( "Interacti* Technologies" ) OR TITLE-ABS-KEY ( "Application Design" ) ) AND
( TITLE-ABS-KEY ( museum ) OR TITLE-ABS-KEY ( exhibition ) OR TITLE-ABS-KEY ( "Science center" ) ) AND
( TITLE-ABS-KEY ( "Application" ) OR TITLE-ABS-KEY ( "App" ) OR TITLE-ABS-KEY ( "Program" ) OR TITLE-ABS-KEY ( "VR" ) OR TITLE-ABS-KEY ( "MR" ) OR TITLE-ABS-KEY("AR") OR TITLE-ABS-KEY("Virtual Reality") OR TITLE-ABS-KEY("Mixed Reality") OR TITLE-ABS-KEY("Augmented Reality") OR TITLE-ABS-KEY ( "Web" ) OR TITLE-ABS-KEY ( "Virtual" ) OR TITLE-ABS-KEY ( "Digital" ) ) AND
( TITLE-ABS-KEY ( "Learn*" ) OR TITLE-ABS-KEY ( "Educat*" ) OR TITLE-ABS-KEY ( "Teach*" ) OR TITLE-ABS-KEY ( "Train*" ) OR TITLE-ABS-KEY ( "Instruct*" ) )
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A.2 ACM Digital Library

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(Title:("Application" OR "App" OR "Program" OR "VR" OR "MR" OR "Web" OR "Virtual" OR "Digital") OR Keyword:("Application" OR "App" OR "Program" OR "VR" OR "MR" OR "Virtual Reality" OR "Mixed Reality" OR "AR" OR "Augmented Reality" OR"Web" OR "Virtual" OR "Digital") OR Abstract:("Application" OR "App" OR "Program" OR "VR" OR "MR" OR "Web" OR "Virtual" OR "Digital")) AND
(Title:("Learn*" OR "Educat*" OR "Teach*" OR "Train*" OR "Instruct") OR Keyword:("Learn*" OR "Educat*" OR "Teach*" OR "Train*" OR "Instruct") OR Abstract:("Learn*" OR "Educat*" OR "Teach*" OR "Train*" OR "Instruct")) AND
(Title:("Interacti* design" OR "User-Centered Design" OR "Interacti* Devices" OR "Interactive Digital Storytelling" OR "Interacti* Technologies" OR "Application Design") OR Keyword:("Interacti* design" OR "User-Centered Design" OR "Interacti* Devices" OR "Interactive Digital Storytelling" OR "Interacti* Technologies" OR "Application Design") OR Abstract:("Interacti* design" OR "User-Centered Design" OR "Interacti* Devices" OR "Interactive Digital Storytelling" OR "Interacti* Technologies" OR "Application Design")) AND
(Title:("Museum" OR exhibition OR "Science Center") OR Abstract:("Museum" OR exhibition OR "Science Center") OR Keyword:("Museum" OR exhibition OR "Science Center"))
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A.3 Web of Science

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(TI=("Application" OR "App" OR "Program" OR "VR" OR "MR" OR "AR" OR "Virtual Reality" OR "Mixed Reality" OR "Augmented Reality" OR "Web" OR "Virtual" OR "Digital") OR AK=("Application" OR "App" OR "Program" OR "VR" OR "MR" OR "AR" OR "Virtual Reality" OR "Mixed Reality" OR "Augmented Reality" OR "Web" OR "Virtual" OR "Digital") OR AB=("Application" OR "App" OR "Program" OR "VR" OR "MR" OR "AR" OR "Virtual Reality" OR "Mixed Reality" OR "Augmented Reality" OR "Web" OR "Virtual" OR "Digital")) AND
(TI=("Learn*" OR "Educat*" OR "Teach*" OR "Train*" OR "Instruct") OR AK=("Learn*" OR "Educat*" OR "Teach*" OR "Train*" OR "Instruct") OR AB=("Learn*" OR "Educat*" OR "Teach*" OR "Train*" OR "Instruct")) AND
(TI=("Interacti* design" OR "User-Centered Design" OR "Interacti* Devices" OR "Interactive Digital Storytelling" OR "Interacti* Technologies" OR "Application Design") OR AK=("Interacti* design" OR "User-Centered Design" OR "Interacti* Devices" OR "Interactive Digital Storytelling" OR "Interacti* Technologies" OR "Application Design") OR AB=("Interacti* design" OR "User-Centered Design" OR "Interacti* Devices" OR "Interactive Digital Storytelling" OR "Interacti* Technologies" OR "Application Design")) AND
(TI=("Museum" OR exhibition OR "Science Center") OR AB=("Museum" OR exhibition OR "Science Center") OR AK=("Museum" OR exhibition OR "Science Center"))
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B PAPER DETAILS

Ref	Title	Learning domain	Learning context	Devices	Affordances	Country
[22]	Design and User Experience of a Hybrid Mixed Reality Installation that Promotes Tinian Marble Crafts Heritage	Archaeology	Declarative knowledge	Desktop devices	Interactive Learning Tasks, Narrative Reconstruction, Simulated Environments	Greece
[37]	O3D-based personal museum designing system in virtual learning environment	Archaeology	Declarative knowledge, Procedural-practical knowledge	Web application	Object Manipulation, Simulated Environments, User-Generated Content	China
[35]	How to play storytelling games with masterpieces: from art galleries to hybrid board games	Art	Others	Mobile devices	Augmented Information Overlay, User-Generated Content	Greece
[17]	The role of digital interactive technology in cultural heritage learning: Evaluating a mid-air gesture-based interactive media of Ruihetu	Art	Declarative knowledge	Projectors	Interactive Learning Tasks, Object Manipulation	China
[11]	Way to inspire the museum audiences to learn: Development of the interpretative interactive installations for Chinese cultural heritage	Art	Behavioral impacts, Emotional experience	Desktop devices, Projectors	Augmented Information Overlay, Object Manipulation	Taiwan
[21]	"Child as the measure of all things": The body as a referent in designing a museum exhibit to understand the nanoscale	Biology	Declarative knowledge	Desktop devices, Projectors	Object Manipulation, Visualization of Abstract Concepts	Spain
[5]	"This Is Nice but That Is Childish": Teenagers Evaluate Museum-Based Digital Experiences Developed by Cultural Heritage Professionals	Biology	Declarative knowledge	Mobile devices	Interactive Learning Tasks	Portugal
[1]	Designing an interactive learning to enrich children's experience in museum visit	Biology	Not specified	Mobile devices	Augmented Information Overlay, Interactive Learning Tasks	Malaysia
[9]	Designing and Evaluating Aventura Marina: A Serious Game to Promote Visitors' Engagement in a Science Museum Exhibition	Biology	Not specified	Mobile devices	Augmented Information Overlay, Interactive Learning Tasks	Mexico
[25]	An Empirical Study of Visitors' Experience at Kuching Orchid Garden with Mobile Guide Application	Botany	Declarative knowledge	Mobile devices	Augmented Information Overlay	Malaysia
[34]	Explore Through the Past: Gesture-Based Mobile Game for Children Observing Geological Layer Exhibit at History Museum	Archaeology	Not specified	Mobile devices	Visualization of Abstract Concepts	Japan
[12]	3D models to educated museum interactive exhibition with computing techniques	History	Declarative knowledge	Mobile devices	Object Manipulation, Simulated Environments	China
[38]	A Human-Computer Interaction System for Agricultural Tools Museum Based on Virtual Reality Technology	History	Declarative knowledge, Emotional experience, Not specified	Head-mounted displays	Narrative Reconstruction, Simulated Environments	China
[15]	Augmenting the Experience of a Museum Visit with a Geo-Located AR App for an Associated Archaeological Site	History	Declarative knowledge, Emotional experience	Mobile devices	Augmented Information Overlay, Narrative Reconstruction, Object Manipulation, Simulated Environments	United Kingdom

Ref	Title	Learning domain	Learning context	Devices	Affordances	Country
[2]	Designing for a socioenactive experience: A case study in an educational workshop on deep time	History	Declarative knowledge	Desktop devices, Projectors	Visualization of Abstract Concepts	Brazil
[10]	Engaging and Shared Gesture-based Interaction for Museums The case study of K2R international Expo in Rome	History	Declarative knowledge	Projectors	Augmented Information Overlay, Interactive Learning Tasks	Italy
[26]	Evaluation of the Educational Potentials - Interactive Technologies Applied to Cultural Heritage	History	Declarative knowledge	Projectors	Augmented Information Overlay, Interactive Learning Tasks	Italy
[24]	Improving Children's Cultural Heritage Experience Using Game-based Learning at a Living Museum	History	Declarative knowledge	Mobile devices	Augmented Information Overlay, Interactive Learning Tasks	Malaysia
[8]	Integrating Historical Content with Augmented Reality in an Open Environment	History	Declarative knowledge	Mobile devices	Augmented Information Overlay, Simulated Environments	United States of America
[30]	Interactive Digital Storytelling in the Sarajevo Survival Tools Virtual Environment	History	Emotional experience	Web application	Narrative Reconstruction	Bosnia and Herzegovina
[16]	Key Technology of Virtual Roaming System in the Museum of Ancient High-Imitative Calligraphy and Paintings	History	Declarative knowledge	Desktop devices	Simulated Environments	China
[7]	Mapping place: Supporting cultural learning through a Lukasa-inspired tangible tabletop museum exhibit	History	Declarative knowledge, Emotional experience	Desktop devices	Object Manipulation, User-Generated Content	United States of America
[33]	MuseumScrabble: Design of a mobile game for Children's interaction with a digitally augmented cultural space	History	Analytical and problem-solving skills, Declarative knowledge	Mobile devices	Augmented Information Overlay, Interactive Learning Tasks	Greece
[6]	Prototype Development of an Interpretative Game with Location-Based AR for Ecomuseum	History	Declarative knowledge	Mobile devices	Augmented Information Overlay, Interactive Learning Tasks	Taiwan
[18]	Religious diversity education: raising children's awareness of religious diversity through augmented reality	History	Declarative knowledge	Mobile devices	Augmented Information Overlay	Taiwan
[39]	Learning impacts of a digital augmentation in a science museum	Physics	Analytical and problem-solving skills, Declarative knowledge	Projectors	Object Manipulation, Visualization of Abstract Concepts	United States of America
[13]	Activities-based virtual reality experience for better audience engagement	Politics	Declarative knowledge	Head-mounted displays	Simulated Environments	Thailand