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Interactive Museum Innovation with Digital Technology to Enhance Education and Preserve Cultural Heritage in Indonesia

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Abstract

Museums play an important role in preserving cultural heritage and educating the public. However, the changing behavior of the younger generation, who are more interested in digital media, has led to a further decline in visits to traditional museums. This research aims to design a digital technology-based interactive museum prototype as an effort to enhance education and cultural preservation in Indonesia. This research method uses a Research and Development (R&D) approach, which includes the stages of needs analysis, system design, prototype development, and user testing. The research instruments include the System Usability Scale (SUS) and semi-structured interviews with 30 respondents. The research findings indicate that the interactive museum prototype achieved an average SUS score of 75.6, placing it in the excellent category, and received positive feedback regarding increased visitor engagement in understanding cultural collections. This research contributes to the development of a digital museum model that meets the needs of Indonesian society.

Keywords—Interactive Museum; Digital Prototype; Cultural Education; HCI; User Experience.

I. INTRODUCTION

Museums play an important role as institutions for preserving cultural heritage, centers for public education, and means of forming a nation's collective identity. However, in today's digital age, museums face challenges in attracting the interest of younger generations who are more accustomed to interactive media and technology-based experiences. The shift in visitor expectations from passive observation to active engagement demands a paradigm transformation of traditional museums into Museum 4.0—museums that utilize Human–Computer Interaction (HCI) principles, user experience (UX), and immersive technologies such as augmented reality (AR), virtual reality (VR), and interactive sensors.

This global phenomenon demonstrates that technology is not only a tool for presenting information, but also a catalyst for deepening visitors' cognitive and affective engagement. Several international studies confirm the important role of integrating UX and constructivist approaches in designing more meaningful digital museum experiences (Lin et al., 2023; Nakarada-Kordic & Reay, 2022). Technology-based interactive museums have proven capable of increasing visitor participation thru multimodal experiences and content personalization based on user needs (Smith et al., 2021; He et al., 2024).

In the Indonesian context, museum digitalization has begun thru 3D artifact scanning and the provision of electronic information media. However, most implementations still focus on technical aspects, and have not comprehensively integrated HCI principles and constructivist learning theory. This often results in a visitor experience limited to static visualizations without meaningful interaction. Some local studies show the importance of implementing interactive media to make museums more attractive and educational (Kuntjoro-Jakti et al., 2024; Lestyaningrum et al., 2022). However, there hasn't been much research exploring the comprehensive integration of UX design, HCI approaches, and constructivist principles within the context of Indonesian digital museums.

The novelty of this research lies in the development of an interactive museum prototype that combines HCI and UX approaches with constructivist learning theory to enhance the educational experience and visitor engagement. This research not only tested the technical aspects of usability thru the System Usability Scale (SUS) but also comprehensively evaluated the user experience using the User Experience Questionnaire (UEQ) to gain a thorough understanding of design effectiveness.

With this focus, this research is expected to contribute to the development of user-oriented digital museum designs in Indonesia, which are relevant to the global transformation toward Technology 4.0, and strengthen the role of museums as educational and cultural preservation media in the digital age.

II. RESEARCH METHODOLOGY

This research employs a Research and Development (R&D) approach, modified from the Borg

& Gall model (1983), to produce an interactive museum prototype based on digital technology and test its effectiveness in enhancing user engagement and experience. This method was chosen because it provides a systematic framework for designing, developing, and evaluating educational technology-based products.

Broadly speaking, this research consists of two main procedures described separately: (1) the research procedure and (2) the system development procedure.

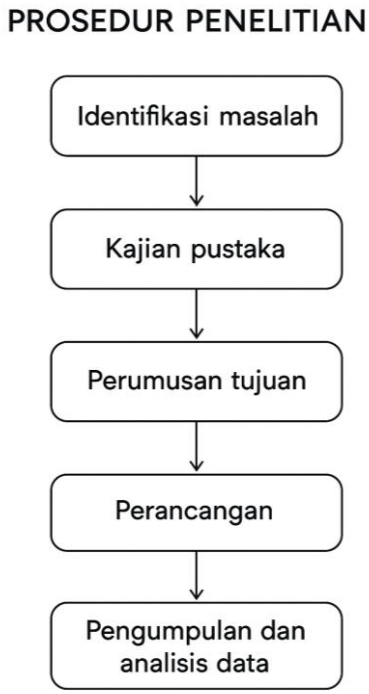

Figure 1. Stage of Research

The research stages are carried out thru five main steps as follows:

1. Needs Analysis This was conducted thru field observations at several local museums in Medan and interviews with visitors and museum staff. The purpose is to identify information needs, expected forms of interaction, and constraints in presenting museum content.
2. Research Instrument Design: The instruments used include:
   - The System Usability Scale (SUS) questionnaire to measure the usability level of the prototype.
   - The User Experience Questionnaire (UEQ) is used to assess six dimensions of user experience: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty.
   - Semi-structured interview guide to qualitatively explore user opinions and experiences.
3. Population, Sample, and Respondent Criteria The study population consists of museum visitors and information technology students in Medan City. The sample
   - was determined by purposive sampling, with a total of 30 respondents who met the following criteria:
   - Have visited a museum at least once in the past year.
   - Having basic skills in using digital devices (smartphones or tablets).
   - Willing to participate in trial activities and interviews.
4. Validity and Reliability Testing of Instruments
   - The validity of the questionnaire was tested using the Content Validity Index (CVI) method, involving three experts in the field of HCI and UX to assess the suitability of the question items with the research objectives.
   - The reliability of the instrument was tested using Cronbach's Alpha coefficient, with a reliability value of $\alpha \geq 0.70$ considered to meet the standard for internal consistency.
5. Data Analysis Quantitative data from the SUS and UEQ were processed using descriptive statistics to determine usability categories and user experience levels. Qualitative data from interviews were analyzed using a thematic analysis approach to identify patterns in respondents' perceptions and experiences.

System Development Method

In creating this website, the author applies a prototype-based system development method. This approach serves as a bridge between developers and users to reduce the gap in technical understanding, while also helping to clarify the requirements expected by users.

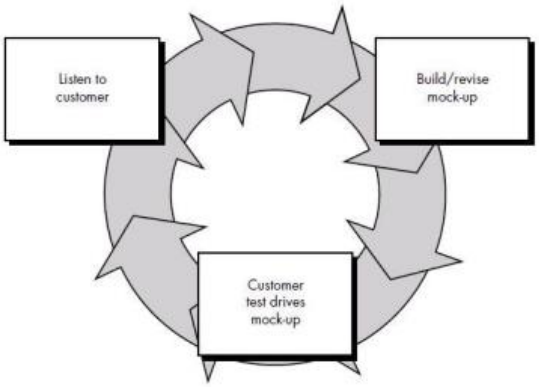

Figure 2. Prototype Model

The development of the interactive museum prototype was carried out using the prototyping method, which focuses on continuous design iterations and user feedback. The main stages include:

- Listen to the Customer
  Gather user needs through observation and interview results to understand the context of use and digital interaction preferences in museums.

- Build/Revise Mock-up
  Create the initial user interface design using Figma, then develop it into a high-fidelity prototype with Unity 3D. Revisions are made based on the results of internal testing.

- Customer Drivers Mock-up
  Involving users in initial testing to gather feedback on the functionality, navigation, and aesthetics of the interface.

- User Testing and Evaluation
  The prototype was tested by 30 respondents for 20–30 minutes. Users were asked to complete specific tasks and fill out SUS and UEQ questionnaires. The evaluation results were used to determine the level of usability and user experience.

III. RESULTS AND DISCUSSION

1. System Usability Testing Results (System Usability Scale)

Usability testing using the System Usability Scale (SUS) showed that the interactive museum prototype achieved an average score of 75.6, categorised as Good. This indicates that most respondents found the prototype easy to use and helpful in understanding museum collections. However, the variation in item scores revealed that aspects such as digital map navigation and audio guide quality still need improvement. The relatively lower scores on orientation ease and audio clarity suggest the need to enhance interface intuitiveness and users' multimodal experience.

Table 1. SUS Score per Item

No	SUS Statement	Mean Score
1	I think I would like to use this system frequently	4.2
2	I found the system unnecessarily complex	3.8
3	I thought the system was easy to use	4.0
4	I think I would need the support of a technical person to use this system	4.1
5	I found the various functions in this system were well integrated	3.9
6	I thought there was too much inconsistency in this system	4.3
7	I would imagine that most people would learn to use this system quickly	3.7
8	I found the system very cumbersome to use	4.2
9	I felt very confident using the system	4.0
10	I needed to learn a lot of things before I could get going with this system	4.1

Average SUS Score: 75.6 (Category: Good)
Comparatively, this result aligns with studies by Lin et al. (2023) and He et al. (2024), which found that key usability factors in digital museums include intuitive navigation and consistent interaction design. This suggests that while the prototype achieved a good usability rating, further refinement is needed to reach the Excellent (>80) category based on Brooke's standard interpretation.

2. User Experience Results (UEQ)

The **User Experience Questionnaire (UEQ)** results showed positive values across all dimensions, with the highest scores in **Attractiveness (6.1)** and **Novelty (6.0)**. This indicates that users perceived the prototype as appealing and innovative. Meanwhile, **Efficiency (5.7)** and **Dependability (5.6)** demonstrated that the system was adequately efficient and reliable for delivering digital museum content.

Table 2. UEQ Scores per Dimension

Dimension	Mean Score	Interpretation
Attractiveness	6.1	Highly appealing
Perspicuity	5.8	Easy to understand
Efficiency	5.7	Fairly efficient
Dependability	5.6	Reliable
Stimulation	5.9	Stimulating

Novelty	6.0	Innovative and engaging

Overall Mean: 5.85 (Category: Positive)
A deeper analysis reveals that the high **Novelty** score reflects the successful integration of AR and interactive QR technology, distinguishing this experience from traditional museums. This finding aligns with **Nakarada-Kordic & Reay (2022)**, emphasizing that innovation plays a critical role in increasing visitors' emotional engagement. However, compared to international studies with larger samples (e.g., >100 respondents), this study remains indicative and cannot yet be fully generalized.

3. Critical Analysis and Study Limitations
The relatively small number of respondents (**n = 30**) represents a major limitation of this study. Although purposive sampling was employed to ensure participant relevance, the sample size does not adequately reflect the diversity of museum visitors in Indonesia. Furthermore, the prototype tested was an early-stage high-fidelity version, meaning it does not yet represent the full potential of a complete digital museum system.
From a methodological standpoint, another limitation lies in the focus on usability and UX without incorporating affective measures such as immersion level or knowledge retention. Therefore, future research is recommended to include larger and more diverse samples, as well as longitudinal testing to assess the long-term impact of interactive museum experiences.

4. Theoretical and Practical Implications
Theoretically, this study expands the understanding of applying **Human–Computer Interaction (HCI)** and **constructivist learning theory** in the context of Indonesian digital museums. The integration of UX principles with a constructivist approach contributes to developing a user-centered learning experience model based on active interaction. This can serve as a reference for future studies in designing educational technology systems focused on user engagement.
Practically, this study provides initial guidelines for developers and museum managers in Indonesia to design digital systems that are adaptive to younger generations' needs. Based on the evaluation results, future development should focus on improving navigation, enhancing audio guide quality, and personalizing content based on user preferences.

5. Reflection on Related Studies
Compared to the study by **Smith et al. (2021)**, which developed a VR-based virtual museum in Europe, this research offers a unique Indonesian context by integrating HCI and UX approaches into an AR- and QR-based system. This approach is technically and economically more feasible for developing countries with limited digital infrastructure. Therefore, this study not only provides local contributions but also offers a new perspective for developing cost-effective yet engaging interactive museum systems.

IV. CONCLUSION

This study successfully designed and developed an interactive museum prototype based on digital technology to enhance visitor engagement and cultural education. The findings indicate that the prototype achieved an average System Usability Scale (SUS) score of 75.6 (Good) and overall positive User Experience Questionnaire (UEQ) results, particularly in Attractiveness and Novelty, confirming that users perceived it as both user-friendly and innovative. Practically, the use of Augmented Reality (AR) and QR-based media effectively improved visitor interaction, motivation, and understanding of cultural artifacts, while theoretically, the research enriched the integration of Human–Computer Interaction (HCI) principles and constructivist learning theory within Indonesia's digital museum framework, contributing to the development of user-centered cultural learning models. Nevertheless, this study faced several limitations, notably the relatively small sample size (n = 30) that restricts generalization, the early-stage nature of the prototype that did not represent all potential features, and the absence of long-term evaluation regarding cognitive retention or emotional immersion. These limitations suggest the need for further exploration through larger, more diverse samples, longitudinal studies, and extended testing on various museum contexts to validate the system's educational and experiential impact. Future research should also advance the prototype into a complete interactive platform equipped with features such as personalized learning paths, immersive storytelling, and adaptive analytics to deepen user engagement. Despite these limitations, this research provides meaningful theoretical and practical contributions by illustrating how digital innovation can revitalize museum experiences. The proposed model demonstrates significant potential to transform conventional museums into inclusive, technology-driven cultural learning spaces aligned with global trends in digital heritage and responsive to the expectations of the digital generation.

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