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Smart Gamification of a Museum Exhibition using Augmented Reality and Generative Artificial Intelligence

Christos Koulouris[1], Stylianos Mystakidis[1] and Andreas Komninos[1]

[1] University of Patras, Greece
smyst@upatras.gr

Abstract. This paper presents the design and development of a smart immersive mobile application tailored for a museum at the University of Patras, Greece. To address the challenge of passive observation in traditional museum exhibitions, a phygital narrative was introduced that transforms visitors into active players. The application combines creatively Augmented Reality with a Generative AI avatar that energizes the game and communicates with players orally. The core gameplay revolves around a museum rescue scenario, where users must locate and disarm digital mines concealed within telecommunication exhibits, such as telegraphs and analog radios. This work contributes to the evolution of a smart immersive game-based learning design in cultural heritage and museum education with the incorporation of three-dimensional conversational agents powered by large language models.

Keywords: Augmented Reality, Generative AI, Museum Education, Gamification, Mobile Learning, Cultural Heritage.

1 Introduction

Science museums act as vital hubs for informal education; however, engaging digital-native audiences accustomed to interactive media remains a persistent challenge. This issue is even more urgent for museums curating cultural heritage collections and exhibitions. Traditional static exhibits often leads to museum fatigue, characterized by a decline in information retention due to physical and cognitive exhaustion [1]. To mitigate this, this project leverages the convergence of Extended Reality (XR) and Artificial Intelligence to transform the Science and Technology Museum of the University of Patras into an interactive playground. Previous studies have applied XR applications in museums both in the humanities as well as in natural sciences [2–4]. AR can be combined with various forms of gameful experiences to enhance learning in formal and informal educational settings [5, 6]. We propose a smart gamified mobile application that overlays a dynamic digital narrative onto the physical space. By utilizing Augmented Reality (AR) for object interaction and Generative AI (GenAI) for adaptive guidance, the system shifts the visitor's role from a passive observer to an active problem-solver.

2 Theoretical Framework

This project was designed by three methodological and technological pillars: Gamification, Augmented Reality, and Generative Artificial Intelligence.

2.1 Gamification

Gamification involves integrating game-design elements such as narrative, quests, and rewards into non-game contexts to enhance user engagement and motivation [7]. Its primary objective is to transform passive or bored activities into active and enjoyable, attractive experiences by leveraging psychological drivers like achievement, problem-solving and competition. In educational settings, gamification has been shown to increase participation and information retention by structuring the learning process through goal-oriented challenges [8].

2.2 Augmented Reality (AR)

AR overlays digital information onto the physical world, enhancing the user's perception of their environment in real-time [9]. Unlike Virtual Reality, which fully immerses the user in a synthetic environment, AR maintains a critical connection to the physical world, making it ideal for situated learning. The technology typically functions through marker-based tracking, where visual cues trigger digital content, or Marker-less tracking, which maps the physical geometry of the space to place digital objects on surfaces [10].

2.3 Generative Artificial Intelligence (GenAI)

GenAI refers to deep learning models capable of creating new content (text, audio, code) based on patterns learned from vast datasets [11]. In the context of virtual, conversational agents, Large Language Models (LLMs) represent a significant evolution from traditional rule-based chatbots. They enable dynamic, context-aware dialogue, allowing virtual agents to understand natural language inputs and generate adaptive, non-scripted responses. This capability facilitates a smart, Socratic interaction, where the AI guides the user through hints rather than providing static information [12].

3 Pedagogical and Narrative Framework

The design is grounded in constructivism and situated learning, positing that knowledge is best acquired through active engagement within an authentic context.

3.1 The Narrative Premise

The experience is built around a cohesive storyline: a secret terrorist hackers' group has planted digital mines on key exhibits to disrupt the museum's operation and educational mission. These mines are invisible to the naked eye and can only be detected via the user's AR device, creating a sense of urgency and purpose.

3.2 The GenAI Conversational Agent

Players are guided by the virtual museum guide Echo, a non-player character in the form of a three-dimensional avatar powered by GenAI (Fig. 1a). Due to the attack, Echo cannot act autonomously and requires the visitor's physical presence to disarm the threats. This symbiotic relationship between the user (who performs physical actions) and the AI (who provides knowledge and guidance) forms the core of the gameplay loop. To ensure continuous engagement, Echo functions as an active conversational partner. Rather than passively dispensing facts, the GenAI provides contextual scaffolding through natural dialogue. For example, when a user struggles with the Telephone Mine, Echo responds with a riddle: "In an era when voice did not fly, liquid was needed to be heard… Pay attention to the telephone timeline for clues". This interaction prevents frustration while prompting the user to actively explore the physical museum exhibits.

4 System Design and Mechanics

The mobile application transforms specific exhibits into interactive puzzles. The virtual disarming process requires cognitive engagement with the artifact's history and function.

4.1 Puzzle Mechanics

The game features three challenges of improving difficulty in the form of cognitive puzzles labeled as virtual mines (Fig. 1b). To sustain motivation, a dynamic Progress Bar updates upon successfully disarming each mine, culminating in a 'Museum Saved' achievement. Each puzzle ties to specific learning objectives:

- **Morse Mine:** [Learning Objectives: Algorithmic thinking, observation]. Upon locating the telegraph exhibit, the user must decode an audio message in Morse code using a provided translation tableau, facilitating experiential learning of early telecommunications.
- **Telephone Mine:** [Learning Objectives: Critical thinking, information correlation]. This puzzle requires critical thinking and observation. The user interacts with a digital keypad and must deduce the correct

code by combining a riddle provided by Echo with historical data found on the museum's telephone timeline. A variation involves scanning an old commutator to reveal hidden AR clues.

- **Radio Mine:** [Learning Objectives: Observation, inductive reasoning] Users interact with a virtual radio tuner. Echo guides them to scan specific photographs in the room (Scavenger Hunt). Each successful scan reveals a digit of the frequency required to disarm the mine. Alternatively, users tune into frequencies playing historical audio clips, requiring them to correlate sound with specific historical eras.

Fig. 1. (a) Echo, the GenAI-powered virtual museum guide (left), (b) 3D model of a digital mine used in the AR puzzles (right).

5 Empirical Evaluation

To validate the system's educational efficacy and usability, an empirical study was conducted with 36 university students, The evaluation utilized a mixed-methods approach, combining structured questionnaires based on the Technology Acceptance Model (TAM) and Flow Theory, alongside automated gameplay logging. The results demonstrated exceptionally high user engagement and flow (Median = 5.0 on a 5-point Likert scale). The GenAI effectiveness was also rated highly (Median = 5.0), with automated conversation analysis (via BERTopic) revealing that users primarily interacted with Echo for puzzle assistance (64% of messages) rather than social chat. Gameplay data showed 100% puzzle completion rate. These metrics confirm that the AR-GenAI integration successfully acts as an engaging tool for museum education.

6 Conclusion

This work demonstrates a novel approach to museum education and guiding by fusing AR's visual immersion with GenAI's conversational adaptability. By gamifying the exploration of the Science and Technology Museum of the University of Patras, the application fosters incidental learning and revitalizes interest in technological history. Moreover, it contributes to the evolution of immersive game-based learning design in cultural heritage and museum education with the incorporation of three-dimensional conversational agents powered by large language models. The integration of GenAI-powered agents renders the app smart as it facilitates learning progress and is capable of adapting to each user's personalized needs and communication.

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