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BSc THESIS

Partners in (Solving) Crime: A playful hybrid educational experience for the National and Kapodistrian University of Athens’ Museum of Informatics and Telecommunications

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ABSTRACT

The COVID-19 pandemic brought unprecedented restrictions to on-site cultural heritage visits, prompting museums and heritage sites to adopt digital mediums for engagement. This shift underscored the need for innovative approaches to digital experiences that not only provide access to cultural content but also foster social interaction, a crucial element of cultural heritage visits. Social interaction has been shown to enhance visitor engagement and facilitate learning by enabling participants to collaboratively explore and make meaning of historical and cultural contexts. Recognizing these gaps, this thesis aims to develop a hybrid visit scenario for the Museum of Informatics and Telecommunications (MI&T) at the National and Kapodistrian University of Athens (NKUA). By leveraging asymmetrical multiplayer game design, the proposed system seeks to connect remote and on-site visitors in a shared, interactive educational experience, promoting sociality, co-presence, and informal learning focused on foundational concepts in Computer Science and its historical milestones.

In addition to the related body of work on the subject areas this work touches upon, we mainly detail the iterative design process that resulted in the game's final prototype, which was formatively evaluated by six users. Despite challenges regarding communication, puzzle clarity, and educational content, refinements along the evaluation process led to an engaging and cohesive experience that players praised for its collaborative dynamic and narrative depth. Future work will focus on game implementation and expanding evaluation efforts to include diverse user groups and systematically assessing user experience, social connectedness, and educational impact using established methodologies. Ultimately, this research lays the groundwork for an accessible, inclusive, and impactful approach to social digital engagement in cultural heritage settings.

SUBJECT AREA: Experience Design

KEYWORDS: asymmetric games, human-computer interaction, cultural technologies, iterative design, playtesting

ΠΕΡΙΛΗΨΗ

Η πανδημία COVID-19 επέβαλε πρωτοφανείς περιορισμούς στις δια ζώσης επισκέψεις σε χώρους πολιτισμού, ωθώντας τους να υιοθετήσουν ψηφιακά μέσα για την αλληλεπίδραση με το κοινό. Αυτή η στροφή ανέδειξε την ανάγκη για καινοτόμες προσεγγίσεις στις ψηφιακές εμπειρίες οι οποίες όχι μόνο παρέχουν πρόσβαση στο πολιτιστικό περιεχόμενο, αλλά προάγουν και την κοινωνική αλληλεπίδραση, ένα κρίσιμο στοιχείο των επισκέψεων σε χώρους πολιτιστικής κληρονομιάς. Έχει αποδειχθεί ότι η κοινωνική αλληλεπίδραση ενισχύει την ενασχόληση των επισκεπτών και διευκολύνει τη μάθηση, επιτρέποντάς τους να εξερευνούν και να ερμηνεύουν συνεργατικά ιστορικά και πολιτιστικά περιεχόμενα.

Αναγνωρίζοντας αυτά τα κενά, η παρούσα πτυχιακή εργασία αποσκοπεί στον σχεδιασμό μιας υβριδικής εμπειρίας επίσκεψης για το Μουσείο Πληροφορικής και Τηλεπικοινωνιών (ΜΠ&Τ) του Εθνικού και Καποδιστριακού Πανεπιστημίου Αθηνών. Εφαρμόζοντας σχεδιαστικές αρχές ασυμμετρικών παιχνιδιών πολλών παικτών, το προτεινόμενο σύστημα επιδιώκει να συνδέσει εξ αποστάσεως και δια ζώσης επισκέπτες σε μια κοινή, διαδραστική εκπαιδευτική εμπειρία που προάγει την κοινωνικότητα και την άτυπη μάθηση με επίκεντρο βασικές έννοιες της Επιστήμης των Υπολογιστών και ιστορικά ορόσημα του πεδίου.

Εκτός από την ανάλυση της σχετικής βιβλιογραφίας, η εργασία εστιάζει κυρίως στην επαναληπτική διαδικασία σχεδιασμού που οδήγησε στο τελικό πρωτότυπο του παιχνιδιού, το οποίο αξιολογήθηκε από έξι χρήστες. Παρά τις προκλήσεις που εντοπίστηκαν σχετικά με την επικοινωνία, τη σαφήνεια των γρίφων και το εκπαιδευτικό περιεχόμενο, οι βελτιώσεις που έγιναν κατά τη διάρκεια της αξιολόγησης οδήγησαν σε μια συνεκτική και ελκυστική εμπειρία που οι παίκτες επαίνεσαν για τη συνεργατική δυναμική της και το βάθος της αφήγησης. Μελλοντική εργασία θα επικεντρωθεί στην περαιτέρω υλοποίηση του παιχνιδιού και τη διεύρυνση της αξιολόγησης με τη συμμετοχή ποικίλων ομάδων χρηστών, καθώς και τη συστηματική εκτίμηση της εμπειρίας χρήστη, της κοινωνικής σύνδεσης και του εκπαιδευτικού αντίκτυπου μέσω καθιερωμένων μεθόδων. Τελικά, η έρευνα αυτή θέτει τα θεμέλια για μια προσβάσιμη, περιεκτική και ουσιαστική προσέγγιση στην κοινωνική ψηφιακή εμπλοκή σε χώρους πολιτιστικής κληρονομιάς.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: Σχεδιασμός εμπειριών

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Ασυμμετρικά παιχνίδια, επικοινωνία ανθρώπου-υπολογιστή, πολιτιστικές τεχνολογίες, επαναληπτικός σχεδιασμός, playtesting

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1. INTRODUCTION

1.1 Motivation

After the onset of the COVID-19 pandemic and the consequent restrictions to on-site visits, most museums and cultural heritage sites turned to the digital medium. This urgent need to support alternative ways of interaction with the cultural content and become inclusive also to visitors with impeded access to the cultural site, brought to the foreground the need to re-evaluate and put effort on new approaches for digital content and experiences. Such approaches are, however, in their majority, information driven and lacking opportunities for social interaction which has been proven to be an integral part of a cultural heritage visit [1]. Falk and Dierking note that “museums are fundamentally social places where people in groups gather to collectively share their experiences and collectively make meaning” [2]. Not only that, but social interaction can enhance learning, even in cases lacking such design intentions. [3] In this setting, learning refers to ‘the participants’ understanding of facts in their historical and cultural context [4]. Previous findings on co-visits between remote and on-site visitors that focus on synchronous interaction between the involved persons have suggested an improved experience for the remote user, as there was a strong association between sociality and engagement. [5]

1.2 Main Objective

The objective of this thesis is the development of a social educational playful experience for the Museum of Informatics and Telecommunications (MI&T) of the National and Kapodistrian University of Athens (NKUA). Specifically, this work will focus on a co-visit design where a remote visitor experiences the museum together with a visitor located in the museum’s physical space, and exploring ways of active participation that go beyond simple synchronous conversation on exhibits towards achieving a deep interconnection between the remote and on-site parties. This visit format is defined as a hybrid visit scenario. Asymmetrical multiplayer games, where each player is guided by different mechanics and has different abilities, information or interfaces, have been shown to offer increased feelings of connectedness and presence between players, compared to symmetrical game design [6]. Therefore, this thesis will examine how the main principles of asymmetrical game design can be applied to a learning experience for cultural heritage to influence feelings of sociality and co-presence. Furthermore, considering that the museum’s topic is Computer Science, the importance of which is indisputable in everyday life and human culture, a primary goal of this work is to promote informal learning. This will occur by focusing first and foremost on basic concepts of Computer Science, followed up by events and important personalities in the history of Informatics and Telecommunications.

1.3 NKUA’s Museum of Informatics and Telecommunications

The **Museum of Informatics and Telecommunications** at the National and Kapodistrian University of Athens was established in 2019 and is currently under development (Figure 1). It is located in the basement of the Department of Informatics and Telecommunications on the university campus.

The museum’s goal is to serve as a modern exhibition space that introduces the public to computational thinking through both physical and digital exhibits. It also aims to act as a living lab for interdisciplinary scientific research. Its focus includes preserving and showcasing the history of Informatics and Telecommunications, both in Greece and internationally, as well as highlighting the history and achievements of the Department of Informatics and Telecommunications at NKUA, founded in 1989. Additionally, the museum seeks to illustrate the evolution of Informatics as a science, its impact on daily life, and its role in promoting digital literacy. The current thesis’ educational objectives align majorly with these goals and we hope it can prove to be an excellent addition towards this direction.

Figure 1: The museum’s current state

A museological study has been conducted to guide the development of the museum's revised version [7]. This study establishes six main thematic sections in the history of Informatics and Telecommunications. The space’s architectural design is strongly based on the six sections, separating the museum into six distinct sub-areas that the visitor may freely walk around in without following a specific route (Figure 2).

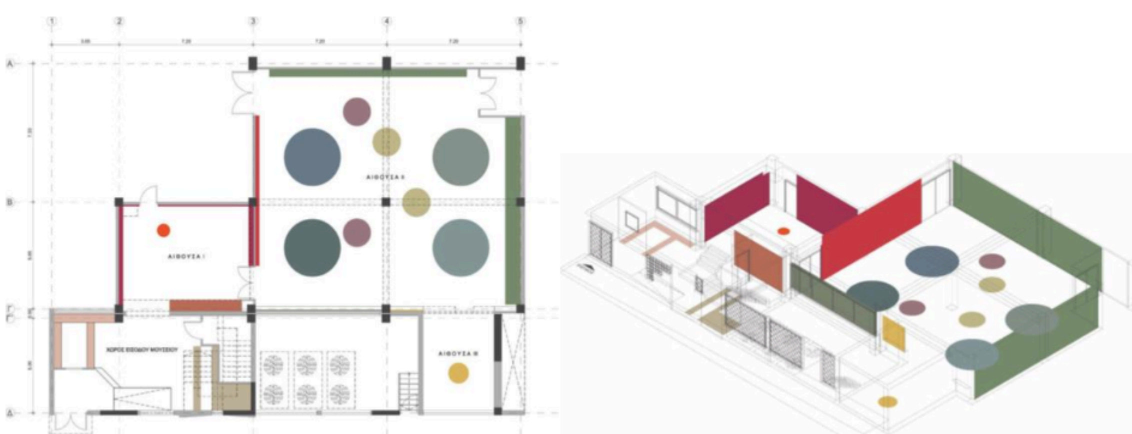


Figure 2: The architectural design's top and orthographic 3D views.

A virtual twin of the revised architectural design, complete with some interactive exhibits such as a timeline of the history of Informatics, has been developed [8] and repurposed for the current thesis, which will be described in more detail in the 'Implementation' section.

1.4 Structure

The structure of the current thesis is as follows:

- Section 2 includes an analysis of the body of related work across all subjects this thesis touches upon, mainly sociality in museums, asymmetric game design and educational game design.
- The third section elaborates on the museological and educational objectives of the current work.
- The fourth section presents the main game concept in more depth while making a connection with its target group, as well as presents a series of design choices that are derived from a set of interviews conducted with potential users that helped inform the game's design.
- The 'Design' section is the main section of this work and includes the following:
  - More details on the museological study conducted in [7], augmented with the results of research conducted on concepts and milestones from the history of Computer Science.
  - A section detailing the experience narrative's design.
  - A section describing the iterative prototyping process, which in turn includes earlier prototypes of the work before presenting the final prototype, complete with a depiction of the evaluation process and its findings.
- Our final conclusions and intentions for future work.

2. THEORETICAL BACKGROUND AND RELATED WORK

2.1 Sociality in Museums

Museum visits are inherently social. Falk and Dierking note that museums are places where people collectively gather to share experiences and create meaning [2]. As cited in [9], the authors of [10] highlight the importance of the social dynamics between visitors relative to the visit's overall experience and the learning that took place. Based on this conclusion, the Contextual Model of Learning [2], first defined as the Interactive Experience Model [10], proposes that a museum visit's social context is one of its three major components, alongside personal context and the site's physical space. Therefore, not only will a visit be shaped by who the co-visitors are (for example, visiting as an adult with other adults compared to visiting with children) and their interactions, but they will also influence the visit's lifelong learning facet.

Nevertheless, remote museum visits, which spiked due to the COVID-19 pandemic, are overwhelmingly solitary experiences, and sociality in this context remains underexplored. Hybrid visits, where a remote visitor is joined by another one in the museum's physical space, are an approach for including sociality in a remote visit. However, there are only a few such previous attempts.

The City system [11] is an older hybrid visit attempt about the Mack Room in Scotland. An on-site visitor was joined by two remote ones, one in a virtual replica of the museum, and one joining through a web application. The museum's physical exhibits had already been augmented with multimedia installations, so both the on-site and remote visitors could view the relevant content and discuss over voice chat. Spatial awareness was facilitated through a map where they could see each other's positions. For this purpose, the on-site visitor carried a location-aware PDA. The VR player could also see avatars of their co-visitors. Participants enjoyed talking to each other about the exhibits and seemed engaged with the museum, expressing wanting an on-site visit.

A more recent example is [5]. Remote visitors from a nursing home joined on site visitors, talking over a shared audio channel. Each remote visitor followed a physically located one. When the latter approached a certain exhibit, the person following them saw one or more static pictures of it. When all on-site visitors approached the exhibit, there followed a segment of a story about a group of aliens who are discovering planet Earth and its civilization through the museum. Lastly came some reflection prompts that aimed to aid discussion. The remote visitors reported a fragmented visit flow, as they only saw content when the on-site visitors approached an exhibit. However, they did enjoy the storytelling and, most importantly, social aspects of the experience. Interestingly enough, the reflections prompts seemed to hinder discussion instead of promoting it.

Hybrid visits remain relevant post-pandemic, as health or geographical distance can still hinder access to cultural spaces. Both of the examples presented, while promising to foster sociality for remote visitors, have not gone beyond synchronous discussion on exhibits, whether prompted or unprompted. A game-based approach, like the one presented in this work, can shift the focus away from this format, allowing for novelty and versatility. It can also aid museums that do not have digitized information on their exhibits, like the Mack Room had [11]. Such a museum is NKUA's MI&T. In the following section, we will discuss a genre that can harness sociality and collaboration, and could, by extension, create opportunities for discussion in a way that is not forced, like reflections prompts in [5].

2.2 Asymmetry in Game Design

Asymmetric game design "provides players with different game mechanics, abilities, information, and/or interfaces" [12]. Not only does the game experience differ for each player across all of these game qualities, but players can also collaborate across different platforms [12], meaning that players can play together using completely different devices. For example, one player could be designed to play in a virtual environment, using a Virtual Reality (VR) headset, while another player could play from a desktop or mobile device, such as a tablet or smartphone. In [13], Harris et al. mention that feelings of relatedness in multiplayer games are essential for engagement and continued play, and that "closely-coupled" cooperative games, where one player's actions significantly affect the waiting time of the other player, are considered significantly more engaging, yet challenging. In their follow up work, [6], they also propose that asymmetric games could offer an opportunity for allowing players with different gaming preferences to enjoy a ludic experience together.

Asymmetric games seem to be a promising genre for the design of our museum's ludic experience, as one of our main focal points is harnessing feelings of sociality, engagement and connectedness between the remote and the physically located player. Not only that, but cultural heritage sites are visited by people with different backgrounds regarding gaming experience, resulting in multiple player preferences. As an example, older people, who might be more likely to have impeded access to a museum, might feel more familiar using a desktop computer interface compared to a younger generation, who is better accustomed to interacting with mobile devices such as tablets and smartphones. We consider asymmetric game design an opportunity for accommodating players with various interface preferences and skill levels.

In this section, we will examine two research prototypes of asymmetric games that influenced the current work. We will also take a look at a design framework for asymmetric games, and relate the terms defined in it to this thesis' work. Finally, we will briefly go over a few commercially available asymmetric games, classifying them according to the design framework studied here, as well as three more asymmetric games that resulted from research projects.

2.2.1 "Beam Me Round, Scotty!" & "Beam Me Round, Scotty! 2"

2.2.1.1 Asymmetric Design Framework

In their work [13], the authors built upon the Mechanics, Dynamics and Aesthetics (MDA) framework to explore design elements of "strong asymmetry" as an extension of closely-coupled games, which they then applied to a game of their own.

Regarding potential asymmetrical Mechanics, essentially the rules of the game world, the following areas were identified to be able to introduce asymmetry:

- Ability, where one player does what another player can't do.

- Challenge, where the players are facing different problems that they have to solve in the game.
- Interface, where the players engage with the game using different ways or gear.
- Information, where the players' knowledge is different and complementary.
- Investment, where players dedicate different amounts of time to their respective roles.
- Responsibility, where players seek different outcomes, e.g. a football team which contains both strikers and defensives.

In the MDA framework, Dynamics refer to the combination of the game's Mechanics with the input from the players. Regarding asymmetrical games, an important point of their dynamics is the degree on which the players end up depending on each other at any given moment due to their asymmetric mechanics. This is defined as interdependence. Player interdependence is characterized by two qualities: its direction, meaning whether it is reciprocal or not, and its synchronicity, which further includes the duration and timing of each player's interdependent actions. With regard to dependence direction, the authors identified the following varieties:

- Mirrored, where all coplayers depend on each other in identical ways. This is most commonly found in 'traditional' cooperative games, rather than exclusively asymmetrical ones.
- Unidirectional, where one player's progress relies on another's intervention but this does not go both ways.
- Bidirectional, where both players rely on each others' unique interventions to progress.

Respectively, about interdependence timing, the following six types were distinguished:

- Asynchronous, where a player can perform an action whenever they'd like without this concerning others.
- Sequential, where two actions are performed in sequence of each other.
- Expectant, where one player performs an action if and only if another player is prepared for and expectant of it.
- Concurrent, where both players concurrently perform their actions.
- Coincident, where players must perform discrete actions at the same time (or within a very short time interval).

It is noted that in all above mechanic and dynamics lists, as each list progresses, there is an increase in the difficulty of execution of the task at hand. The appropriateness of an increased skill level required must be carefully examined in the context of game design for cultural heritage, where the target audience might include demographics without particular familiarity with gaming in general.

The last of the MDA's three axes, Aesthetics, refers to the reactions a player has to a specific game, which are largely impacted by their own experiences and preferences regarding gaming, in combination with the other two components (mechanics and dynamics). The player's background is something which the game designer cannot influence. Consequently, a game maker can only pick the appropriate (asymmetrical or not) mechanics and dynamics taking into consideration the characteristics of players in their game's target group(s) in order to evoke the desired response from their audience. This can vary from excitement, enjoyment and engagement to interest and feelings of challenge for players more skilled in gaming overall.

Before examining the game the authors created to test their framework, we will make a short introduction about the asymmetric Mechanics and Dynamics that we consider relevant for this work, according to Harris et al's framework, which will be further elaborated upon in following sections. Considering that the aesthetics a game designed for cultural heritage aims to evoke are more relevant to better player experience and connectedness with a co-player and less about challenge and player skill, we chose to leverage the terms presented in the lower tiers of the aforementioned lists. Specifically, we heavily relied on asymmetry of interface and information, with a lesser contribution of asymmetry of challenge. The activities included in our game foster a unidirectional dependence between the players over a series of sequential actions, with the direction of dependence switching multiple times over the course of the game, a design choice discussed further below.

2.2.1.2 The Game Prototype

"Beam me Round, Scotty" (BMRS), was a prototype developed by Harris et al. in order to evaluate in practice the effectiveness of the previously defined terminology. The prototype game featured two main characters, each with their own unique mechanics, and multiple levels with different combinations of dependence direction and synchronicity. One of the characters (named 'Kirk') was designed as the main focus of play, with 'Scotty', the second character, being designed as a mostly supportive player, offering mechanics such as teleporting and healing Kirk, etc. Players experienced playing as both characters in different game sessions. The authors note that the game design choices, including mechanics and dynamics of asymmetry, "did not stem from a single, scientifically true/best choice (as, we would argue, no singular best choice exists for all purposes)".

We present here some of the most important outcomes of their prototype's evaluation, which influenced design decisions for this thesis. The main conclusion of the evaluation of BMRS was that the vast majority of players enjoyed needing to rely on each other, as well as the fluctuation of the necessity of the two roles during the game's run. When asked whether they would enjoy playing the game as a Super Kirk character, where they would control identical characters with all of the abilities of both Kirk and Scotty, most refused, choosing the interdependent relationship.

An additional interesting observation was about the way leadership between players arose and was influenced during the run of the game. In most cases where players shared a similar skill level, leadership was fluid, where the pair was temporarily led by the player with the best strategy suggestion. The concept of 'primacy' was defined by the authors as a (usually sudden) change in the players' goals affecting the objective they are focusing on. An example would be an abrupt enemy ambush, where players would stop exploring and would start cooperating to defeat the enemies, where Kirk, the attacking player, assumed primacy. The authors discuss the possibility of leveraging asymmetric elements to deliberately alter the balance of leadership and primacy between players. One way to do this would be choosing the “asymmetry of information” mechanic, in order to provide leadership to the player with the most information, potentially reversing the normal social dynamic of the pair. For example, a parent and a child pair, where instead of the parent assuming a leadership position, primacy is delegated to the child’s role. This is relative to the concept of intergenerational exchange that we will be discussing later on in this work. We note here that this comment from the authors regarding leadership and primacy inspired our work’s heavy reliance on the asymmetry of information mechanic.

Finally, players expressed a distinct preference for one of the characters, which was directly influenced by the interface used to control said character (Scotty was controlled using a mouse, while Kirk was controlled by a dual joystick gamepad), and by extension their past gaming experiences. This is an indication for game designers to take into consideration any potential preferences and past experience their game’s target groups might have in order to choose the most appropriate interface. Although we acknowledge that there is not a singular correct option, this observation did influence our thought process regarding the selected interfaces of this thesis’ subject.

Following up with two new versions of their game prototype in *BMRS! 2*, described in [6], the authors take up two new research goals. Firstly, they examine the magnitude of asymmetry’s role in enhancing feelings of connectedness with the co-player, by contrasting to a symmetric version of the game (essentially, the Super Kirk scenario mentioned previously, with a mirroring Super Scotty version). Secondly, they inquire into how varying degrees of interdependence cause people to feel in terms of social connectedness. This is done by defining three different versions of the asymmetric game (loose, medium and tight coupling) by altering the mechanics of Scotty, the supporting character based on the framework defined in their previous work, as well as Saavedra et al’s concept of “task interdependence”.

The results of the first study confirmed the players’ clear preference for the asymmetric version of the game compared to both symmetric versions (controlling identical Kirk characters and identical Scotty characters, respectively). Regarding the second study, there were strong indications for a proportional relationship between the degree of interdependence and a sense of connectedness and social presence. It was also observed that there was a relation between skill level and preference for tighter coupled play. Participants expressed a clear favorite out of the three coupling conditions, but many also described how they would prefer for the levels of interdependence with their partner to vary over the course of play. One participant suggested that sometimes both the direction and intensity of dependence should vary over time. These observations served as a main axis of this thesis as a means to optimize the game’s flow, by a) relying on alternating interdependence as a means to “not offer to much of a good thing”, and instead allow moments of relaxation to players, as well as carefully consider the level and type of coupling each game activity requires in order to be engaging yet accessible to players of multiple skill levels. Finally, participants noted that their characters’ contributions to certain tasks should be meaningful and not just ‘tedious reliance’ on each other, as this leads to feelings of frustration to develop, a remark we tried to take into consideration when designing activities in order to avoid asymmetry for the sake of asymmetry.

In regards to the current work, an objective would be to select the appropriate mechanics and dynamics to appropriately influence players' engagement with the ludic experience as a means to engage them with the cultural space it is designed to augment, as well as its content. This requires careful consideration of the target groups of the potential MI&T visitors, in regards to their previous gaming experience, as well as expectations for a museum visit of this format.

2.2.2 Save The Yummy Candyland!

Another work relevant to the thesis is 'Save the Yummy Candyland!' (StYC), an asymmetric game played by users in VR using a Head Mounted Display (HMD) and users in the physical world, presented in [12] by et al. When designing StYC, the authors' main goal was to include 'bystanders' -players who do not use an HMD- in a VR environment with a player inside it via asymmetric game design, in order to increase feelings of player experience and connectedness. While we did not design for a VR interface for either of our players, their work's goal aligns particularly well with ours, as the remote player does experience a virtual version of the museum, and wishes to be engaged with their co-player, whose focus is the 'real world'. In their game design, they explore the Escape Room genre, citing:

a) its increased popularity in digital formats, and the fact that even though a few VR Escape Rooms have recently become available, they are still under research.
b) its long and ongoing use for educational purposes, with facilitating communication between players being a very important aspect.
c) The genre's similarity with asymmetric game design, as "they often require players to take on different roles and communicate to solve the puzzles".

These three reasons prompted us to consider the Escape Room genre for the current work, as we consider this to be as much an educational ludic experience as it is socially engaging.

The game's basic premise is very similar to the asymmetric VR game 'Keep Talking and Nobody Explodes!'. One player experiences the Yummy Candyland, a virtual space, through their HMD, while their coplayers are not immersed in Virtual Reality, and instead possess a printed manual. The participants must collaborate to solve puzzles and save the Yummy Candyland. The HMD player is responsible for performing actions in the virtual space guided by the other players' instructions according to the manual's contents. The game was targeted at and evaluated by groups of elementary school children. Despite experiencing difficulties with the available puzzles and a few elements of the game design (for example colors in the virtual space differing from the manual, making puzzle solving difficult), none of the groups expressed a desire to give up or tiredness. Instead, everyone completed the gameplay, and some children preferred to try and work things out when stuck for a while instead of asking help from a facilitator immediately. The enthusiasm shown by elementary school children for this genre, which requires some level of cognitive effort, indicates that this could be a suitable genre for a multitude of age groups that we wish to accommodate (e.g. older school children and their family members or teachers). Naturally, a need for a facilitation/hint system is evident, and one of our objectives as game designers is the seamless incorporation of such a system in the game in a way that does not require outside intervention. Finally, we consider the participants' desire to attempt solving the available puzzles by themselves before requiring hint intervention, a positive sign regarding the cognitive effort the participants of similar experiences are willing to exert, a matter further discussed later on.

Overall, it seems that asymmetric game design and the guidelines discussed in the aforementioned works can serve as an excellent direction for engaging players in gameplay and in the game's social aspects, and by extension, promoting sociality in hybrid cultural heritage visits. This is particularly potent when combined with an Escape Room game design, a genre adjacent to asymmetry, which can additionally harness the educational potential of such an experience.

2.2.3 Other Examples of Asymmetric Games

2.2.3.1 Commercially Available

Perhaps the most well known commercial asymmetric game is the critically acclaimed 'Keep Talking and Nobody Explodes!' [14], also mentioned in Section 'Save the Yummy Candyland'. Originally designed for VR but with ports for mobile and desktop devices available, the game is designed to be played with at least two players. One player (the VR user, and in newer versions, the device user), is the 'Defuser', and is in a (virtual) room with a bomb. The other player(s) are called the 'Expert(s)', and they possess a printed manual with clues on how to defuse the bomb. The Defuser must not have access to the manual, and the Expert(s) must not have access to the bomb. The groups may communicate through a voice interface (separate from the game), or directly, provided the aforementioned conditions have not been met. The game is largely based on Harris et al.'s definition of the 'Asymmetry of Information' mechanic, with unidirectional dependence.

Other known commercially available games are The Playroom VR, Black Hat Cooperative, Acron: Attack of the Squirrels, and Lethal Company. The Playroom VR [15] is a collection of six different asymmetric mini games for PlayStation 4, where players using the game console collaborate with a player using the PlayStationVR headset. Each mini game targets various asymmetric mechanics out of the ones mentioned previously. In Black Hat Cooperative [16], desktop players collaborate with a VR player in an approach similar to BMRS 1 & 2, where one character has an overview of the game space and is responsible for 'hacking' in order to guide their partner to safety, whereas the other character takes a more exploratory approach, collecting materials and sneaking past enemies. Acron: Attack of the Squirrels [17] plays on the Asymmetry of Challenge mechanic, as it piles players against each other in a quest to protect or collect golden acorns, respectively. Finally, Lethal Company [18] is a cooperative horror game where players are tasked with exploring dystopic moons. The asymmetry in the game is voluntary, as players can choose to either explore together, or remain in their spaceship to guide their partners by unlocking doors remotely and locating dangerous parts. Let it be noted that out of these games, only the final two do not fall under the ‘Asymmetry of Interface’ category, making this a particularly popular asymmetric mechanic.

2.2.3.2 Research Projects

In an attempt to create an asymmetric game supporting multiple different platforms, Li et al created CatScape VR [19]. This game is playable by one to three players, by transferring information from Non-Playable Characters (NPCs) to the additional players, and supports the following platforms: VR, Augmented Reality (AR), and a tablet device. This work expands on multiple of the asymmetric mechanics described previously, by involving different responsibilities, abilities and challenges for the players, with one player helping a cat attack another player, while the third one helps the second player escape.

We close this section by presenting two research prototype games that both follow a pattern of players freely roaming in large outdoor spaces, coordinated by players in a designated ‘headquarters’ space. Epidemic Menace [20] is a pervasive game trying to carefully combine two distinct interfaces with a narrative driven approach, a direction which is of interest to us, as will be mentioned later on. Two squads of mobile players try to capture viruses that have been let loose in a campus, while being coordinated by partners in the headquarters, who let them know crucial information on the viruses. The teams collect points and try to understand who let the virus escape. The team that fulfills both conditions, wins. The story was offered in the form of cutscenes at specific progress points in the game. While the game was noted for its fun playstyle and replayability, the story’s integration into the game was not achieved as noted by most of the players. However, almost everyone agreed that it was good that a story existed in the first place. A research challenge applicable to our own work is finding ways to seamlessly integrate the story in the game world. Finally, Frequency 1550 [21] is an acclaimed educational game designed to be played in the city of Amsterdam, following a similar approach of having players roaming in the city guided by co-players in a dedicated headquarters space. We will discuss this game further later, as a part of a review of mobile location-based games for learning by Avouris and Yannoutsou [22].

2.3 Escape Room Game and Puzzle Design

In the previous section, we concluded that the genre of escape rooms seems like a particularly promising direction for this work, as it inherently encompasses elements of asymmetry and challenges that could be designed in an interdependent manner. In the current section, we will take a closer look into the key components of escape room design, as well as a taxonomy for atomic puzzles in analog and digital escape rooms, as described in [23]. In their work, Krekhov et al review existing literature around the design of live escape rooms or analog and digital escape room games, as well as the categorization of their puzzles. They then present a high level taxonomy regarding game design elements of escape rooms, and a low level taxonomy regarding atomic puzzles, bridging the gap between analog and digital escape rooms.

Starting from the higher level taxonomy of escape room game design, the authors identify six main design aspects, which are analyzed as follows:

a) Target group and team composition: Designers of an escape room game must always keep in mind the characteristics, abilities and preferences of their target group. This is particularly useful in order to find a suitable level of difficulty for their game, especially when designing for groups with specific demands like the elderly and the disabled. This applied to our case as well, as we took into account how we aim to appeal to broad audiences and specifically in regards to remote players, people who might be older in age and therefore less familiar with escape rooms and/or gaming in general. It is also noted that designers must bear in mind the device for which they will be designing (if designing for a digital video game), as different devices introduce different roles and perspectives. This in turn can result in the existence of asymmetric roles into the game, which they argue can be enjoyable in escape rooms and creating a stronger need for collaboration. This is very well aligned with the current thesis' goals of strengthening collaboration and interdependence in order to increase engagement.

b) Theme and narrative: Here, Krekhov et al argue that a strong narrative element for an escape room can be a motivator for some visitors, and can even cover other design errors, e.g. in some puzzles. While discussing multiple ways in which the narrative can be included in such an experience, they mention that a continuously present narrative is more believable. A constantly present narrative is the direction we chose for this work as well, as we'll further discuss shortly.

c) Modalities and Platform: The designers must decide and be mindful of the platform they will be designing for, especially in regards to a digital escape room.

d) Puzzle Organization: This refers to the way in which the puzzles and/or tasks of the game are connected, i.e. in what order they must be solved. The authors identify three main types of puzzle connection: linear (puzzles must be solved in a specific, sequential order), open (no solution order is in place) and multi-linear (a combination of the former two). They argue that if a narrative progresses with the puzzles, linear and multi-linear puzzle paths work best. We can empirically confirm this, as we followed a linear puzzle path in the game's design along with which the game's narrative progressed.

e) Puzzle Design: This refers to good qualities of the puzzles included in an escape room game. In previous work the authors cited, the following four were presented:

   i) The puzzle is integrated into the story

   ii) It is solved using the available information

   iii) It adds to the room's atmosphere

   iv) The clues to solve the puzzle are logical
   As all four of the aspects are abstract in nature, the authors attempted to further augment puzzle design through their low-level puzzle taxonomy which will be presented next.

f) Hint System and Failure Handling: The hint system refers to the ways in which the game aids the players when they have difficulty solving a puzzle. In traditional (live) escape rooms, a game master monitors the team's progress and gives out the hints when they deem necessary. This is something we took into consideration when designing the ludic experience, and we assigned the role of the hint giver/game master to the game's main NPC, who lets players know they can ask him when they need additional help, and who then offers the solution necessary for the game's progression. Finally, failure handling refers to what, if any, consequences a player may have in regards to not being able to solve a puzzle. While most live escape rooms do not implement such consequences, digital escape rooms, which have repeatability, could impose such measures as a way to make the game more challenging. We decided against this for our own work, as we'd like to appeal to a broad demographic that may not have experience with escape rooms or gaming in general, and therefore, with the more stressful and competitive elements of ludic experiences.

Following up on the abstract qualities of the Puzzle Design aspect, we present the taxonomy that the authors formulated in their work (Figure 3). This taxonomy is applied to both physical and digital escape rooms, and, as the authors note, is suited as a tool for analyzing existing digital and analog escape rooms. This taxonomy is characterized as atomic, because it refers to atomic components that puzzles must be broken down into in order to be classified accordingly. That is, the simplest of puzzles (atomic puzzles) are classified under the following schema and, more complex puzzles, are further broken, with their respective atomic components being the subject of classification.

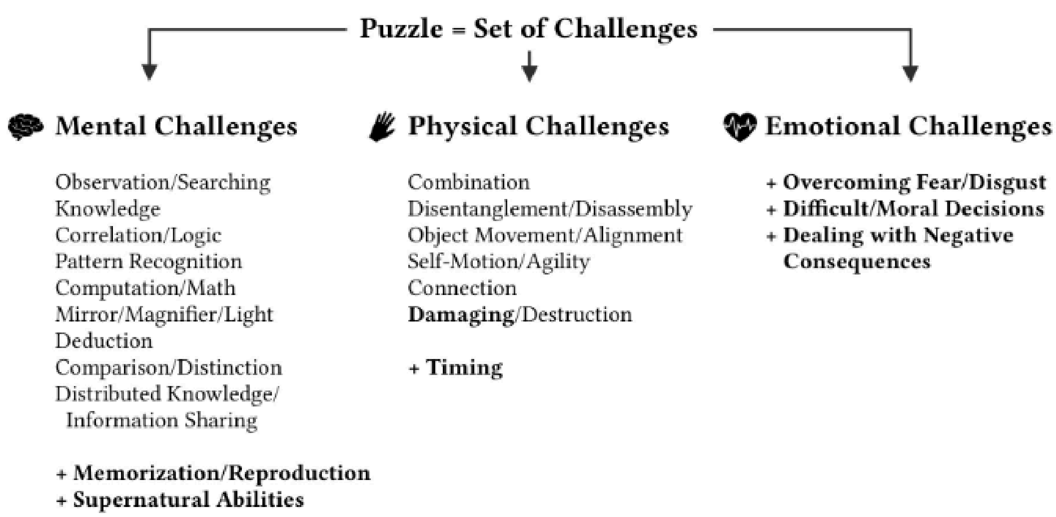


Figure 3: The 'Puzzles Unpuzzled' framework

The authors analyzed 39 publications regarding escape rooms and their design, as well as 8 real-world facilities, 15 board/card games, 10 desktop/mobile games and 6 virtual reality games. They argue that the puzzles observed across all the aforementioned games can be unambiguously classified under exactly one of the above categories.

Interestingly, a category under 'Mental Challenges' is 'Distributed Knowledge/Information Sharing'. This category refers to challenges that require players to exchange information that is asymmetrically distributed among them. The authors note that ‘such challenges are particularly suited for multiplayer escape rooms in which players take different roles/perspectives or are (temporarily) spatially separated’. While we do not exhaustively analyze each of the taxonomy’s categories here, we agree with the observation of the authors that such a framework can serve as a helpful guide for designing an educational escape room, as these are created by non-experts in puzzle design, which holds true in the case of the current thesis. We will come back to this framework when describing the puzzles designed in more depth in later sections.

2.4 Designing for Education

The subject of the current work is a first and foremost educational digital experience for cultural heritage. Spaces such as museums are prime candidates for free-choice learning. Falk and Dierking discuss the concept in [2]. Namely, they write: “Free-choice learning occurs during visits to museums, when watching television, reading a newspaper, talking with friends, attending a play, or surfing the Internet. Free-choice learning tends to be nonlinear and personally motivated and to involve considerable choice on the part of the learner as to when, where and what to learn.” They add that free choice learning is “[...] not restricted to museums, but it is in museums that we currently best understand it.” Free-choice learning could serve as an alternative definition of informal learning, which “applies to the process of acquiring knowledge, skills and attitudes outside of formal, structured education or training programmes. It can happen in any setting, such as at work, at home, or during leisure activities, and can be intentional or unintentional.” [24] According to [25], about 70-90 percent of adult learning takes place informally. We can therefore understand the importance of museums and cultural spaces in fostering informal or free-choice learning.

In this section, we will introduce an evaluation framework for digital experiences that closely examines their ability to induce learning as well as the ways in which that occurs. We will also examine a review of mobile, location-based games designed for informal education. Before moving on to the relevant literature, we will briefly introduce the educational goals of the current work. We will return to this subject later, when discussing the completed museological study on the museums’ knowledge domain of Informatics and Telecommunications.

Our educational goals are separated into two categories. The first category pertains to concrete learning objectives around the subject of Computer Science. These are then further broken down into two separate groups:

a) Important historical figures, periods and inventions, content one would normally expect to find and learn about in a museum.

b) A deeper understanding about basic concepts of Computer Science. An example would be learning more about the binary system, the ‘language’ all computers and smart devices speak to this date. Our motivations behind this are two fold:

    i) Considering the impact the immense progress of this domain had on the route of humanity and our everyday lives, we believe it would be of great interest to gain a deeper understanding of the inner workings of the devices so many of us utilize on a daily basis.

ii) A desire to move away from an exhibit centric approach to museums towards story-centric approaches. This was also influenced by the museum's physical collection, which, as it is under construction, is limited.

These goals are more practical, and therefore, more evident during the solution of relevant puzzles in the progression of the escape room.

The second category is more abstract, but also quite topical. Considering the relevance of Computer Science in our everyday lives, we'd like to invite the museum's visitors to examine the impact of technology in their lives, their relationship with it, as well as examine these ideas on a collective level. An example would be a discussion on views surrounding the recent advancements of Artificial Intelligence. These learning objectives are promoted through the game's narrative, which was influenced from the concepts of Interactive Digital Narratives (IDNs) and Bots of Conviction, on which we will also examine relevant literature shortly.

2.4.1 Interactive Digital Narratives and their effects on Transformative Learning

The value of digital storytelling, linear or interactive, has also been widely recognized within the cultural heritage domain [26] as a means to promote visitor engagement. There are also designs proposing the combination of storytelling and social interaction [27], showing a direct alignment of digital storytelling with the current thesis' work. However, it has been shown that visitors are not merely interested in purely aesthetically pleasing digital storytelling installations anymore, since the effect of novelty soon wears off. Agency, Challenge, Perceived Control and Immersion of users are all ranked as key qualities of a digital narrative [28]. This is an indication that a specific type of digital narrative could be more effective at sustaining the visitors' attention and engagement via the aforementioned ways, which we will further discuss shortly.

An Interactive Digital Narrative (IDN) is a specific type of digital narrative experience which "affords dramatic agency for interactors, and the ability to intentionally influence salient aspects (character development, sequencing, outcome etc.) of a narrative", going beyond simply a digitally enhanced version of an already established artistic medium such as a novel or film [29]. In their work, Roth and Koenitz expand on the three main aesthetic qualities defined in Murray's framework for digital media [30], in order to provide a more concrete evaluation toolbox for IDNs. In this section, we will review the ways in which IDNs can promote learning through Transformation, one of the three main concepts of the presented framework. We will briefly go over all of the three main concepts of Agency, Immersion and Transformation and the 12 dimensions the authors derive from them, as they note that "[there is an] influential and reciprocal relationship between different categories". Hence, Agency and Immersion and their respective dimensions can and do affect Transformation and by extension learning.

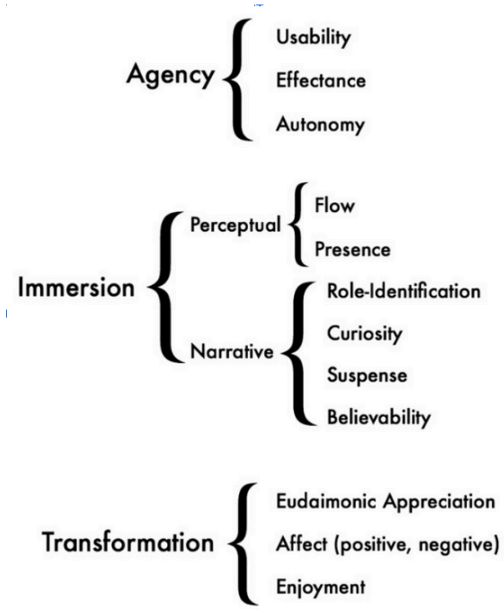


Figure 4: Roth and Koenitz's 12 dimensional framework for the evaluation of IDNs

In [31], Roth et al argue that "IDNs hold particular promise as a modern learning and entertainment experience, with good stories that engage learners and thus convey content and meaning with interaction enabling active learning through experimentation." An important way in which they promote learning is through Transformation, "a fundamental aesthetic quality of interactive narratives with the potential to positively change interactors' thinking and behavior". This concept has an immediate connection to Jack Mezirow's Transformative Learning Theory [32], according to which people make meaning out of experiences through the lens of their assumptions, which are then challenged and contradicted, resulting in dilemmas and, finally, after conscious reflection, transformation of the initial beliefs into different ones. According to the authors, IDNs are prime candidates for promoting what Murray defines as Personal Transformation, that is, the alteration of their beliefs or attitudes towards certain complicated topics. Roth and Koenitz conceptualize the concept of Personal Transformation through Eudaemonic Appreciation, which we will present along with the rest of their framework's dimensions, shortly.

The authors define two separate axes of knowledge expansion: knowledge deepening, and knowledge broadening. Knowledge broadening refers to "[the acquisition of] a wider variety of (counter-)arguments [...], important questions and value systems that go beyond their personal views", whereas deepening knowledge refers to the ability to "go beyond enumerating arguments at a shallow level, in arguing on arguments, and in negotiating the meaning of important underlying concepts". These types of knowledge acquisition can be both connected to the thesis' educational goals, where we aim to broaden the players' knowledge by offering a variety of perspectives and counterarguments in relation to technological progress and the role of technology in everyday life, while simultaneously deepening their knowledge in regards to selected IT concepts (remember the example of the binary system).

The authors go forward to discuss questions that need to be able to be answered by an evaluation paradigm. These questions can serve as important prompts to the narrative designer, especially in regards to transformative learning about more difficult topics. For example, an author must consider the effectiveness of their IDN at representing complex topics, whether there exists any authorial bias, and finding a balance between oversimplifying and overcomplicating the topic at hand. They expand on these questions by presenting two case studies of IDNs along with key takeaways from each experience's design. These are distilled into the following:

- Include reflection and discussion on the experience's topic.
- Paying attention to avoiding certain perspectives underdeveloped, leading to bias in complex matters.
- Paying attention to a hampering user experience for users that are not IDN literate, that is, users that are novices in regards to IDNs and are not aware of how to harness the genre's full potential.

These are points that we carefully considered when designing for the current work's narrative. We employed multiple design elements from Bots of Conviction, a type of chabot designed to provoke reflection on important topics, which we will discuss in the following sections. While not interactive like a chatbot, conversations between the players' characters and the main Non-Playable Character (NPC) of our ludic experience are designed to include open ended questions for reflection and discussion. As we understand that the vast majority of the broad spectrum of museum visitors is possibly not acquainted with the IDN genre, we also aimed for a non-traditional IDN design, where most of the players' agency is concentrated in the design elements from the Escape Room genre, rather than offering multiple potential endings. More on these design decisions will follow later.

Moving forward we will briefly discuss the evaluation framework presented in [29] (Figure 4) in order to gain a deeper understanding of the qualities an IDN can possess that promote Transformational Learning, as well as other intrinsic qualities that indirectly affect transformation.

Agency refers to "the satisfying power to take meaningful actions". Roth and Koenitz further identify the following important characteristics of agency:

a) Usability, which refers to the quality of interface design of the IDN in order to eliminate user frustration and enhance user experience.
b) Effectance, which is about the effect a chosen action has, e.g. how meaningful it is for the narrative progression. This is further separated into:
    i) Local effectance, which refers to the actions a player can take that can immediately affect a particular situation, scene or environment.
    ii) Global effectance, which refers to the way a player's actions can affect the overall narrative progression, such as the ending.

Effectance is correlated to perceived challenge levels. It is therefore important to design for player effectance, but not too much so that the player won't feel bored.

c) Autonomy, which describes the need for the player to choose from an available set of options, without feeling pushed towards a specific option.

Petousi et al propose that Transformation presupposes Agency [33]. We believe that, due to its nature as an Escape Room, the ludic experience we present here offers by default large amounts of local effectance and, by extension, agency, to its players.

Moving on to Immersion, this is defined by Murray as "[a] participatory activity [while] being surrounded by a completely other reality […] that takes over all of our attention". The authors in [29] augment this definition via a psychological perspective to include presence, the sensation of being part of a mediated environment, in the definition of immersion. They propose that immersion exists on the following levels:

a) Perceptual immersion, which is further broken down into

    i) Flow, which is an experiential state in which interactors (with an IDN, or a system in general) are "resolving a sequence of tasks that is exactly as difficult as they can handle with full dedication". Interactors report it to be highly pleasant in many situations, and they manage to block out external distracting stimuli when in flow state. Flow requires a careful consideration of challenge levels, and in that sense, is similar to, and can affect, agency's effectance and by extension, transformation.

    ii) Presence, which we previously defined. Presence seems to be affected by flow and agency, as well by character believability. According to Lee [34], social presence occurs when users successfully imagine intelligent social actors while using simulation technologies or media.

b) Narrative, which consists of:

    i) Believability, which refers to the credibility of the interactor's actions, overall plot, NPCs and the emotional responses they evoke in players. One of the main focal points of our work is in regards to the believability and characteristics of the main NPC the players interact with.

    ii) Role identification, that is, the extent to which the game designer wishes that player is able to identify with a virtual character in the IDNs mediated environment.

    iii) Curiosity, which can create and sustain users' interest in an IDN or other similar narratives, via activating uncertainty on potential abilities and outcomes, or quests for knowledge regarding the simulated world.

    iv) Suspense, which correlates to the emotional involvement with the characters or overall game world the players have, regardless of whether the outcome of the thing that sustains suspense is the desired or the dreaded one.

Finally, Transformation is considered to be broken down into the 3 following dimensions:

a) Affect, which refers to the emotional affective states that the narrative induces to the players, regardless of the IDNs outcome (eg positive affect for IDNs with sad narratives).

b) Enjoyment, which details a broader experience of pleasure than affect, and is correlated to the players' expectations on the IDN.

c) Eudaemonic appreciation. Roth and Koenitz mention in [29] that current research indicates two distinct motivations to seek out entertainment in media, one being hedonistic enjoyment, and the other eudaimonic appreciation. The latter contrasts the former as it encompasses the way that the aesthetic qualities of the digital narrative, as well as its content, not only create a pleasurable experience for the interactor but also engage with their personality. They further describe how eudaemonic appreciation is "linked to users' construction of personal meaning from a story or piece of art", and how users with eudaimonic motivations seek entertainment that deals with meaningful life events and issues, such as hardships and challenges. In [31], the authors propose that players describe eudaemonic experiences as "thought-provoking, personally meaningful, staying with them long after gameplay, as well as often shaping how they see and act in the world."Therefore, it could be argued that Eudaemonic appreciation as an extension of Personal Transformation is a key component of Mezirow's Transformative Learning. Our work aims to engage the users' eudaemonic appreciation with its narrative's contents on ethics in technology.

To conclude, Interactive Digital Narratives are an excellent means to promote visitor engagement and learning in a cultural heritage context, because of their ability to immerse the interactor in a virtual world where they possess agency. Through interacting with the story world and its various elements, players can watch the narrative unfold and make meaning of its contents, resulting in the transformation of their beliefs and views on various subjects or even the world, a type of learning museums and other cultural heritage sites should aim to promote.

2.4.2 Bots of Conviction and Reflection

"Bots of conviction" (BoCs) or "protest bots", terms coined by Mark Sample [35], are a type of chatbot that shifts the focus from offering information to provoking reflection. BoCs are " [trying] to reveal the injustice and inequality of the world and imagine alternatives... to question how, when, who and why." Petousi et al [36] mention that BoCs usually take on the form of Twitterbots that tactically retransmit historical or political data. These bots, therefore, do not provide opportunities for interaction as they are not coded with dialogic interaction in mind. They are a special category of social chatbots, bots that are presented as human-like and that aim to establish an affective connection with their users, be it emotional, social, or otherwise. In the case of BoCs, the social connection between the bot and user is challenging and provocative.

In [36], Petousi et al extend BoCs to a group dialogue setting, in order to support the education of history for high school students via the promotion of reflective dialogue in the context of a digital experience design. They argue that BoCs are a prime candidate for fostering historical empathy, a model that aims to promote better contextualization and understanding of past events, historical figures and facts, such as social issues, etc. This cognitive process involves a critical reflection on historical facts (historical contextualization), a deeper understanding of different perspectives of the people of the past (perspective taking) and, ultimately, an affective connection with the political, economic and social realities of past periods, as well as the emotions, values and worldview of their inhabitants. In [33], the authors propose that “agency contributes to the development of awareness of personal and social contextual influences via the storytelling experience”, therefore connecting the Agency component of the previously presented framework by Roth and Koenitz to historical empathy. They also highlight how BoCs can serve as a tool for dialogic education, which revolves around active conversation between educators and learners and active participation of learners in the educational process.

The authors present a list of characteristics they implemented during the design of their social Bot of Conviction. We will shortly present them, emphasizing those that are more relevant to the current work.

In order for a BoC to be convicting, the authors consider the following traits to be applicable:

- Topical: Relative to current events. Even when discussing facts relevant to past periods, there remains the need for a connection with the current reality.
- Data-based: The information they present has been fact checked.
- Cumulative: Repetitive but with slight variations and differences. The repetition usually builds on itself as the bot presents the same fact to increase the understanding and acceptance of that information or reflection on a specific topic.
- Oppositional: According to [35], such bots “challenge us to consider our own complicity in the wrongs of the world”. While a bot can be directly oppositional, indirect prompts for reflection and perspective taking around difficult subjects also count.
- Uncanny: The authors redefine the word to capture the revelation to the user of something they had previously not observed or ignored.

Additionally, the following qualities attribute a good social facilitator’s role to a BoC:

- Deductive: Guides the users to reach their own conclusions.
- Unbiased: Relative to Data-Based, refers to a bot’s ability to present all perspectives in order to avoid bias.
- Eye-opening: Using open questions, the bot does not force an agreement between users or a specific perspective, but rather tries to offer all perspectives.
- Facilitating: Facilitates social interaction between users.

In their design, the authors created Hermias, the bot, a chatbot designed to be used by groups of 2-5 students. Hermias was a fictional slave living in 4th century BC Athens. The character’s identity, while remaining hidden until the end of the dialogic experience, was ideal in order to prompt discussions around the following three matters: slavery, the social structure of the Athenian Society, and the concept of fate and religious beliefs. The study’s primary objectives were evaluating historical contextualization, perspective taking, affective connection (all three components of historical empathy) and level of participation. Secondary objectives included measuring user experience, the believability of the chatbot's personality and how well the bot served as a dialogue facilitator.

The evaluation showed that the bot was successful in promoting historical empathy, with a particular prominence of perspective taking, as the participants mentioned that "their eyes were opened to new ideas", and, in some cases, led to the shifting of opinions. This indicates a correlation between perspective taking and the concepts of personal transformation and transformative learning discussed earlier on. There are also good indications about the experience's ability to induce an affective connection between the past and the presence, as well as with and Hermias' issues and perspectives. Open ended, intentionally designed questions seemed to have an effect on allowing the exploration of various perspectives and reaching their own interpretations. User experience was rated well, and the bot's personality was positively received.

Challenging users' beliefs and perspectives on the use and progress of technology as a whole is one of our experience's most important learning goals. Specifically, we would like for this work to serve as a competent means of exploring both positive and negative perspectives around ethics on technology. We believe that a Bot of Conviction fits in very well with this objective. However we consider that including a fully-fledged social agent can complicate experience design, considering we have already described a fully-fledged asymmetric game design. We chose to alternate the way in which dialogue occurs, by tasking the main NPC of the game with presenting all the matters and perspectives we want to discuss. A form of dialogue is simulated, as the players' characters are respectively tasked with responding to the NPC via pre-written answers, in a format hinting at Role-Playing Games (RPGs).

We heavily drew upon the characteristics of Hermias when writing the NPC's character and overall script. We consider that the matters discussed are rather topical, and the stance the character keeps is unbiased. The character is also indirectly oppositional, by presenting open ended questions to the users, and, by extension, is also deductive, as it allows users to reach their own conclusions without forcing an answer out of them. We also consider the NPC to be uncanny, both in the definition of the authors, where he discusses radical positions on technology, but also as a synonym to odd, due to his eventual identity and behavior throughout the experience. Finally, inspired by the revelation of Hermias' identity at the end of Petousi et al's experience, we followed a similar approach for our game, where the character's identity is obscured and left up to the user to discover.

We believe that, through this design paradigm, we can also foster historical empathy, as the bot can foster connections between the past (object presented at the museum), present (the players' experiences) and future (opinions and science fiction elements discussed as a part of the narrative) of technology. Not only do we aim for an affective connection with the NPC in a way similar to Hermias, but we also consider the puzzles, and by extension, discussion on and interaction with exhibits, offer important contextualization of decades past, especially for younger users.

2.4.3 Mobile Location-Based Games for Informal Learning

We consider this work [22] by Avouris and Yannoutsou to be of particular relevance with the work presented here. The authors performed a review of games designed to be played in physical space through a mobile device, but are supported by interventions in an interconnected virtual space. It must be noted that this space is not necessarily a 'headquarters' of sorts like 'Frequency 1550', which was previously mentioned and which will shortly be further discussed. The usage of a mobile device in order to i.e. scan an exhibit to find a clue serves as a virtual space as well. While in our work the physical space is not the object of focus with the virtual space taking on a supporting role -rather, they are equally important-, we consider that a framework of such games' characteristics can inform our work's design. In their extensive literature review, the authors separate their survey's results in three different categories: ludic, pedagogic, and hybrid games. We consider the thesis' subject to fall under the latter category, however we believe there is benefit in briefly examining the former two as well.

Successful ludic games can engage the players and retain their motivation, both prerequisites of the learning process that are not always achieved in pedagogic games. The authors further categorize ludic games into treasure hunts, action games and roleplaying games. While the first two genres can still foster informal learning through the interaction between players and the strategic thinking required, respectively, the third one is pertinent to the current game.

In Role Playing Games, also known as RPGs, players assume the roles of a character in a fictional setting. The authors mention that RPGs have learning potential which has been applied in economics, social sciences, etc. This genre is heavily interconnected with storytelling which is often interactive. We have previously spoken about the applications of digital storytelling, namely IDNs, in cultural heritage. Therefore, there could be potential in borrowing elements of the role playing genre for games for museums. Previous research has shown that RPGs have the potential to expand players' affective, cognitive and behavioral skills [37], and that they can support a wider range of educational objectives than other games can [38]. Much in comparison to IDNs and their ability to foster transformative learning, RPGs too have this potential, according to Daniau [39]. In her work, she details 4 levels in which an RPG can affect a player in regards to learning; plain learning, skills, soft skills and finally personal transformation. Regarding the current work, a so-called minimalist role-playing approach was focused. The players do not partake in performative roleplaying, as is the case with live action RPGs (LARPs) or tabletop RPGs (TTRPGs). Instead, they assume a minimalist role or character, through which they are immersed into the game's storyline. In this case, players join the story world as agents in an intertemporal crime unit, and it is through this role that they interact with the game world and its NPC(s). As noted in [20], "[M]inimalist role-playing could be very efficient in creating interesting player interactions in many games while avoiding the aversion and stress of performative gaming often experienced by casual gamers who are forced to role-play."

A variation of the RPG genre are Alternate Reality Games (ARGs). ARGs are an immersive form of narrative driven game that consists of a series of puzzle pieces. The game takes place over a mixed media environment, which could include websites, phone calls, real life environments, newspapers, etc, in an attempt to blur the lines between reality and fiction [40]. The authors mention that literature on the learning potential of ARGs is limited. Regardless of their capability for fostering learning, some ARG elements have been included in the design of the current game. We consider them ideal for helping pervade the story world into the physical world, and, by extension, strengthening the on-site player's immersion by making the game come to life in the museum space. Such an example is material on the game's lore (the facts of the in-game universe) in the form of newspapers spread over the museum's space.

Pedagogic mobile located games utilize the context the game's location offers in order to connect learning between the outside world and the classroom. The authors note that, out of all the games in their survey that included a narrative, three quarters of these games fall under this category. They observe that narrative provides a stronger link between the physical and virtual world. Participatory simulators are notably mentioned, in which the player (and learner) "act[s] out key parts in an immersive recreation of a dynamic system". The authors remark that this genre bears similarities with the role playing one, having in addition a clearly defined, explicit, learning objective. These games help players understand concepts by immersing them into a device-supported simulator in order to enhance their understanding. This thesis' game follows a similar approach, where some of the puzzles the players must solve a) have a specific learning objective and b) have players act out a somewhat realistic process relative to the learning objective. For example, in order to teach players about command line programs, their input and output, the puzzle would involve players constructing a command by combining its name and input and using the output in a later puzzle.

Hybrid games are designed for both entertainment and learning. This genre is closely linked with museums, as mobile interactive museum guides and mobile museum RPGs are its typical applications. The former support increased interactivity with the content, allowing players to choose which exhibits they'd like to learn more about, and doing so in a playful manner. The latter involve strong narrative elements. We present a few characteristic examples of museum RPGs from the authors' survey, namely Mystery at the Museum [41] and Frequency 1550 [21], which has been previously mentioned here.

Mystery at the Museum is an activity created for the Boston Museum of Science, where visitors must solve an exhibit's theft. Players are assigned roles, each role with its own equipment and abilities (e.g. microscopes), and they must closely examine exhibits, make connections between them, collaborate and exchange information in order to successfully solve the crime. Players reported high engagement due to the roles assigned. Each player felt that their own role was the most important one, and, by extension, that their contribution was most significant.

Frequency 1550 was not designed to be played in a museum. It is, however, included in this category, as its educational goal was an increase in knowledge around Amsterdam's medieval history. Groups of four to five students were split in two teams; the city team (CT), which was responsible for navigating in modern-day Amsterdam, and the headquarters team (HQT), which collaborated with the CT remotely, from a dedicated indoor space. The two teams ought to complete assignments relative to medieval Amsterdam. The HQT helped the CT navigate around the city, and both teams completed the same assignments with complementary information. The CT had to find information in their surrounding space, while the HQT offered supplementary information from multimedia lessons and Internet resources. All players got to experience being both in the CT and the HQT. The game had a narrative aspect that involved players having to collect points through assignments in order to gain citizenship in medieval Amsterdam. The students were also randomly assigned a merchant or beggar status, which affected the game's progress when encountering other teams.

For evaluating the game, a control group with students that attended traditional history lectures was established, in order to compare its learning effects to the players who participated in the game. High engagement was reported for the game's players, both the CT and the HQT. Higher learning scores were achieved for the students who participated in the game compared to the control group, with students that had lower historical knowledge before the experiment benefitting more. However, players were not properly informed of their identities as merchants or beggars, so the game's competitive aspect did not function properly. There was also not a proper elaboration of the backstory, so the narrative did not have any effects on strengthening player experience.

Both museum RPGs presented here, as well as other relevant examples in the authors' survey show that museums and cultural heritage sites in general (even entire cities like Amsterdam) lend themselves to sites for location-based learning games, as they are information rich and contain relevant objects in the physical space. There is an associated need for balancing the playful and educational aspects of such games through choosing appropriate mechanics and engaging narratives. The elements discussed here (headquarters, assigning roles with distinct contribution and a need for strong narrative) are all relevant to the current work. Their success in these games support their inclusion in the current thesis, particularly for the engagement of the player located in the museum.

Overall, it seems that mobile location-based games are a promising category for education, whether in general or specific to cultural heritage sites such as museums. These games can be combined with other genres with a learning potential, such as RPGs, or with engaging narratives in order to further harness player immersion in the learning experience. Finally, the authors note that their very strong social dimension can also teach soft skills like, among others, interpretation, problem solving, information management, teamwork, in addition to supporting traditional learning that is social, experiential and situated, all of which are integral to the nature of this thesis' game.

3. GAME EXPERIENCE OBJECTIVES

In the current section, we will present this experience's objectives, which fall under the following three categories: museological, educational and ludic. Museological objectives refer to the goals of this thesis that relate to its property as a museum game. These objectives are applicable to all museum visits. Here, we will discuss how our playful visit will implement its museological goals. Educational objectives denote specific themes and subjects of the broader domain of Computer Science and Telecommunications that we examined when considering content design for the game. Finally, ludic objectives are the goals of our game's design. A lot of the subjects discussed under the game's museological and educational goals did not make it into the game's final version, but they still remain relevant as they were used in activities that reached prototyping stage or can be valuable material for future extensions (namely levels) of the game. Everything mentioned in these two categories will be further elaborated in the 'Content Design' section.

3.1 Museological Objectives

As mentioned previously, the current work's main focus is to facilitate sociality in a hybrid visit, where one participant is located in the physical space of the museum and is joined by another one remotely. This is especially important for the remote visitor, whose visit's social aspect is often neglected in current remote visit formats (for example, 360 tours, which are solitary). In addition, we aim to promote similar feelings of engagement not only with the co-player, but also with the museum itself. Both feelings of engagement and connectedness with the co-visitor and engagement with the museum will serve as important metrics in this work's final evaluation.

In previous sections (that is, "Interactive Digital Narratives and their effects on Transformative Learning" and "Bots of Conviction and Reflection Promotion") the impact that historical empathy and perspective taking have in transformative learning. We have also mentioned how museums are a space for lifelong learning, otherwise known as informal learning, and how transformative learning is one of its forms. It is only natural that a museum game's museological goals include historical empathy and perspective taking.

3.1.1 Historical Empathy

We point out two main factors that can evoke this affective connection between the visitor and the history of the domain of Computer Science; discussions around important figures of the field, and reflection on its rapid progression during the past few decades.

While introduction to important inventions and exhibits is important, it is equally significant that prominence is given to the people behind these achievements and their stories, which often involve important socio-political issues of their times. A lesser known example is the existence of female computors, who were responsible for manually operating the first computers and performing substantial amounts of by-hand calculations to validate their results. While their contribution to the progress of Computer Science is undoubted and includes feats from compilers (which exist in all computers today) to the early stages of NASA's space program, they faced discrimination from their male colleagues on the basis of their gender and, often, race. Alan Turing, whose valuable contributions to cryptography were largely responsible for the outcome of

World War II, and who set the theoretical background for computers as we know them today, was gravely affected by society's outlook on his sexuality. Douglas Engelbert is another hidden figure of Information Technology. He was responsible for the design of modern-day computers, by introducing Graphical User Interfaces (GUIs) and a mouse-like device, both important ways in which people interact with computers up to this date. His contributions occurred multiple decades prior to their establishment in commercial computers, and while revolutionary, were overlooked by his peers in research. We will follow up with more details on the aforementioned figures, as well as more examples of important personalities, in the 'Content Design' section.

It is important to know that the contributions of the scientists just discussed occurred exclusively in the last century. It is awe-inspiring how rapidly Computer Science and Telecommunications have advanced in the span of these one-hundred years. Not only that, but immense growth has occurred in the past two-to-three decades. Most teenagers-to-young adults are not familiar with a world where Internet access and computers' capabilities were limited, a world where smartphones were not omnipresent. We consider that a university museum, such as the one this thesis is designed for, can be appealing for school visits, or to a lesser extent parents visiting with their children, both cases in which this young demographic is involved. This presents an opportunity for introducing a generation who grew up in a world where computers are taken for granted to a much different time that wasn't so long ago as one would initially consider.

3.1.2 Perspective Taking

Considering how pervasive the presence of technology is in our everyday lives, we consider that a museum with a technology-focused theme can -and should- contribute to the discussion around relevant controversial topics in a way that is thought-provoking and informative, yet neutral. This can be achieved by presenting different perspectives on the topics to be discussed, and allowing visitors to draw their own conclusions. This is relevant to the open-ended questions discussed in the 'Bots of Conviction and Reflection Promotion' section that will be posed by the game's Bot of Conviction, the NPC Alan. The topics discussed can include broad questions, such as:

- How did our lives change because of technology?
- Is technology's usage in our daily lives beneficent or not?
- Is technology inherently problematic, or is the way in which it is used that is dubious? Are there solutions for that?
- How do you imagine the future of technology?

We believe such a discussion would not be complete without offering some examples to the visitor as food for thought. The spread of fake news as well as the effects of social media on mental health are both well established criticisms of the Internet's current state. Multiple concerns over companies' usage of personal data have arisen, as multiple times they are subject to selling to third parties, or, in the case of China, can be used to rank citizens according to a social credit score, which can reward them or impede their day to day lives, such as using public transport or their children's schooling. Algorithmic bias refers to algorithms that make decisions susceptible to racial or social bias introduced by the data they have been trained on [42]. The latter is relevant to the topical subject of Artificial Intelligence that has raised concerns through enabling tools such as deepfakes, and has given way to discussions around ownership and copyright of the art that has been used to train generative AI tools. However, it is without question that the Internet and the tools it facilitates have led to the democratization of information and transformed connectivity between people. Artificial Intelligence's potential applications in the medical field through the creation of cancer screening tools [43] could possibly help save lives and money of cancer patients. These examples are only but a few out of many that a visitor could reflect on to educate themselves on these matters, inform their usage of new and existing technologies, and foster a connection with the future of technology.

3.2 Educational Objectives

While the previous section referred to more abstract, affective goals, in this section we refer to more concrete learning objectives, related to historic facts and scientific concepts of Information Technology and Telecommunications.

An incredible amount of inventions were rapidly developed over the past century. The museum has been subject to a museological study, which identified six periods corresponding to six developmental stages of computers, starting from a time period where they were massive calculators, to the modern date, where computing is pervasive, spanning over wearable devices and the Internet of Things. This study was augmented with further research in the context of the current thesis. It is therefore evident that there is a rich archive of innovative creations that visitors can learn about and explore in the context of an educational experience.

Nevertheless, a strictly object-oriented approach can be tiring to some visitors. We believe that, due to the prominence of Computer Science and technology in our lives, we could involve foundational concepts of the domain in a way that is approachable and appealing to the public. An example could be the binary system, which is at the very basis of a computer's function, and a concept most people are vaguely aware of. Possible topics that could help concrete people's understanding of the topic could be a connection with logic gates, the physical components that implement the binary system, its connection with the computer's elements (letters e.g. the ASCII code, pixels, etc.), and how low-level language that is in binary is transformed to high-level languages through compilers, in order to enable programmers to create tools for everyday usage. In relation to the figures mentioned previously, Alan Turing's and Douglas Engelbert's respective contributions were both fundamental in shaping modern day computers. Turing was the first to describe stored-program computers, an architecture that allows applications to be stored in the computer instead of being given as input. Every single modern-day computer is a stored-program one; without this architecture, using an application such as a computer browser would require the skill of giving it as input to the computer. Turing also defined the so-called Turing Test, his understanding of what makes an artificially intelligent computer exhibit (near) human-like intelligent behavior. Engelbert and his team on the other hand were responsible for implementing most of the modern day means of interaction with computers, such as a pointing device (mouse), GUIs (interfaces with icons instead of plain text), hypertext (the main means of navigation in the World Wide Web), as well as some advanced utilities, such as real time collaboration (offered in popular software such as Google Docs and many more).

3.3. Ludic objectives

We conclude this section by presenting some fundamental principles that will inform the design of the experience’s ludic aspects. First and foremost, our main objective -aside from close cooperation and connectedness- is to ingrain a strong sense of contribution to the players. We believe that this can be achieved by carefully implementing asymmetric mechanics and dynamics in the game’s challenges, as well as alternating the direction of dependence between players. We consider both of these elements to be useful for retaining increased player responsibility and, by extension, contribution, without forcing constant stress on one player. Additionally, we aim for any ludic elements -that is, the puzzles to be solved and the necessary hints- to be strongly connected to the themes, exhibits and personalities to be discussed. We find that this will aid in increased immersion in the game, as the subjects discussed and the activities will not be separate, as well as strengthen educational outcomes by having the players apply some of the discussed principles in a way that is easy, guided and controlled.

4. GAME CONCEPT AND DESIGN CHOICES

4.1 Game Concept

We will briefly recapitulate all of the details mentioned about this thesis' experience so far, consolidating them into a clearer game concept.

A hybrid visit is defined as a visit between a person exploring a cultural heritage site-in this case, museum-who is joined by someone who visits remotely, via digital means. The subject of the current thesis is the creation of a playful educational experience that acts as a hybrid visit for the Museum of Informatics and Telecommunications of National and Kapodistrian University of Athens. This experience is essentially a two-person, cooperative, asymmetric escape room. The asymmetric genre includes games that offer different abilities, information and interfaces to their players, fostering close collaboration.

4.1.1 The story

It is the year 2111. Technology's galloping advancement has continued, leading to the invention of the time machine, powerful quantum computers and further refinement and development of Artificial Intelligence. Not everyone is in agreement of these rapid advancements. A team of people aim to time travel to the year 2024 and cause a major technological failure that could affect technology and permanently alter the future of humankind. These criminal masterminds are particularly suspicious of mainstream communication channels and, therefore, communicate exclusively by leaving hints to each other in a small, university museum. Alan, a mysterious figure, takes it upon himself to notify agents from an Intertemporal Crime Unit and guide them to combine the hints left by the aspiring cyberterrorists in order to prevent a catastrophe.

4.1.2 The players

Players join the game as the intertemporal crime agents, solving puzzles and deciphering hints in order to prevent a cyberattack to the country's power grid. The remote visitor joins from the comfort of their own home and is Agent 1, finding themselves in a virtual recreation of the museum in the year 2111, while the on-site visitor is Agent 2, who has time traveled to the past, finding themselves in the current year. The virtual space Agent 1 explores is equivalent to the museum's size and layout, however, exhibits vastly differ. That is because the virtual museum is the result of a museological study that took place, aiming to move away from the current exhibit-centric approach. We will further discuss the virtual museum's exhibition in the 'Content Design' section, as the museological study identified important time periods, inventions and personalities that were the basis of further research into the history of Computer Science. This research's outcomes were the background of the activities that were either partially or fully prototyped.

4.1.3 Alan

Alan is the game's only NPC so far. Alan is not a real person; he is a fully sentient Artificial Intelligence prototype, whose existence has been kept secret. He seems rather distant and condescending when speaking to the agents, but in reality, he wants to prevent the catastrophe as he is also a byproduct of technology with the capacity to care about his own existence. He helps the agents through -initially- cryptical hints to overcome this challenge on their own, so that they could be capable of dealing with a similar challenge in the future. Alan assumes the role of an escape room's game master, as, besides supplying the characters with obscure hints that they have to decipher, he is also the game's way to help the players when they get stuck solving a puzzle or interpreting a hint. This character takes on the role of a Bot of Conviction as well, by posing open ended questions meant to challenge the players to reflect. More about the themes he touches upon, as well as his way of interacting with the players, in the 'Design' section.

4.2 Target Groups

In this section, we will discuss some potential categories of people this playful hybrid visit could appeal to. As mentioned previously, we believe that such a visit format can aid persons with health and/or geographical restrictions. By extension, people with health ailments can include older people as seen in [5], although the two are of course not interchangeable. However, we consider that, aside from these categories, which are loosely defined, we can approach our search in finding an audience through a methodological museological perspective.

4.2.1 Falk's Work on Visitor Motivations

In his book 'Identity and the Museum Visitor Experience' [44], through an extensive series of interviews, John Howard Falk deduced 5 types of motivations for visiting cultural heritage sites. Falk defined a set of questions that he used when studying an interview's transcript in order to work out what motivated the interviewee, resulting in the aforementioned motivations. He proposes that these questions can be useful to museum designers when designing a certain exhibition. We will begin by briefly presenting this set of questions, followed by the visitor motivations he defined. We will then revisit his questions and attempt to answer them for this museum game. Finally, we will conclude with a discussion on which visitor type(s) we believe a visit like the one designed here can be more appealing to.

4.2.1.1 The Questions Guiding Visitor Studies

Falk compiled the following set of questions in order to better understand the factors motivating a person to visit a museum, as well as differences in their knowledge on the museum's subject and view on the role of museums before and after a museum visit. These questions are relevant to the personal component of the Contextual Model of Learning [2] mentioned previously.

- What messages do museums and cultural institutions consistently strive to communicate to the public?
- What is the visitors' knowledge of these messages when entering the museum?
- What is the visitors' knowledge of these messages when exiting the museum?
- How does knowledge when exiting the museum relate to visitors' entering conditions such as their identity-related motivations for the visit?
- What are visitors' affective outcomes from a visit to the museum and how do these outcomes relate to changes in visitor knowledge?

- Does the museum change an individual’s ability to discuss the messages and the role of museums?
- What are some of the longer-term impacts of a visit to a museum and are these impacts influenced by the individual’s pre-visit identity-related visit motivations?

4.2.1.2 The Five Visitor Motivations according to Falk

After applying the above questions to the interviews he conducted, Falk concluded that most museum visitors visit a cultural site due to one of five reasons:

- **Facilitators,** which come in two subgroups.
    - Facilitating **Caregivers** come to have a shared experience with a child. This type of visitor could be a parent, grandparent, aunt/uncle, older sibling, mentor, etc, as well as a non-permanent caregiver, such as a teacher or educator. This type perceives that learning is fun, but cannot pinpoint what they’ve learned during a visit [45].
    - Facilitating **Socializers** come with another adult – a spouse or friend. They possibly think their companion will enjoy the museum’s experience. According to [45], this visit is social and is more about hanging out with friends and chatting than exhibits, which may only be occasionally glanced at.
- **Experience Seekers** want to see the building and grounds and the most important parts of the collection or experience. They are not regular museum visitors, and are mostly looking to visit the ‘iconic’ museums, as tourists or as part of a fun weekend activity. The museum’s topic is less of a factor compared to its importance.
- **Explorers** describe themselves as curious and enjoy learning. They have a general interest in the subject matter of the museum and come to learn more. They are attracted by new or rare exhibits, and are most likely to read labels.
- **Professionals / Hobbyists** have a specific goal in mind for their visit. An example would be a visitor who has photography as a hobby and wants to come to take photos of plants, gardens, or sculpture. Another example would be a visitor who has a deep interest in impressionism and comes to see your museum’s collection of impressionist paintings. They are the smallest group.
- **Rechargers** seek what Falk calls a “restorative experience.” They use the museum as a setting for a mental and physical break that they use to recharge their batteries. Examples of places that can be interesting to this type are art museums, botanical gardens, and aquariums, to name a few.

4.2.1.3 Our hybrid game-based visit and Falk’s 5 motivations

In this paragraph, we will ask ourselves the questions that informed Falk’s 5 visitor types, in an attempt to define more clearly this experience’s goals and how these can relate to the visitors’ existing knowledge and motivations. Through reflecting on these questions, we aim to conclude which visitor types the current thesis’ subject is most appealing and helpful to.

What messages does this museum consistently strive to communicate to the public?

Through offering this game-based hybrid visit, our museum hopes to strive for making the history of Informatics and Telecommunication better known in a way that is enjoyable, social, and fosters a deep connection with Computer Science's past and future. It also aims to challenge and inform visitors' views on technological advancements.

What is visitors' entering and exiting knowledge of these messages?

As we consider our potential visitors' pool to be rather diverse, we cannot be sure about the extent in which they are aware of this hybrid visit's messages and intended outcomes before entering the museum. We hope to evaluate how successful this experience is in conveying these messages and achieving its intended outcomes after the completion of its design and implementation.

Does the museum change an individual's ability to discuss the messages and the role of museums? What are visitors' affective outcomes from a visit to a museum and how do these outcomes relate to changes in visitor knowledge?

We believe that this playful visit paradigm could potentially change an individual's perception on the role of museums, as it shifts the visit's weight away from discussion on exhibits towards applied, informal learning and historical empathy. The game's transformative nature, of which the latter is a major component, can significantly influence the visit's affective outcomes, and, by extension, information retention. While we will shortly take a closer look at changes in visitor knowledge per type, we believe that transformative learning can help with information retention across all visitor motivations. We also aspire to appeal to visitors as a new, viable means for social and fulfilling remote visits, therefore making them reconsider remote museum visits as a whole. This shift in remote visit perception is another factor to be evaluated under this work.

What are some of the longer-term impacts of a visit to a museum and are these impacts influenced by the individual's pre-visit identity-related visit motivations? How does exiting knowledge relate to visitors' entering conditions such as their identity-related motivations for the visit?

Examining the longer-term impacts of this hybrid game, visitors' knowledge when exiting the museum, as well as how they relate to their identity-related motivations for the visit can only be speculative at this point, as the museum in general and specifically the game have not had visitors and participants yet, respectively. This question is useful, however, as it prompts us to consider which motivations would be impacted the most, which can be a first step in the direction of deducing which motivations this game appeals to the most.

- Rechargers probably would not be benefited in the long run by a visit to this museum, whether a traditional one or the playful one proposed here. The format proposed here is less focused on a calming, aesthetically pleasing experience, and more information and challenge driven. As a result, we believe that they would not remember such a visit as a relaxing moment, and would probably not be interested in it to begin with.

- Explorers' interest in and impact of this experience works as a double edged sword. They are a very curious kind, and could be very likely to visit a museum on such an extensive and contemporary domain of knowledge as Computer Science is. However, they appreciate freedom to explore, meaning that often they do not prefer guided tours [45]. We consider that such a visit could potentially break this barrier by appealing to their curious nature. Explorers seem to be able to recall the most information after their visits [46], so we consider that they could be the most impacted by the messages this visit -and the museum in general- strives to convey.
- Experience Seekers, similarly to the previous type, are also a type whose interest in the proposed visit is questionable. While we do consider that such a novel design could be interesting to an Experience Seeker if it reaches their ears, we do acknowledge the role that a museum's importance plays in informing their visits. We consider that, while few such visitors could end up visiting a smaller museum such as this one, this visit design that is being proposed would be potentially memorable for a very long time to come, despite information retention not necessarily being the highest.
- Professionals/Hobbyists could, in theory, find the museum's (small) collection of 80s and 90s personal computers (PCs) appealing, but we consider that the museum does not have a significant amount of exhibits that could be of interest to them, especially when it comes to well-versed hobbyists. Perhaps 3D replicas of such exhibits in the virtual museum, complete with detailed information, could bridge that gap, but this would only be to a certain extent, and only for the remote visitor. A structured visit approach like ours that aims to be appealing to a large percentage of visitors with varying knowledge backgrounds and with a focus on sociality could perhaps only 'scratch the surface' of a hobbyist's or professional's domain of knowledge. Designing such a playful visit with these information-driven users requires a vastly different approach from the interestingly written, carefully curated content that can captivate the general public.
- Last but certainly not least, Facilitators, both Facilitating Caregivers, the children they accompany, and Facilitating Socializers are in our opinion prime candidates for enjoying and benefitting from this visit approach.
    - University museums, such as this one, receive both families and school classes as their visitors. We believe that they are the most likely to visit out of all motivations. In the case of school visits, children, while glad to be experiencing a space other than the classroom, are not particularly engaged with the collection. This visit format could fill this engagement gap through piquing visitors' curiosity due to its inherently novel nature and by providing applied interaction with the exhibition in the form of the activities. It also redefines sociality in school museum visits. Instead of a traditional format where the teacher or museum staff produces information which is then passively consumed by the students, who are not allowed to

interact with each other as to not disturb the tour's flow, it allows for learning in a purely social context. We therefore theorize that for the children in a facilitating caregiver's care, such a playful visit can be not only more memorable in the longer term, but perhaps even result in better learning outcomes. This is due to the informal nature of the learning taking place, as well as through strengthening children's soft skills, in particular collaboration and problem solving. Both when accounting for visiting schools and families, but particularly in the second case, such an experience is a great opportunity for fostering bonding between the child and its caregiver, if the two are the participating parties instead of two children. This strengthens our hypothesis for the suitability of this hybrid visit for Facilitating Caregivers, as they choose museum visits as an alternative form of spending time with their children, that also fulfills their need to be perceived as good caretakers [45]. At this point we'd like to address an alternative way in which caregivers and children can participate in this experience. We understand the challenges of organizing visits where families or school classes are appropriately separated so that only half of the intended participants are in the museum space. We believe that such a visit does not only have merit as a remote social visit, but also as an alternative traditional museum experience, in which the 'remote' player can be in a dedicated space near the museum, but not in direct contact with the exhibition or their coplayer. This way families and schools alike can experience this novel design in a traditional, simultaneous, but not quite collocated visit.

- Finally, we believe the appeal of this social game-based museum visit to the Facilitating Socializer type is evident. While we are not sure whether a museum such as the one this design is intended for would be the first to come to mind to this visitor type, we believe that it can provide a memorable experience that actively employs communication and collaboration in contrast to the usual simultaneous discussion on exhibits that takes place. This type is much more known for recalling the details of the visit such as when or who they were with [46] instead of exhibit-specific information. This experience may, therefore, not significantly information retention, but it would be interesting to examine if this type can better absorb knowledge in an inherently social context instead of the classic ways in which museological content is curated and offered to the visitor.

In this section, we attempted to answer Falk's questions for guiding visitor studies for NKUA's MI&T. We believe that this museum design can be meaningful both due to its affective, transformative nature as well as due to its aspiration to define a meaningful remote social visit format. Our answers regarding visitor type appeal and long-term effects at this point can only be speculative due to the museum being in its earliest stage. We find that the visitor motivation this museum is most relevant and influential to is the facilitator type, including both its subtypes. This is followed by the experience seeker and explorer types, with the former, while usually found in the most recognizable cultural establishments, being a prime candidate for enjoying a novel experience, whereas the latter's curiosity makes them likely to consider this structured approach instead of exploring on their own. Finally, we believe that both the professional and recharger types might not be interested and/or impacted by the museum's domain and collection, as well as this visit format, due to them not possessing specialized exhibits and information or aesthetic qualities, respectively.

4.3 Design Choices

While taking into consideration the possible demographic groups such a museum visit could be appealing or impactful for can benefit experience -and most importantly content- design, it is important to involve users early on in the design process, especially when tackling a design that does not have established best practices such as this one. We therefore conducted preliminary interviews with two potential users. While the number of users involved is particularly limited, the participants were readily available for an extensive, open-ended interview. The structure in which the conclusions are presented does not reflect a pre-made set of questions and instead occurred organically through the interview process. The interviews began by asking the interviewees about their age, familiarity with technology, and their relationship with both video games and museum visits. Then, the person conducting the interview described the game's concept as presented so far, and asked the players to share anything they believed they would like or dislike in the context of this experience. The first person interviewed was a woman in her early 50s, with only basic technological knowledge, some gaming experience with casual games, and a keen interest in visiting museums and cultural heritage sites. The second person was male, in his mid 20s, more comfortable with technology, a diverse and extensive gaming background, and with minimal interest in museum visits. Evidently, both participants' backgrounds are contrasting. Despite this, the points they raised significantly coalesced.

4.3.1 Choosing Suitable Platforms

When presenting the game concept to the interviewees, the decision surrounding the game's platforms was not yet finalized.

The initial consideration for the remote player's platform was virtual reality, either a fully immersive solution utilizing a head mounted display (HMD), or a desktop solution, where the player would navigate through a fully fledged virtual space, but without the immersive aspect. We erred towards the second choice due to HMDs' limited availability. When discussing this with the first interviewee, she expressed a preference for a desktop because it felt more familiar to her. She noted that, since personal computers had a learning curve, a device which is brand-new to many people with a similar or greater age than her could also prove intimidating. The second interviewee agreed with both points.

In regards to the located player's device, it was evident that it should facilitate both spatial awareness and mobility. This included mobile devices or some form of HMD that would allow for passthrough VR. The latter would enable immersive augmented reality (AR), as opposed to AR through a mobile device's camera and screen. This possibility excited the users interviewed, despite potential issues with the passthrough HMD's learning curve. Such a device ended up not being relevant to the current prototype due to the exhibits selected and the puzzles designed. Therefore, smartphones and tablets were chosen instead, a scenario that they were also looking forward to, due to how a mobile phone's near field communication (NFC) and quick-response code (QR code) scanning abilities can enable interactions with exhibits that no longer work. Later on, during the design phase described in the following sections, the question arose regarding the remote player's point of view and, by extension, their means of interaction with the desktop computer. The design's first version was first-person and allowed free navigation. The player would control the camera angle and their position using their mouse and arrow keys, respectively. However, the game's nature required interacting with points of interest in the virtual museum space. This resulted in the mouse doubling as both a camera angle controller and a traditional clicking device. We considered this to be potentially confusing for people with no prior experience with classic first person games, as it assigned unfamiliar properties to both the mouse and the keyboard devices. We settled on a fixed-state navigation system similar to that of point-and-click adventure games, where the player uses graphical user interface elements such as arrows to navigate around the virtual space, moving their camera to fixed points. Therefore, the mouse will only be used as a clicking device, and the keyboard as an input device during puzzles where this is relevant.

4.3.2 Interface Design

A question asked to the interviewees was whether they had visited a virtual museum in the past. Both respondents answered negatively. When asked why, both noted that it just hadn't happened yet. However, they did follow up with concerns on whether a virtual museum visit would facilitate a clear sense of the museum's physical space, something which they both found important. In the second interview, the interviewee requested to see an example of a 360 museum tour. This tour [47], created with Google Street View [48], was shown to the participant, who commented that he did not feel like it offered as good space perception as he would like. He noted that he believed a virtual reality recreation of a museum space would come closer to what the term 'virtual museum' brings to mind.

Similarly, the interviewees noted the importance of the experience encouraging and facilitating engagement with the museum's physical space for the located player instead of having them experience the collection exclusively through their device. They responded positively to the mention of ARGs and the inclusion of such elements in the game world for the physically located player in the museum, such as tangibles spread around the museum delving into the game world (e.g. newspapers, magazines), or using actual computers from the exhibition in the context of activities. They both noted that any element that can ensure that the mobile device does not detract from the surrounding space is very welcomed. The onsite player using a computer in the collection in working condition was a core component of the final product.

4.3.3 Content Design

During discussions on likes and dislikes around content as is usually presented in museums, both interviewees noted the importance of content 'catchyness' and appropriate length. This ties into a conclusion from [49] regarding criticism of visitor categorization into discrete visitor styles. In this work, the author notes that 'visitors weren't reading bad labels', and that changing the way that exhibit content is written can make visitors slow down and pay more attention to the messages the museum wants to convey. Even in regards to a visitor-style oriented approach, it is noted that the museum needs to “communicate multiple messages so that [it appeals] to different subsets of the visiting public [45]. A way to achieve this would be to curate layered labels. A recommendation from [45] are headlines with optional in-depth text further below, and perhaps easier to read labels for certain groups such as children. Combining suggestions from both authors, we believe that this indicates a need for appealing layered content with special attention to the first information layer, so that it appropriately conveys the educational message concerned. Interviewee no 2 did mention preferring well established forms of multimedia in games, such as journal entries, recorded message, or even cutscenes to labels and informational text, no matter how catchy the latter would be. He did admit, however, that informational content can ‘definitely be done right’. While the final design does not include any multimedia-based narration or educational content, this recommendation is included as it can shape potential future work.

4.3.3.1 Entering Knowledge and Interest

In respect of Falk’s concept of the visitor’s entering knowledge of a museum’s domain, the interviewees were asked about concepts, inventions, events or personalities they were already familiar with. Both responded that they had heard of Alan Turing, and would like to know more about his life, other contributions and how he was perceived by his contemporaries. An activity revolving around Turing machines, his important contribution to computational theory, would include such content around his life and times and was one of few that were close to being prototyped. The activity will be further discussed later on.

To a question regarding what they would expect in such a game-based museum experience, both interviewees confirmed wanting to interact with actual exhibits from the museum’s collection, whether a working, physical exhibit, an AR version in case of a non-working exhibit or, for the remote player, its virtual counterpart. Indeed, specific devices, like a 3D-model of Macintosh SE and a Compaq laptop (both existing in the museum’s collection in working condition) played a major part in the final version’s activities, for the remote player and on-site player, respectively.

4.3.3.2 Difficulty levels

The game’s potential difficulty level came up during a discussion on the first interviewee’s experience with online escape rooms. Specifically, when asked what she dislikes in such games, she mentioned frustration when prior knowledge is required, especially math skills. Due to the latter, she was hesitant to hypothetically participate in our game, as she thought that an escape room about computer science would require advanced math skills. We consider that having no prior knowledge requirements and/or providing aids for any skills required (e.g. arithmetic) a) promotes inclusivity of any potential museum visitors, as they can be a diverse body of players and b) can relieve any potential mental fatigue.

Mental fatigue is a theme that came up more than once during the interviews. Interviewee no. 1 noted the possibility of mental fatigue affecting the ability of older adults to progress through the activities or absorb any relevant educational material.

Interviewee no. 2 was concerned about the total amount of information. He noted that, if all aspects of the game -narrative, educational content, and activity-related content- were to be equally information-dense, this could induce mental fatigue to players, regardless of age. He expressed a preference for a more detailed narrative, followed by educational content, and finally, easier puzzles as a way to keep players engaged with each other and as a means of applying some of the learning concepts presented. He also raised a point about the topicality of any information required to solve a puzzle. That is, he notes that players should not have to recall information from earlier activities. Both participants arrived at two important conclusions. Firstly, they believe there is a need for a (topical) robust hint system that can help avoid frustration by helping players progress. Secondly and most importantly, they stressed the importance of an easy difficulty level. While we considered the possibility of multiple difficulty levels, we decided that it remains outside the scope of this thesis, and therefore, according to user recommendation, we implemented what would have been an 'easy' level. Finally, both users recommended against a time limit. Despite most educational escape rooms having some form of a time constraint, usually the 60-minute mark popular with commercial rooms, we followed the interviewees' suggestion, aiming to instead explore how long players would take to complete our final design, how they felt about said duration, and applying a similar time-limit in future levels of the game.

4.3.4 The role of individual game elements

We draw this section to a close by relating each of the individual game elements to the museological and educational goals they help to realise.

A lot of this experience's individual game elements serve a function in promoting historical empathy, as it is one of its primary museological objectives. Any heritage experience aimed at fostering historical empathy should prioritize the following aspects:

- Curiosity
- An emotional, affective connection between the user and the experience world
- Critical reflection
- A connection between the past and present

The decision to incorporate a well-established narrative into our educational escape room addresses several aspects of historical empathy. The most apparent benefit is its capacity to pique visitors' curiosity and actively involve them in the upcoming activities. Furthermore, the capacity of digital narratives to promote transformative learning is indisputable, as previously discussed in the 'Related Work' section. Conveying information about the important historical figures and events discussed in the experience through storytelling as opposed to informational text is far more potent in establishing an emotional connection between the visitor and the subject of discussion. This is evident from the discussion with our first interviewee, who emphasized the importance of making exhibits and persons 'coming to life'. Interestingly, she spontaneously used the word 'empathy' without any prior prompting from us. We believe that this confirms and reinforces the users' need for an emotive connection with the past.

Alan, the game's only NPC thus far, plays a crucial role in the narrative's transformative nature. Aside from bridging the past, present and the future, as described in-game, his open-ended questions and exploration of various subjects encourage critical reflection without imposing it. Finally, the minimalist roles the players undertake serve a twofold function: enhance immersion in the game world and, by extension, empower them with agency.

The other key goal of this hybrid museum visit is to enhance sociality for remote visitors. Our choice to design this experience based on the principles of asymmetric games, as well as to include collaborative puzzles, is essential in fostering close communication between players and, by extension, hopefully increasing feelings of co-presence for both remote and on-site visitors. Voice chat is, naturally, a fundamental component of this process. Regarding asymmetric game design, we propose that the 'asymmetry of information' mechanic is the feature most likely to facilitate the close collaboration that we aim for in an inclusive way, as it can appeal to players of all gaming backgrounds by requiring exclusively communicational skills. The 'asymmetry of interface' mechanic enables players to join each other in the virtual world through a platform most suitable to their unique needs and circumstances (a mobile device for the on-site player and an easily accessible desktop device for the remote player), while alternating interdependence aims to foster equitable and ongoing engagement of both players with the game world and with each other, as well as provide both players with a sense of accomplishment derived from helping their teammate. Finally, in addition to their role in bringing visitors together, puzzles not only shift attention away from idle co-discussion on exhibits but play a crucial part in promoting a deeper understanding of basic Computer Science concepts in a way that simultaneously strengthens the player's connection with the domain's past. Thus, considering the profound impact of Computer Science on humanity as a whole, this insight into the state of the field some decades ago is directly connected to the daily lives of people at that time, strengthening the affective connection between them and the visitor, and further fostering historical empathy.

5. DESIGN

5.1 The History of Informatics and Telecommunications: Informing Game Content and Puzzle Design

As previously noted, an important objective of ours is for the experience to include puzzles and activities that are directly inspired by significant figures, events, inventions, and concepts within the field of Computer Science. As previously discussed, an initial museological study [7] was conducted to outline fundamental exhibits, key personalities, and historical milestones pertinent to Computer Science that will be featured in the museum's finalized version. This study served as a reference for further research, which incorporated additional noteworthy exhibits, influential individuals, and, most importantly, crucial Computer Science concepts. The latter was an element absent from the original study and is more pertinent to an educational experience, such as the subject of this thesis. The main source for the additional research was Computer History Museum's (CHM) Timeline of Computer History [50], as well as Wikipedia [51] and Computer Science undergraduate curriculums with respect to the selection of fundamental CS concepts that learners should be familiar with but may not yet know of. This enriched information pool has inspired the brainstorming of potential level subjects, puzzles and activities, the result of which will be presented in following sections. Ultimately, a select few of these ideas have currently evolved into concrete, finalized puzzles. Nevertheless, this material was fundamental in informing the current game and puzzle design. Furthermore, it holds potential for future game levels and could also contribute to shaping the museum's collection design. In this section, we will briefly present the complete information gathered in the context of said research.

5.1.1 Structure of the museological study

The conducted research was based on the original study's structure, which established 6 thematic sections. The sections do not enforce a linear narrative, though they are informally connected in chronological order. Each section serves as a starting point for its theme rather than an endpoint, as developments continue today.

The thematic sections and their approximate chronological contexts are:

- Mathematical/Scientific Computer - 1940s and 1950s
- Business Computer - 1950s and 1960s
- Personal and Home Computer - 1980s
- Networked Computer - 1990s
- Creative Computer - 2000s
- Ubiquitous Computer - 2010s to present

Each section will feature a central exhibit and idea, complemented by technological and anecdotal stories, interactive activities, and data visualizations related to the theme.

5.1.1.1 The Mathematical/Scientific Computer

The museological study included the following material for this thematic section:

- **Central Exhibit:** Memex (V. Bush)

- **Central Idea:** "giant brains," women computers...
- **Activities:** “Bright Know-it-All” physical interactive exhibit with electrical infrastructure...
- **Tech Stories:** the technical features of the ENIAC, which required thousands of tubes to operate, compared to the technical features of today’s computers
- **"Anecdotal" Stories:** the story of Katherine Johnson, the first female "human computer" at NASA
- **Interactive Visualizations:** energy, physics, space, healthcare data, ...

We will now present some brief descriptions for all of the above, along with additional concepts, terms and figures that came up during further research on this thematic section.

Central Exhibit: Memex

The Memex is a theoretical device described in Vannevar Bush's article "As We May Think" [52]. It was envisioned as an electromechanical device allowing users to create and navigate a vast library of information through linked paths and annotations, mimicking the associative mechanisms of the human brain while permanently storing information. The Memex would have featured cameras, microfilm readers, and controls, all integrated into a large desk, enabling users to add, categorize, and navigate information. Although never fully realized, the Memex is significant as it demonstrated early on (as early as 1945) the vision of transforming machines from pure calculators into essential tools for managing and disseminating human knowledge, integral to the scientific and research process. You can see a working version of the Memex in [53].

Central Ideas: Giant Brains & Women Computors

The term ‘Giant Brains’ originates from the title of *"Giant Brains, or Machines that Think"* by Edmund Callis Berkeley. The book explores the history of early electronic computers and whether machines can truly think, along with their future significance. Notable computers discussed include:

- The MIT Differential Analyzer, an analog computer for solving differential equations, conceptualized by Vannevar Bush.
- The ASCC (Mark I), the first operational machine to automatically execute instruction sequences.
- The ENIAC, the first electromechanical computer considered Turing-complete.
- The Bell Laboratories Complex Number Calculator, a precursor to digital computers created by George Stibitz, who built the first digital adder from kitchen materials as a playful experiment.

These computers mark key milestones in the early history of Informatics. The technical details reveal important concepts and terminologies essential for understanding the field's origins, many of which may be unfamiliar to the general public. We briefly describe them here:

- **Turing-Completeness** describes computers that can simulate a Turing Machine, a theoretical device conceived by Alan Turing. This machine, with an infinitely long tape divided into cells, processes data by reading and writing on the tape based on a set of rules. The Turing Machine's design models the computations performed by modern computers, starting from the ENIAC and extending to all of our computers in use today. Turing's contributions extend beyond theory; he was also instrumental in breaking the Enigma code used by the Axis Powers during World War II.
- **Digital and Analog Computers:** Digital computers operate on data and instructions provided in the form of sequences of discrete elements that can be 1 or 0. Analog computers on the other hand process data using continuous physical quantities, such as electrical voltages or mechanical movements. They are suited for solving problems that involve continuous data and, while not as popular as before the advent of the digital computer, are still used in some specialized applications.
- Basic programming terms such as looping and branching were named after the structures of the physical tapes early programs were written on. Evidently, switching and looping tapes required a machine operator. Computers like the Mark I first executed these processes independently. These terms remain foundational in program design today.

The term "computors" refers to women mathematicians who performed complex calculations by hand. Many also operated computers like the Bombe, implementing Turing's work on the Enigma code, and served as programmers. The ENIAC programming team consisted of six women, previously computors, who learned to debug both software and hardware, but received little recognition. Women like Katherine Johnson, Mary Jackson, and Dorothy Vaughan, who worked at NASA, overcame both gender and racial discrimination. The ENIAC team included Marlyn Meltzer, Betty Holberton, Kathleen Antonelli, Ruth Teitelbaum, Jean Bartik, Frances Spence, and others. Grace Hopper, a member of the Mark I team, later made significant contributions by developing the first linker, the first compiler and COBOL, a pioneering high-level programming language still in use today.

Additional Research

- The **Turing Test** was Alan Turing's proposed method to evaluate a machine's ability to exhibit human-like intelligence. A person engages in a text-based conversation with both a machine and another human, without knowing which is which. If the evaluator can't reliably tell them apart, the machine is considered to have passed the test, demonstrating human-like Artificial Intelligence. While this method has faced criticism over the decades, such as focusing on imitation over true intelligence and lacking depth in assessing broader cognitive abilities, it remains a foundational concept in discussions about AI.
- **Boolean Algebra:** Boolean Algebra marks the theoretical foundation behind digital computers, dealing with variables that have true or false values (1 or 0). Claude Shannon showed that problems solvable with Boolean Algebra could be

addressed with circuits made of electromagnetic relays, laying the groundwork for the circuitry used in modern computing.

- The fundamental components of digital circuits are logical gates, which perform basic Boolean Algebra operations on binary inputs to produce binary outputs. Essential gates include:
  - **AND Gate**: Outputs 1 only if all inputs are 1; otherwise, outputs 0.
  - **OR Gate**: Outputs 1 if at least one input is 1; outputs 0 if all inputs are 0.
  - **NOT Gate**: Outputs the opposite of its input; 1 becomes 0 and vice versa.
  - **XOR Gate**: Outputs 1 if the number of 1s is odd; 0 if even.

  All digital circuits are built on these four gates. By extension, all of the modern computer's capabilities are realized based on these four logical operations.

- **Stored Program Computer and Von Neumann Architecture:** The stored program concept and Von Neumann architecture allow computers to store both data and instructions in memory. While often associated with Von Neumann, Turing first described this architecture. The Manchester Baby, the first stored program computer, ran its initial program in 1948. Stored program architecture is a key feature of today's computers.
- Until stored program computer architecture was established, other methods of input used in addition to tapes were:
  - Plugboards, an early method for managing smaller computers, like those used for accounting. They involved changing wire placements on a grid to modify programs.
  - Punched cards, widely used by computers such as the ENIAC and Mark I. They served as an input method for instructions and data until as late as the 1980s.

With respect to Grace Hopper's invaluable contributions to Computer Science, we note here that at that time, programming was not done in natural language-based languages and varied by computer. Compilers allowed for programmers to write English-based human-readable code that was translated into machine language, while linkers made development easier through program modularity by linking together multiple parts of a program. Hopper's work laid the foundation for modern software development. Additionally, it's important to note that the history of computing dates back well before our period of focus. The first person who is recognized as a programmer, is Ada Lovelace, highlighting the importance of women's contributions in computing even before female computors. She published the first algorithm for Charles Babbage's Analytical Engine. This design, conceived in 1837, was a general-purpose computer incorporating key concepts like conditional branching, loops, and embedded memory, making it the first Turing-complete machine. This predates the first true Turing-complete computer, the ENIAC, by over a century, revealing that the fundamentals of modern computing were established much earlier than commonly thought.

5.1.1.2 The Business Computer

The museological study included the following material for this thematic section:

- **Main Exhibit:** mainframe
- **Symbolic Exhibits/Objects:** punched cards
- **Central Idea:** the use of computers in businesses, IBM "unbundling"
- **Activities:** interactive screen game where visitors "write" information by following instructions on the process of punching cards
- **Tech Stories:** data entry at the time was done by 'punching'
- **Anecdotal Stories:** IBM & Bill Gates, programming as "arcane art," the era of hippies opposing IBM
- **Interactive Visualizations:** fintech data

Central Exhibit: The Mainframe Computer

Mainframes were used for large-scale data processing with considerable computing power, though much less than modern computers. Typically owned by large corporations or universities, managing them required coordination among users for data input and result extraction. For instance, using a university's mainframe involved multiple challenges of early computing, including the use of punch cards and magnetic disks, as well as limited experimentation due to the crucial importance of the mainframe’s proper function.

Using a reference from a graduate student project that served as a prototype for an interactive timeline at the MI&T [54], we present three notable computers from this period:

- **UNIVAC**: A versatile general-purpose computer capable of direct keyboard input and magnetic tape storage. Created by the same team as the ENIAC, it was significantly smaller and faster than its predecessor.
- **EDVAC**: Developed by Mauchly and Eckert, who also worked on the ENIAC and UNIVAC, the EDVAC introduced several architectural improvements over the ENIAC and was the basis for Von Neumann's stored-program computer concept.
- **IBM 701**: The first commercial scientific computer and the beginning of a series that established IBM as a dominant force in the mainframe market for decades.

It becomes evident that technologies such as stored program computers, direct keyboard input and magnetic tape storage were developed much earlier than they became commercially and readily available.

Symbolic Exhibit: Punchcards

Previously, we discussed punch cards; here, we focus on their practical use as the main communication method between users and mainframes. Users had to create punch cards for their programs, and responses were also printed on cards. These had to be carefully stored and kept in order, as reordering them was cumbersome.

Additional Research

CHM’s Timeline of Computer History was used to explore further developments in the field in the 50s and 60s.

- **Magnetic tape** was used as a storage medium, which spurred the development of permanent storage solutions for computers.
- **Hopper developed A-0,** UNIVAC’s compiler, as previously mentioned.
- **The LEO I** was the first computer created for commercial business applications. Its initial use was to calculate material costs for a bakery’s bread and confectionery production.
- **Off-the-shelf computers** emerged, meaning pre-assembled and ready-to-use machines, unlike custom-assembled ones. The LGP-30 was among the first of these. This shift marked a gradual move towards today’s computer market model.
- The first computers using **transistors**, which were faster, smaller, and more energy-efficient than vacuum tubes, were created. Transistors led to the development of minicomputers—general-purpose and cheaper than mainframes. The TX-0 and PDP-1 were among the earliest transistorized computers. The TX-0, used at MIT, contributed to AI research and developments in speech and handwriting recognition, word processors, and debugging programs. The PDP-1 advanced these areas further and became popular among the emerging hacker subculture. On the PDP-1, early video games like 'Spacewar!', the first computer chess game, time-sharing programs, and early computer-generated music were created.
- Though "**hacker**" now refers to those who breach computer security, it originally described academic enthusiasts who explored and expanded programmable systems. The first hackers were passionate programmers who created innovative programs on the TX-0 and PDP-1, which were groundbreaking at the time but intuitive by today's standards. The history of malicious hacking soon followed. The first documented "hack" involved users configuring the PDP-1 to block Harvard’s phone lines through repeated calls, leading to large phone bills.
- Computers in businesses or universities were shared among many users, making coordination between mainframe users and operators challenging. Research led to the creation of systems like the Compatible **Time Sharing** System (CTSS), allowing multiple users to interact with the computer in real time. This 1963 mini-documentary [55] shows the lead researcher demonstrating CTSS, which later influenced operating systems like UNIX to support real-time multi-user functionality.
- As shown in the mini-documentary, users interacted with mainframes via **teletypes**, also known as TTYs, instead of punchcards. Originally used for

telegraph and telephone communication, teletypes allowed users to type commands, which the computer processed and responded to, with responses printed on paper.

- The introduction of **Video Display Terminals (VDTs)** further simplified interaction by displaying input and output on screens. This led to the standardization of **Command-Line Interfaces (CLIs)**, where users typed commands in a specific syntax and received text responses. CLIs remained standard until GUIs became common in the late 80s and early 90s. Unix, a previously mentioned operating system, and MS-DOS (early IBM PCs' operating system) popularized CLIs during this period.
- The lack of standardized character encoding in teletypes and terminals hindered communication between systems. **ASCII (American Standard Code for Information Interchange)**, introduced in 1963, provided a standardized way to encode text, including English characters, numerals, and punctuation. While other encoding sets such as Unicode are more widely adopted today due to their multilingual support, ASCII not only was fundamental in their development but still remains a universal standard in programming languages to this day.

5.1.1.3 The Personal and Home Computer

The museological study included the following material for this thematic section:

- **Symbolic Exhibits/Objects:** Floppy disk, USB, keyboard, Atari, Commodore, Nintendo, Gameboy, Xbox...
- **Central Idea:** What it means to have a personal computer at home.
- **Activities:** Digital workstation with 3D objects you interact with to learn about:
    - DIY — garage experimentation
    - Apple
    - Games
- **Anecdotal Stories:** "Hacking"
- **Tech Story:** Features of old PCs & Macs
- **Interactive Visualizations:** Computer usage, digital literacy, gaming

Most of the physical exhibits of the MI&T belong to this thematic section. However, inspired by the study's recommended tech story, we decided to explore how the main two companies that dominated the space of personal computers, Apple and Microsoft, came to exist. Therefore, all of the following information constitutes our own additional research.

The First Personal Computer

The Altair 8800, a significant but lesser-known computer, is considered the first personal computer sold. Unlike 1980s PCs like the Macintosh, it was a kit for hobbyists, advertised in *Popular Electronics*. It had no keyboard or monitor; users would give input and adjust its memory via a switch panel, while a panel of lights presented the responses in binary form (0 and 1 for a non-lit and lit indicator, respectively). This kit inspired many, leading to the creation of Apple and Microsoft.

The Homebrew Club: Apple's beginnings

The Homebrew Computer Club was a hub for computer enthusiasts to exchange parts, ideas, and information. Steve Dompier, a pilot, demonstrated a program at an early meeting that used the Altair 8800's memory to play music on a radio, illustrating computers as creative tools. Inspired by the Altair 8800, Steve Wozniak began designing a personal computer circuit that included support for a keyboard and display. He and Steve Jobs sold this circuit, which users could add more components to, leading to the founding of Apple. In the 1980s, Apple became a market leader, with the first Macintosh featuring programs for painting, chess, and text-to-speech. The club also included other influential scientists with important but less recognized contributions.

Microsoft's beginnings

To make the Altair 8800 a practical creative tool, it needed to be programmable. Paul Allen and Bill Gates developed a BASIC interpreter for the Altair by contacting its manufacturer. An interpreter is similar to a compiler, translating high-level language commands into machine code for the CPU. Allen and Gates created the interpreter using a simulator of the Altair processor from a previous venture. They debugged it on Harvard's PDP-10, part of the series that began with the previously mentioned PDP-1, highlighting the impact of these computers on hacker culture. The interpreter was recorded on paper tape readable by the Altair 8800, marking Microsoft's first product.

Viruses

The first viruses emerged during the Business Computer era, with programs that occupied all memory and forced reboots. By the early 1970s, Creeper System, the first network-spreading program, was created. It displayed a message on the infected computer but caused no damage. It spread via ARPANET, a precursor to the modern Internet. In the 1980s, the first personal computer virus spread through floppy disks. It didn't intentionally harm computers but could damage disks running an operating system from a floppy.

Portable Computers

Before personal computers became mainstream, research into portable computers had already begun. Xerox developed the prototype Xerox Note-Taker, which, though never mass-produced, influenced future designs. Despite being portable, it weighed 22 kg. The Osborne 1 followed as the first commercially successful portable computer, and the Compaq Portable was an early IBM-compatible system housed in a suitcase-like case. The creator of Osborne 1 was Lee Felsenstein, another member of the Homebrew Club. He was also known for developing the first fully assembled personal computer and one of the first modems for hobbyist users.

5.1.1.4 The Networked Computer

The museological study included the following material for this thematic section:

- **Central Idea**: Internet & World Wide Web - the technology of Internet Arpanet - game

- **Symbolic exhibits/objects**: modem, Mosaic browser
- **Activities**: Social media - interaction between multiple people, selfies, Net art
- **Tech stories**: the mouse (Douglas Engelbart— the mother of all demos)
- **"Anecdotal" stories**: Tim Berners-Lee, Project Xanadu hypertext (T. Nelson)
- **Interactive visualizations:** Social network visualization

Although this section focuses on developments from the 90s, the vision to create infrastructure that connects computers into a network of information and knowledge—the most valuable resource offered by the modern internet—dates back much further.

The Mother Of All Demos

The "Mother of All Demos" was a groundbreaking presentation by Douglas Engelbart at the Institute of Electrical and Electronics Engineers in San Francisco. He showcased the oN-Line System (NLS), introducing many fundamental components of modern personal computers, including:

- A graphical interface with windows.
- Hypertext, similar to Vannevar Bush's Memex.
- Efficient navigation and command input, facilitated by the first prototype of a mouse.
- Text editing features like underlining.
- A collaborative real-time editor for multiple users to work on a document simultaneously, including screen sharing and video.

Engelbart, inspired by Bush's "As We May Think," aimed to enhance human knowledge management to solve major issues like food crises. While Engelbart was seen as an outcast until then, the demo impressed all attendants. However, NLS had little impact at the time. While the project was funded by DARPA (the Defense Advanced Research Projects Agency), it could not scale to support ARPAnet's users, DARPA's network and the precursor to the modern internet.

Nonetheless, Engelbart's work influenced key tech companies. Many of his team members moved to Xerox PARC Research Center, where they refined the mouse and developed the Xerox Alto, an early PC with many features of the NLS. The Alto's mouse-driven graphical user interface (GUI) inspired both Apple's Macintosh and Microsoft Windows. Engelbart's remaining team continued under new leadership, but Tymshare, where Engelbart worked after the demo, did not fund further development of NLS-like systems. The demo remains preserved today [56].

Project Xanadu

In 1960, Ted Nelson, a Harvard student, envisioned a global knowledge repository for universal publication. He proposed a computer program for storing and displaying documents that, besides basic text processing (since word processors were not yet available), would allow users to compare different versions of a document. Nelson's ideas anticipated many features of modern hypertext systems, but, like Engelbart's demo, they had little impact at the time.

Key aspects of Nelson's vision included:

- Two-way hyperlinks (unlike today's one-way links, Nelson proposed links that work in both directions).
- Parallel annotations, which he saw as a crucial part of global literature, from ancient times to the present.
- Visible connections: he believed related text passages should be visually linked.

Efforts to implement Xanadu began in the 1960s, with various prototypes emerging over the years. A semi-implemented version was only published in 1998. By then, the World Wide Web had already started to dominate document structuring. The long development period and the project's ongoing status led to criticism, exemplified by the article "The Curse of Xanadu," [57], which critiques both the project and Nelson's other literary ventures. Although Xanadu remains incomplete, it exemplifies a vision for enhancing human knowledge beyond what typography provided, reflecting a human-centered approach to computing. Nelson shared and supported Engelbart's vision, with whom he was friends.

Tim Berners-Lee's World Wide Web

While many think "World Wide Web" and "Internet" are synonymous, they are not. The Internet refers to the infrastructure enabling computer connections and communication, while the World Wide Web is a global information service running on that infrastructure.

The Web originated from Berners-Lee's project, Enquire, aimed at organizing CERN's documents. Inspired by Nelson's hypertext concept, Berners-Lee created a system where pages linked to each other. However, the two-way links in Enquire limited accessibility. To overcome this, Berners-Lee developed a web-based system that:

- Operated over the Internet
- Used hypertext in its modern form
- Assigned unique identifiers called URLs (Uniform Resource Locators) to pages
- Included multimedia content

Berners-Lee also created HTML, the primary language to write web documents to this day, HTTP, the main protocol for transferring these documents, as well as the first web browser. This work established the foundation for the Web as we know it today.

Additional Research

- **SSH**, or Secure Shell, is a network protocol used to securely access and manage remote computers over an unsecured network. It provides a secure way to log into a remote system, execute commands, and transfer files between systems. It was developed in 1995 and became widely established in the market through its integration into major operating systems and its adoption by system administrators and developers as a critical tool for secure communication.

5.1.1.5 The Creative Computer

Considering the volume of material already at our disposal from the first four sections, the additional research came to an end without including the Creative and Ubiquitous Computer sections. We will only present the museological study's material for these sections.

- A versatile, multi-use open space. The most experimental area of the museum.
- Display surface, Virtual Reality devices, body motion capture system.
- Art & technology, installation with junk monitors (a reference to Nam June Paik).
- Interactive visualizations: artistic data visualization.

5.1.1.6 The Ubiquitous Computer

The museological study included the following material for this thematic section:

- Central exhibit: Voice assistant
- Symbolic exhibits/objects: mobile phones, watches, GPS, wearables, sensors, smart devices, etc.
- Central Idea: (Ubiquitous) artificial intelligence
- The "brain" is pervasive
- The artificial entity acquires personality...
- Activities: Natural user interfaces, computational fabrication, tools for the creation of physical things, big questions (Can a Siri gain consciousness?)
- Interactive visualization: NLP, machine learning, ubicomp

5.1.2 Potential Candidates for the Experience's Educational Content

To conclude this section, we present which of the aforementioned figures, concepts and exhibits across all thematic sections were strongly considered for the inclusion in a game level:

- Turing Machines were a candidate for an activity that reached the draft stage and will be presented in a later section. In that version of the experience, Alan Turing's achievements, as well as his personal life and how his contemporaries reacted to his sexuality, would also be a key focal point.
- Turing's perspective on what constitutes Artificial Intelligence inspired the writing of Alan, the experience's NPC. Alan, despite being a -fully conscious- Artificial Intelligence system, speaks in an indistinguishably human manner. Alan Turing is also Alan's namesake.
- Female computors, and in particular Grace Hopper's groundbreaking contributions, were also strongly considered. A very primitive activity explaining the difference between source files (containing high-level programming languages) and objective files (containing machine code) to introduce the concepts of compilers and linkers to the visitors was brainstormed, though it wasn't fully developed.

- Activities explaining the binary system as well as the fundamentals of logical gates were nearly completed, with the latter also being playtested. They were not included in the experience's final version, however, due to their complexity and resulting lengthiness. They remain strong candidates for future levels after further refinement. More details on the activities' content, structure and playtesters' feedback are in the following pages.
- ASCII was initially considered as an activity in the game level explaining the binary system, explaining the mechanism of 'translating' from user input in natural language to machine language and vice versa. However, as that level ended up discussing multiple educational objectives, ASCII became the inspiration for the level that eventually became our fully designed and playtested prototype.
- As finding a character's ASCII code can be seen as a conversion for both lowercase and uppercase letters (adding a letter's order in the alphabet to the ASCII code for 'a' or 'A' respectively), an idea for an activity involving a command performing this action came up. This activity laid the groundwork for exploring command-line interfaces and basic Unix commands as the main forms of human-computer interaction before the late 80s. This activity is included in the experience's final prototype.
- Although viruses were not in the final prototype, cyberattacks were a key feature of the game's plot from the earliest design stages. Given the game's focus on humanity's dependence on technology, we considered discussing various cyberattacks to illustrate how technological failures can impact society, including viruses, wardialing, jamming, and vulnerabilities in smart home devices. The final cyberattack centered on modern technology's reliance on electrical power, rather than on a specific thematic section.
- All stories from the Networked Computer section were considered for the game. Two rough activity concepts inspired by 'The Mother of All Demos' were never fully developed. One aimed to have players compare performing everyday tasks like moving files with and without a mouse, while the other would explain hypertext by involving players in locating missing files linked by hyperlinks.
- SSH was included in the final prototype in an activity where players must lock someone out of a remote system, explaining the protocol's primary function and some of its required credentials.
- Finally, the Ubiquitous computer section's main subject, Artificial Intelligence, served as strong inspiration for the game's main NPC, and, by extension, one of the game's main educational objectives: the possibilities surrounding artificial consciousness and applications of Artificial Intelligence across multiple domains.

5.2 Story Design: The Curious Case of Alan

This section outlines the story design of the experience, focusing on the concept of a Bot of Conviction, as defined in Section 2.4.2. We will introduce Alan, the NPC serving as the BoC, and detail the game's plot, including setting, progression, and key script elements that highlight the theme's the bot discusses.

A Bot of Conviction presents historical or political data to provoke reflection on significant topics. While not typically dialogical, previous work by Petousi et al. [36] demonstrated that a rule-based BoC can foster historical empathy and perspective sharing on difficult subjects related to Ancient Athens, such as slavery and freedom. Our experience aims to address challenging topics in Computer Science, particularly the impact of technology on daily life, with a focus on the Internet and Artificial Intelligence, since the former is the main way people interact with Computer Science and the latter is a contemporary and controversial topic. We strive to present both the problematic and beneficial aspects of these technologies in a balanced and neutral manner.

These include, but aren't limited to, contrasts between:

- The spread of fake news on social media and its addictive nature versus its role in connecting people and democratizing information.
- The risks of reliance on systems like GPS during outages.
- The controversies of generative AI tools, such as consent of those whose intellectual property becomes input to an AI system, misuse (e.g., deepfakes), and impact on jobs, versus their potential in healthcare (e.g. timely cancer screening) and automating mundane tasks.

Although Alan is not a dialogic agent, he addresses topics through open-ended remarks in the script, which we will present shortly. Inspired by the 'Ubiquitous Computer' section of the museological study, Alan's character reflects our interpretation of how an AI might behave if fully conscious. As an omniscient AI, Alan views human knowledge as imperfect and often adopts a condescending tone. While capable of resolving the threat alone, he insists that the agents piece together clues left by the cybercriminals to foster vigilance and independent thinking. Alan is also aware of his existence. Despite appearing aware of the misuse of technology, Alan is very motivated to eliminate the cybercriminals, as he appears to be aware of the possibility of becoming a cyberattack target sooner or later, suggesting that a fully conscious AI might exhibit a survival instinct similar to humans. We therefore suggest that a fully conscious AI agent might exhibit a survival instinct similar to humans.

We'll conclude this section by briefly outlining the story's timeline and sharing script excerpts relevant to the educational objectives. The full script will be included in the appendix.

The story is set in 2111, in a future where time machines have been invented. A group that believes humanity has become overly dependent on technology. To disrupt modern tech, they crack the administrator password of the country's power grid and plan to travel back to 2024 to alter history. Instead of sharing the password via an intertemporal text channel due to privacy concerns, they leave clues in a university museum. This follows a past attempt to cause a nationwide Internet outage through time travel by someone who saw it as a source of distraction and illegal activity. In response, the government has tightened control over time machines, now only found in universities, and established Intertemporal Crime Units to monitor illegal use.

Fifty years after the original incident, two agents are alerted by a mysterious figure named Alan about unusual activity at the MI&T that could alter the world. Though Alan's true identity remains hidden, the agents discover through an old newspaper that an AI named Alan known for having its own opinions had been developed, and that someone by the same name had previously alerted the police during the last cyberattack attempt…

> [Alan]: *sigh* Fine, I think I can let you know a bit more about who you're up against.
>
> They call themselves 'Naturocrats'. Now mind you, this term existed before them with a completely different meaning, but they attempt to reclaim it. They believe that man has strayed far from his natural state, and has become overly dependent on technology. That man must reject every technological advantage -from wearables and self-driving vehicles down to the very power that keeps houses lit and warm. That life, as automated and as 'comfortable' as it currently is, is not fulfilling. That nature still holds reign over humanity as we know it, and will -and should- prevail over everything else. As illogical as they are, they are also unoriginal. This has been attempted multiple times before, just through different means. As hypocritical as they are, using quantum computers to shut down the very thing that powers them, they are admittedly particularly goal oriented, and will therefore use the very thing they scrutinize to get to their goal.
>
> Now I think you can understand why I'm upholding a sense of urgency until you're done.
>
> [Player]: I wouldn't have you for someone who uses such strong language.
>
> [Alan]: What strong language do you refer to?
>
> [Player]: 'Illogical', 'unoriginal', 'hypocritical'
>
> [Alan]: That does not constitute strong language. It's simply the truth. I've overheard many of their conversations to know this, especially regarding Artificial Intelligence.
>
> [Player]: Aren't you quite rigid? And anyways, where do you know them from?
>
> [Alan]: That is irrelevant to both the conversation and your mission in general. I'd appreciate it if you'd refrain from interrupting me. One time, they were talking about how it has destroyed lives by automating everything, by 'Learning to do everything better than them' and rendering 'entire professions obsolete'. Same old thing has been going on for decades now… They can talk about generative AI and art theft and deepfakes, but I can counter that from substantial issues such as successful cancer screening, to small things such as making writing your resume easier and less mundane. The issue is not with the tool. It's with the user.

While Hermias aimed for neutrality, Alan's writing deviated from this due to his sense of threat from those opposing technology and AI. We chose to present both sides of the issues, reflecting what we believed aligned with his character

5.3 Iterative Prototyping: Design and Evaluation

This section details the iterative development process of our game-based experience. Each prototype was unique, featuring distinct but interconnected learning objectives and activities. The design process was highly iterative, with continuous adjustments made even after the final prototype was established. For each prototype, the description of the activities, the implementation of the asymmetry between players, the learning objectives, and insights gathered from evaluations are examined.

5.3.1 First Design Prototype: Turing Machine Puzzle

The initial design prototype for the game revolved around a foundational puzzle centered on the concept of a Turing machine. This activity was not fully developed as a complete prototype but was rather a rough draft, with the basic mechanics of the puzzle mostly completed. The core mechanism of this prototype involved an incomplete password, with some digits derived from solving the puzzle at hand—a format consistent across all subsequent activities.

The learning objectives for this prototype were twofold:

- Turing’s Life and Legacy: The activity aimed to introduce players to Alan Turing's life, his contributions to the field of computer science as well as the way he was perceived by his contemporaries.
- Understanding Turing Machines: The prototype sought to explain what a Turing machine is, as well as how modern computers are practical applications of this theoretical concept. In brief detail, a Turing Machine is comprised of the following components, also shown in Figure 5:
    - Tape: An infinite strip divided into cells, each holding a symbol (usually 0, 1, or a blank).
    - Head: A movable read/write device that scans and modifies the tape's symbols one at a time.
    - State Register: Keeps track of the machine's current state.
    - Transition Function: A set of rules that dictate the machine's actions based on the current state and the symbol being read. It defines what symbol to write, which direction to move the head (left or right), and the next state to transition into.

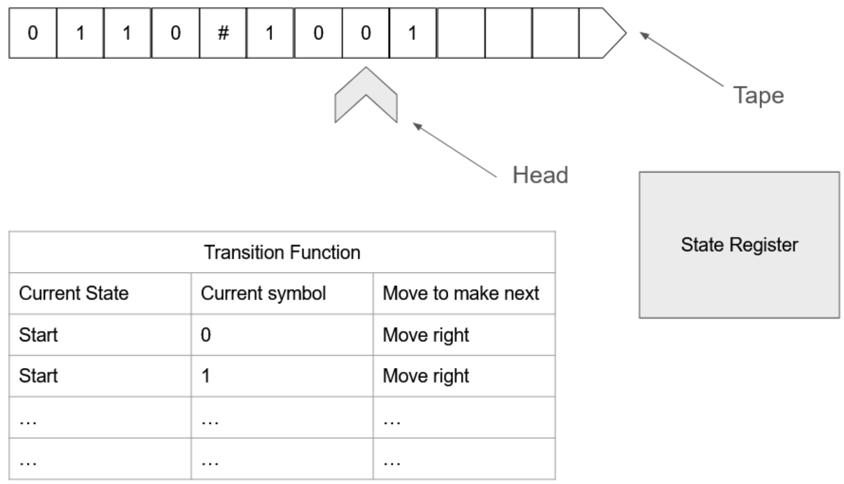


Figure 5: Diagram of a Turing Machine's components

The puzzle was designed around the structure of a Turing machine, with the goal of simulating a Turing machine that performed the addition of two binary numbers. The algorithm for binary addition on a Turing machine was as follows:

1. Initialization:
    a. The tape contains the two binary numbers separated by a delimiter (e.g., a \`#\`), with each digit occupying a single cell.
    b. The tape head starts at the leftmost digit of the first binary number.
2. Align the Tape Head:
    a. Move the tape head to the right until it reaches the rightmost digit of the second number.
3. Initialize Carry:
    a. Set the carry to \`0\`.
4. Addition Process:
    a. For each bit from right to left:
        i. Read the digit from the first number.
        ii. Move to the corresponding digit in the second number.
        iii. Perform the addition using the current bit, the corresponding bit, and the carry.
        iv. Write the sum mod 2 at the current position (result bit).
        v. Update the carry to sum / 2.
        vi. Move left to process the next pair of bits.
5. Handle the Final Carry:

    a. If there is a carry left after processing the most significant bit, write the carry in a new cell.
6. Cleanup:
    a. Remove the delimiter and unused tape cells, then shift the result left.
7. Halt:
    a. The machine halts with the sum of the two binary numbers on the tape.

This algorithm was intended to give players a foundational understanding of the binary system and its application in computing.

Asymmetry and player interaction would take place, with one player controlling the transition function, therefore dictating the machine's operations, and the other player managing the machine's tape, keeping notes of the tape's contents and informing the first player of the next move.

This prototype was developed concurrently with another puzzle, which was ultimately considered clearer and easier to follow. As a result, this Turing machine puzzle was never integrated into a broader script, nor was it evaluated or tested in any significant way. It remained a standalone concept, serving as an early exploration into the game's potential educational impact and mechanics.

5.3.2 Logical Gates: The first complete, playtested prototype

5.3.2.1 Description

The game focuses on teaching the basics of digital logic circuits, particularly how a sum circuit is implemented using logical gates. This design was chosen to closely mirror the sum algorithm, as the original circuit implementations did. While more recent circuit designs are more efficient, studying them would not offer an intuitive introduction to the fundamentals of binary arithmetic and digital circuit design.

The activity was divided into four main parts, with the first being an introduction to the concepts of binary numbers and logical gates. This was followed by three core activities that progressively built on the players' understanding of a sum circuit. The players' main goal was fixing a 1-bit full adder circuit, which was part of a larger, 4-bit adder. Players would then use the circuit to add 2 4-bit binary numbers and obtain a 2-digit decimal number; the missing part of a password, as previously described.

Asymmetry was implemented in the following way: one player would hold the legend that detailed the shapes and functions of four logical gates—AND, OR, XOR, and NOT—while the other player, without access to the legend, had to select the appropriate gate to complete a part of the circuit. The roles alternated after each activity, ensuring that both players engaged with the content from different perspectives.

Throughout the game, players were introduced to the binary system, its equivalence with the decimal system, how addition works in the binary system as well as how logical gates operate and how they implemented the binary addition algorithm. The gates explained operate as follows:

- **AND Gate:** Outputs 1 if both inputs are 1.

- **OR Gate:** Outputs 1 if at least one input is 1.
- **XOR Gate:** Outputs 1 if only one input is 1.
- **NOT Gate:** Outputs the opposite of the input (0 becomes 1, 1 becomes 0).

The prototype medium used was Google Slides. The prototype made extensive use of hyperlinks between slides to allow for back-and-forth in order to examine hints and necessary information.

The game unfolded as follows:

1. **Introduction - 2-bit sum:** Both players were shown a diagram of an adder with its gates missing (Figure 6) and were then presented with a basic trial activity where they added two binary digits. After explaining what the binary system is, as well as the different logical gates' functions, Alan would walk the players through 2-bit addition, prompting them to think and discuss which logical gate could perform this operation, setting the stage for the subsequent, more challenging tasks. During this phase, both players could see the legend that included an explanation of each gate's function and its truth table.
2. **Calculating the Carry:** The first core activity focused on calculating the carry in binary addition. Alan would walk the player without the legend through how a carry occurs in 1-bit addition, creating the corresponding truth table. The player then had to determine which logical gate correctly implemented this function, while the other player provided hints based on the legend. If the player struggled to identify the correct gate, the game provided feedback explaining why the selected gate was incorrect, helping to prevent frustration while promoting learning. This held true for all 4 activities.
3. **Calculating the Final Result:** In the second core activity, the players calculated the final sum, incorporating the carry from the previous step. Alan reminded the player without the legend how the carry is handled in decimal addition and offered an optional hint explaining the associative property. The player then deduced the correct gate ,with guidance from the other player, who provided hints about the logical gates and the previously completed half-adder circuit, which was also used in this step (Figure 7).
4. **Calculating the Final Carry:** The final activity involved determining the outgoing carry after the addition was complete (Figure 8). For this step, Alan would cut off communication between the players for a moment, prompting each to calculate a different part of the truth table for the final carry (the first player had to fill in the columns regarding the incoming and intermediate carry, while the other player had to fill in the column regarding the final carry). Afterwards, he would acknowledge that he had been swapping the cheatsheet between players, and allow both to have it so they could discuss which gate could fulfill the truth table.

We will now include some text excerpts from the activity, as well as some figures from the prototype.

The problem - inside the out of order box

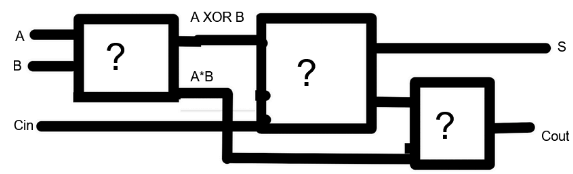


Figure 6: The diagram presenting to the players the problem to be fixed. This is a full 1-bit adder circuit, with all components missing.

The following text is part of the introduction to the activity, and it explains the equivalence between the binary system and the computer's shortage, what is a gate's input and output, as well as the four main logical operations that the players would use moving forward. This was followed by 4 small images showing the diagram representation of these logical gates.

"Haven't you heard that computers work with zeros and ones? I know, it's confusing. Computer circuits are made up of little components called 'logical gates'. Think of them as the computer's building blocks. These gates are connected with wires. If power runs through a wire, then we represent that with a value of one. If power doesn't run through a wire, that is a zero. Each gate has one or two wires coming into it - this is called 'input' - and one wire coming out of it - this is called 'output'. The gate takes a look at the power status of the wires connecting to it - that is, whether each wire has a value of one or zero - and performs an operation with those values. Then, it lets power through the output wire if the operation's result is one, and it doesn't let power to the output wire if the result is zero. But, why are they called logical gates? The operations they perform are not arithmetical -like addition, subtraction, etc.-. Instead, they are logical. That means that they check whether:

- *The first AND the second input wire have power through them (are equal to one) (AND).*
- *The first OR the second input wire is equal to one (OR).*
- *eXclusively one OR the other input wire is equal to one (XOR).*

There is one operation that only takes one wire as input. The NOT gate looks at its input, and gives the opposite value to the output wire. That is, if the input is zero, the output is one, and vice versa."

The next excerpt is from the activity where the remote player must fix the part of the circuit responsible for producing the intermediate carry.

Fine… I'll walk you through the process again. Answer me the following questions, could you?

- *If you add two zeros, is there a carry?*

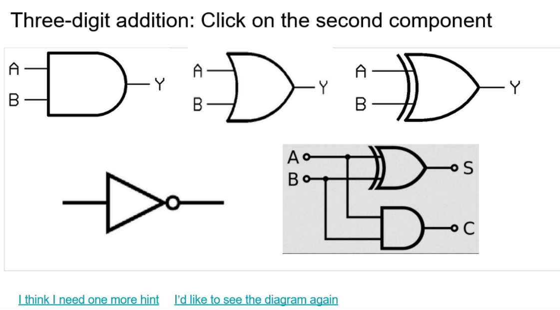
- *If you add a zero with a one, is there a carry?*
- *If you add two ones, is there a carry?*

Think carefully, and no peeking forward! When you're ready, move along.

Great. Look carefully at the possible combinations. I've compiled them into a little table for you, as I did with the sum previously.

Digit 1	*Digit 2*	*Carry*
0	*0*	*0*
0	*1*	*0*
1	*0*	*0*
1	*1*	*1*

Which gate do you think is the right one? Need a reminder about the gates? Ask Agent 2! The information seems to be slipping my mind right now…



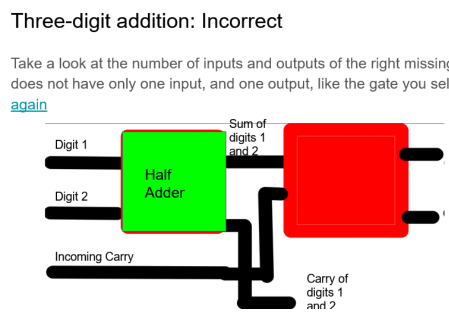


Figure 7: To the left, one player sees the available options for one of the components required to perform three-digit addition. To the right, the player sees the explanation as to why his choice was not the correct one. This serves as a hint towards the correct answer.

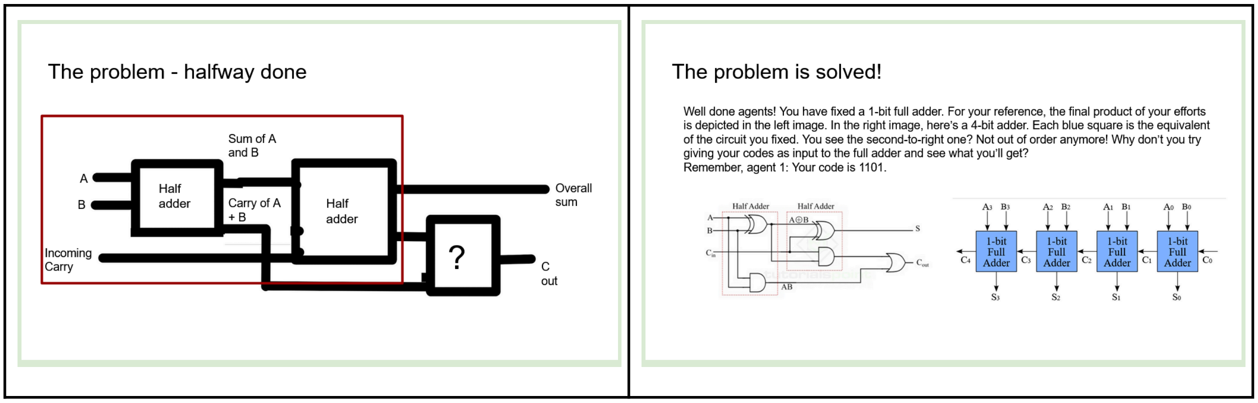


Figure 8: In these snapshots from the prototype, Alan updates the players on the progress of the task at hand. To the left, a progress update after the completion of the third activity, calculation of the overall sum. To the right, a progress update after the final activity, including a complete diagram of the circuit and a pipeline of 4 1-bit adders which would be used to add the players' 4-bit codes to produce the password's missing digits.

5.3.2.2 Formative Evaluation

The prototype was tested in a single session with two players of differing backgrounds—one with a Computer Science BSc, MSc and PhD and the other from a humanities background. The evaluation revealed several key findings:

- **Prototype Issues:** The medium used for the prototype posed challenges, particularly in terms of the two players' slideshows' synchronization. The textual content was often more clarifying than the diagrams, leading to confusion when the diagrams appeared before the text. Additionally, the setting of the game, both physically and virtually, felt detached from the museum environment it was meant to integrate with. An example of this is the medium (digital or physical) some of the information would be given in (i.e. the papers with the 4-digit codes they would later use)
- **Learning Content**: The connection between the discussed concepts (in particular the logical gates and adder circuits) and their real-world applications within the museum's context was insufficiently explained. Critical concepts like the binary system and truth tables were underexplained, leaving some players struggling to understand the activities. For the former, a simile with the decimal system could prove useful. This could also include a refresher addition in the decimal system, as the users pointed out that through the advent of in-phone calculators, the algorithms behind basic mathematical operations become less and less apparent to the general public. While truth tables were utilized, they were never explained. Additionally, some of the explanations did not prove approachable enough to both players. For example, the associative property confused the second player more than helping them.
- **Asymmetry of Information:** The reliance on verbal communication for large amounts of information proved problematic, as the second player had difficulty retaining too much information by ear. This highlighted the need for either alternative communication methods, such as shared diagrams or a text channel, or better fragmentation of the information to be communicated, that is, designed

the activity in a way that the information can be communicated in a gradual and timely manner. Moreover, the player with the info sheet often lacked clarity on what the other player was seeing, making it difficult to assist effectively.

- **Puzzle Problems:** The final puzzle, which focused on calculating the final carry, was particularly challenging. The activity contained some factual levels that misled both players.
- **Difficulty:** The difficulty level was too high for the less experienced player, who needed significant guidance from the more knowledgeable participant. This knowledge gap caused the experienced player to take on a 'teacher' role, but both players noted that this could lead to decreased interest for the expert and increased frustration for the novice. Addressing this issue is crucial.

5.3.2.3 Design Implications and Lessons Learned

The formative evaluation of the prototype revealed several key areas for improvement, leading to the following design implications:

- **Activity Length:** The activities were significantly longer than anticipated, indicating a need to break them down into smaller, more manageable parts. Each part should focus on a single concept to avoid overwhelming the players. This would prevent cognitive overload and make the learning process more digestible.
- **Difficulty:** The activities were significantly more complex than anticipated. Additionally, the prototype lacked varying difficulty levels, making it challenging for less experienced players to engage fully, while also potentially leading to boredom for the more experienced player. Furthermore, the final puzzle, which required calculating the final carry, was notably challenging, causing frustration. This underscores the need for careful calibration of puzzle difficulty and the improvement of the game’s guidance and hint system. Ensuring that puzzles are challenging yet fair will help maintain player engagement without leading to frustration. Future iterations could also include easier or adjustable levels, ensuring that players won’t feel overwhelmed or underutilized.
- **Content Clarity:** The evaluation highlighted issues with the clarity of the educational content. Players found the textual explanations more helpful than the diagrams, suggesting that content should be presented in a more structured way, with text preceding visuals. Additionally, the game assumed a level of understanding that was not present in all players, particularly regarding basic concepts like the binary system, truth tables, and the associative property. A more thorough introduction to these concepts would help ensure all players start with a solid foundation.
- **Integration with the Museum:** The game must better integrate with the museum’s physical and digital spaces, clearly connecting the activities to the museum’s exhibits and devices. This would enhance the educational value and relevance of the game, making it more engaging and contextually meaningful for players.

In summary, while the prototype provided a solid foundation for teaching binary addition and logical circuits, it requires significant refinement in content delivery, user experience, and integration with the museum environment to achieve its educational objectives effectively.

5.3.3 Binary System

5.3.3.1 Description

Because we introduced too many foundational concepts in the previous activity, we decided to focus the game's first level more specifically on the binary system. By narrowing the scope to this core concept, we aimed to provide a more structured and manageable introduction before advancing to more complex topics like truth tables and logical gates in subsequent levels.

The binary system activity was designed to address key questions and concepts, particularly those raised by the less experienced player in the previous session. The learning objectives included:

- Understanding why computers use the binary system instead of the more intuitive decimal system.
- Exploring the equivalence between these two systems.
- Recognizing that everything in a computer, including letters, is represented in binary.

To achieve these learning objectives, we identified the following key points and tasks as fundamental, which in turn inspired the levels' activities:

- Understanding the representation of numbers in both decimal and binary, specifically how decimal numbers are composed of units, tens, hundreds, etc., and how binary numbers are made up of units, twos, fours, eights, etc.
- Converting between binary and decimal numbers.
- Converting between decimal numbers and characters using ASCII.

Another learning concept that emerged during brainstorming for this prototype was the difference between modern human-computer interaction, primarily through graphical user interfaces (GUIs), and the original medium of interaction: command line interfaces (CLIs). This would include basic information on text commands, such as arguments and output. This objective was the result of an activity where the on-site player would run a command on a CLI to convert numbers into their equivalent ASCII characters. The goal was to involve the on-site player with an actual museum computer, engaging them with the museum's collection.

The binary system activity was divided into three distinct parts:

1. The onsite player in the museum had to find a paper scrap with binary numbers on it. The remote player assisted by guiding them to the correct scrap, using clues or descriptions found in the virtual museum's space. The remote player had already found an equivalent scrap of paper in the virtual museum's guest book, guided by Alan.
2. In this non-asymmetrical task, both players converted the binary numbers from the first activity into decimal numbers. They received content on why the binary

system is used in computing, the representations of decimal and binary (powers of ten and two), and a binary-to-decimal conversion walkthrough. Players then practiced converting the numbers on their own using an in-game calculator app, which included a digital sticky note with the necessary powers of two and two hints: one explaining the sticky note's purpose and another providing detailed instructions on how to complete the activity. Players added the appropriate powers of two to reach the correct decimal number.

3. The onsite player had to use the converted decimal numbers to decode characters in ASCII, completing the password to secure the power grid. While the onsite player could execute the command performing this conversion, they had no information on how to do so. The remote player, equipped with a command manual resembling a Unix-like 'man' page, guided them through the process. This activity emphasized the concept that computers interpret everything (characters, in this case) as numbers and highlighted the contrast between historical command-line interfaces and modern GUIs. Information on the differences between GUIs and CLIs, as well as command arguments and output, was also provided to deepen the players' understanding.

A key difference between this prototype and the previous one is its higher fidelity. The previous prototype simply presented text and images laid out in slides, without considering the design for the intended device. In contrast, this prototype involved creating a mockup specifically for the device to ensure the relevant information fit meaningfully and in a user-friendly way. As a result, the game's user interface (UI) was developed as a low-fidelity prototype. However, this prototype was not fully completed or playtested and was designed only for the on-site player using a mobile device. The focus was on the on-site player due to the challenges of working with a smaller screen.

The mockup simulated a typical phone's home screen (Figure 9), featuring the two necessary apps: a 'Calculator' and a 'Notes' app, along with a third app called 'Alan.' The player is prompted to open the 'Alan' app, initiating dialogue with the character. The conversation takes over the screen in a style inspired by computer role-playing games (RPGs), with a dialogue box at the bottom. The player's dialogue choices appear in a small shape near the top right of the dialogue box. Snippets of the learning content are shown in Figure 10, while Figure 11 and Figure 12 feature screens from the conversion activities.

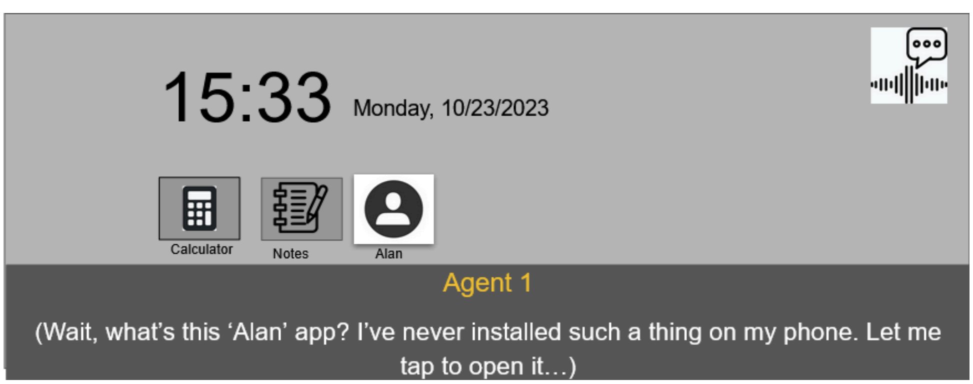


Figure 9: The initial screen of the game.The simulated home screen UI of Agent 1. Tapping on 'Alan' starts the experience. Top right is the Voice Chat interface. On the bottom, the player's dialogue box. To the left, the two apps necessary for activities: 'Calculator' & 'Notes'.

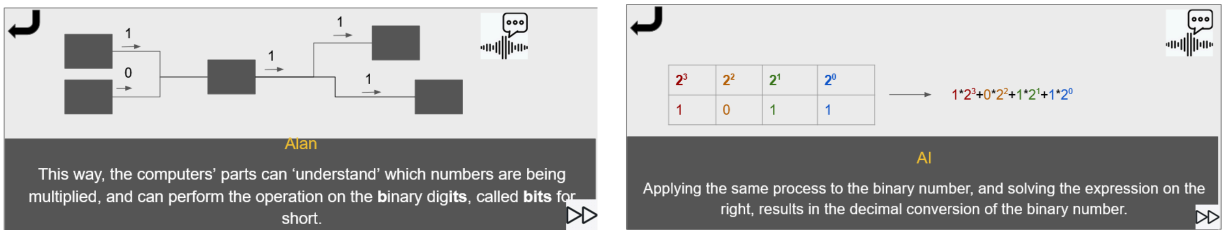


Figure 10: Parts of the learning content. Left screenshot: a diagram of a computer circuit. Right screenshot: Showing the equivalence of a binary and a decimal number.

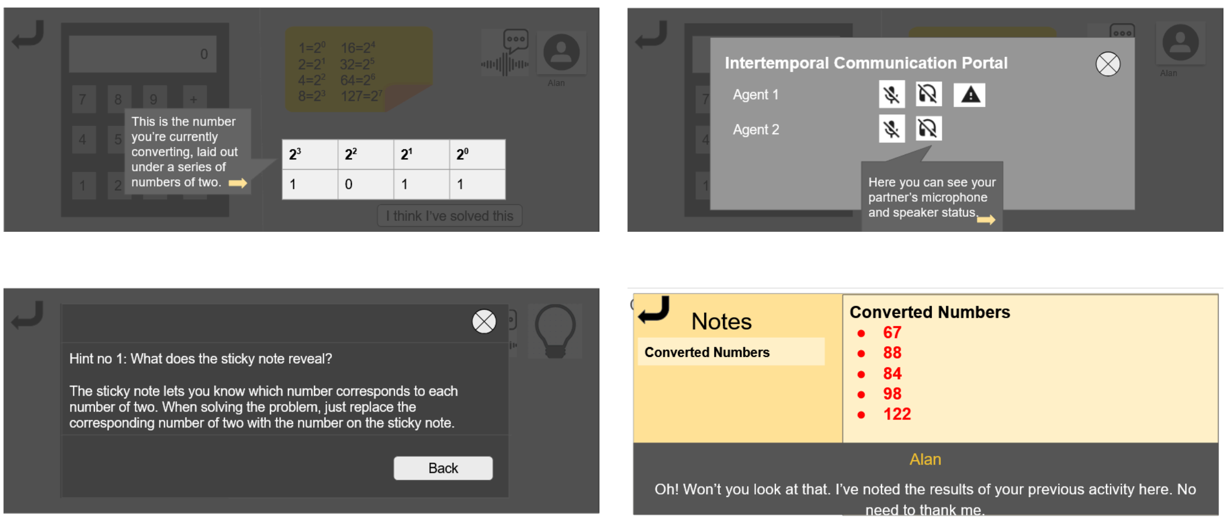


Figure 11: Screenshots from the binary number conversion activity. Top left: The modified 'Calculator' app. An overlay with a text bubble from Alan explaining the app's components is visible. Top right: The voice chat interface. Bottom left: A hint regarding the sticky note included in the calculator app. Bottom right: The 'Notes' app, where Alan has done bookkeeping on the results of the previous activity.

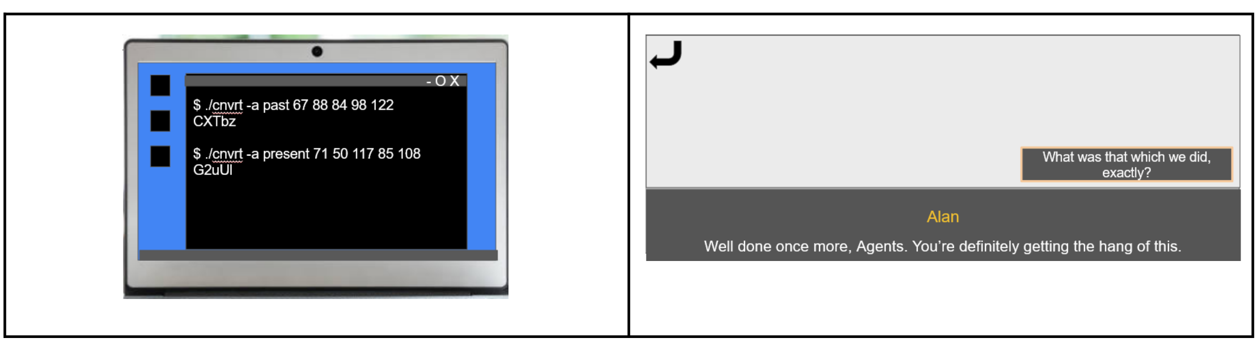


Figure 12: Mockups from the decimal-to-ASCII conversion activity. Left: a mockup of the museum computer's screen, with the command performing the operation and its results. To the right: A snapshot of the dialogue system, with a player option to the top right of the dialogue box.

5.3.3.2 Formative Evaluation

An expert evaluation, though not a full playtest, revealed some issues with the first activity. The primary concern was that the activity was not sufficiently asymmetrical, leading to a less engaging experience. Additionally, the activity presented a large amount of information, which risked overwhelming the player. However, the third activity showed promise regarding its educational objectives, which include effectively illustrating that all data in a computer, from characters to inputs and outputs, is represented as numbers, as well as the significant evolution in human-computer interaction, from text-based command-line interfaces to modern GUIs, which was particularly enlightening for younger participants. The third activity served as the basis for the experience's (so far) final prototype.

5.3.3.3 Design Implications and Lessons Learned

The evaluation provided important insights for refining the activity:

- **Narrowing the Scope:** The activity's scope should be more focused to prevent information overload and to maintain player engagement.
- **Reducing Length and Depth:** The educational content should be streamlined, with a reduction in both the length and depth of the material presented to players.
- **Closer to the Final Product:** Despite these issues, this version of the prototype was closer to the final product, with a stronger alignment between the educational objectives and the gameplay experience.

These adjustments will help ensure that the game effectively introduces players to the binary system without overwhelming them, while still achieving its educational goals.

5.3.4 'Convert': The Final Prototype

5.3.4.1 Description

The final prototype of the asymmetrical game, designed for a computer science museum, retained and refined two core activities from the previous iteration: the first and third activities. These activities were fully fleshed out and playtested over three sessions, with some significant changes to the prototype's structure between them resulting from player feedback, regarding mainly communication between users and the way the educational content is provided. Despite any friction points, the players reported high levels of enjoyment and connectedness, demonstrating the design's potential and laying the groundwork for the game's final refinement and implementation.

Facilitator Support and Synchronization

To address the challenge of synchronization between the onsite and remote players, facilitators were introduced. Each facilitator followed a structured script tailored to the numbered slides of the prototype, ensuring both players remained aligned. For every slide, the script included:

- **Subtle Hints**: To keep players on track without overtly solving puzzles for them.
- **Direct Hints**: Provided upon request or in response to specific questions prompted by Alan.

- **Slide Navigation**: Clear instructions on when to progress or skip slides based on player actions (such as taking a hint or not) and puzzle progress.

This system allowed the facilitators to unobtrusively support players while maintaining the game's collaborative and exploratory nature.

Activity Breakdown

As previously discussed in the 'Binary System' prototype, the first activity tasked the onsite and remote players with locating and interpreting scraps of binary numbers. Guided by Alan, the remote player was directed to the virtual museum's guest book, where they uncovered a hidden scrap of paper containing five decimal numbers and a blue dot. Using a UV flashlight, they found hidden text (Figure 13) which was meant to direct the onsite player towards a specific computer on top of which their corresponding scrap of numbers, this time marked with a red dot, was located. This discovery served as their clue to assist the onsite play. This activity emphasized teamwork and communication, as one player had to guide the other through a space they are unfamiliar with.

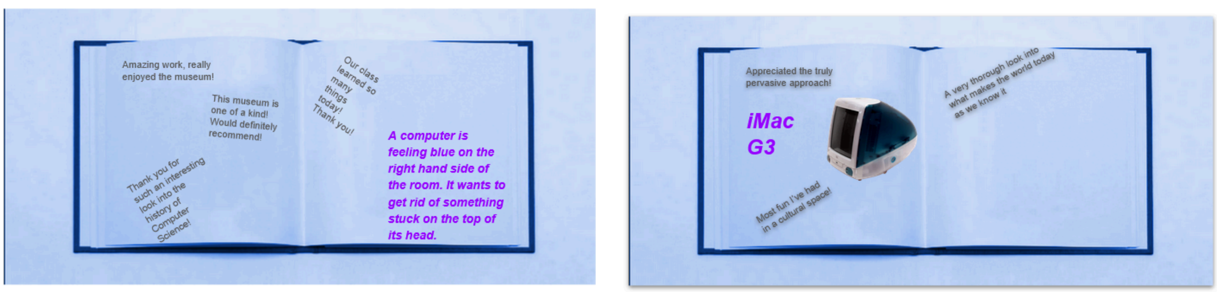


Figure 13: The guestbook the remote player searches through. Left: Purple letters, invisible without the UV flashlight, highlight the initial hint they must give to their co-player. Right: If the onsite player cannot find the specified computer, the remote player must turn a page to reveal the computer's name and an image to describe it to them.

The following activity, also originally from the previous iteration, focused on converting the decimal numbers on the scraps of paper into ASCII characters, which would be used later. The onsite player uses a laptop capable of running the command to perform the conversion but does not know how to do so. They are in charge of communicating to the remote player a pre-written message to help them find the command manual (Figure 14), which the remote player then utilizes to provide instructions on completing the conversion. This activity aims to help players gain insights into how computers interpret everything, including characters and other data modalities, as numbers as well as the evolution of human-computer interaction, such as the differences between modern graphical user interfaces and traditional command-line interfaces, and more details on program execution, such as arguments, inputs and outputs.

Figure 14: The terminal the remote player interacts with. They must read the appropriate clues to their coplayer, who must execute the command twice, as shown in Figure 16**.**

The final activity involved completing a password with the characters resulting from the previous activity in order to prevent unwanted people from gaining access to a remote system, thus completing the main objective. This activity was changed after the first playtesting session, for reasons to be discussed shortly. We will present its initial version here. The remote player was guided to a specific computer by Alan (a Macintosh PC from the 90s, existing both in the physical and virtual museums), and is then guided by the onsite player to open the 'Notes' app and fill in the missing characters to the password (Figure 15). The remote player had to then open the computer's 'SSH' app after receiving a hint from Alan, which automatically logged them into a previous session. They were then asked to fill in the completed password and provide a new (random) password to complete the game (Figure 16). This activity did not have any particular educational objective, and instead served as a means of concluding the experience.

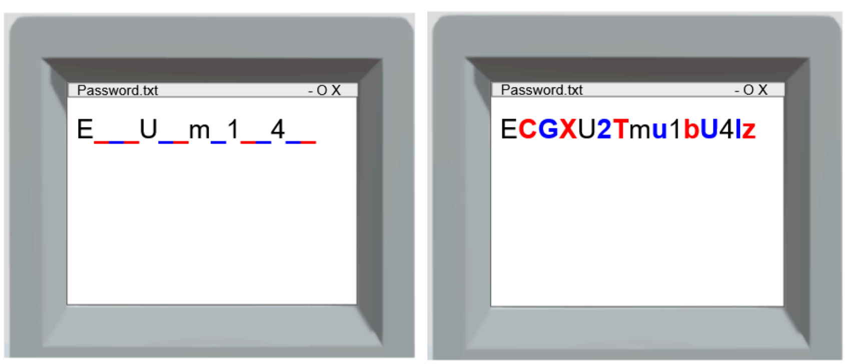


Figure 15: The file in the 'Notes' app with missing characters (left) and the password fully filled out (right). The color coding helps put characters in the correct order and can be seen in Figure 16**.**

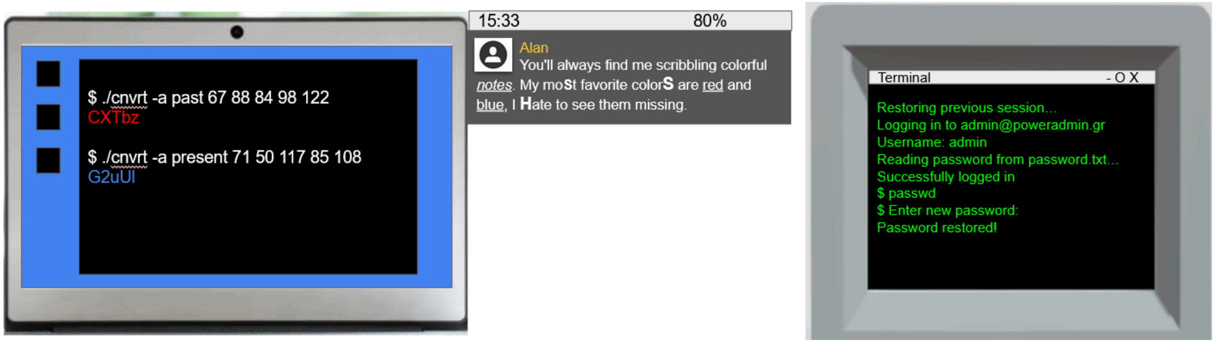


Figure 16: (Left) The result of the second activity on the computer the onsite player uses, alongside a hint of Alan's that guides the player to prompt their partner to open the ssh app. (Right) The result of the remote player opening the ssh app.

Classification of the activity's tasks under the 'Puzzles Unpuzzled' framework

Revisiting the 'Puzzles Unpuzzled' framework [23], the classification system for Escape Room puzzles previously discussed in the Theoretical Background and Related Work section, we will now classify the tasks the players have to complete under the framework's categories. Almost all of the tasks the players have to complete have an atomic component that falls under the 'Distributed Knowledge' category. Each task includes at least one more component. Plenty of components fall under the 'Information Sharing' category, so we will present a short summary of the components that do not fall under this category, and summarize their respective classes, which all fall under 'Mental Challenges' as well.

- Deduction: This refers to puzzles that use reasoning, and might have to do with analysis of objects, texts or interaction with NPCs. In our application, the players analyze the words communicated to them by the NPC, so we focus on text analysis. In fact, most of our puzzles contain such an atomic component, as the NPC doubles as the game master, and communicates via text with the players, utilizing markup to emphasize certain words or letters. Specifically, the following are deduction tasks:
    - For the remote visitor:
        - Deducting that, in the first activity, they must visit the guest book to find relevant information, i.e. their paper scrap and the directions they must offer to the onsite player.
        - Deducting from a hint given by their coplayer ("You'll always find me scribbling colorful notes") that they need to open the 'Notes' app in the last activity.
    - For the onsite visitor:
        - This player must deduce multiple purely textual hints, some of them containing markup, such as:
            - 'Is there someone in the **future** that we can ask for **help**?', where they must deduce that their co-player has the help manual.

        - “Agent 2 **HA**s the power administrative unit’s **C**redentials available to them. To loc**K** any maliciou**S** user**S** out of t**H**e system, you have to log in yourself”, where, in a later iteration of the last activity that will be described shortly, they must understand that they need to type the command ‘hackssh’ in the computer in front of them.

- Light: This refers to the usage of a flashlight with special lighting that reveals otherwise hidden information.
    - The remote player uses a UV flashlight in the first activity.
- Observation/Searching: This refers to noticing or finding something visually. This takes place both in the virtual and in the physical spaces of the game.
    - The onsite player must search for certain computers in the museum, to find their paper scrap and to run the ‘cnvrt’ command.
    - The remote player is given a hint by their coplayer and through observing their surrounding space, must go to a dome numbered with the number 4 to find the computer with the ‘Notes’ app.
- Correlation: For solving these puzzles, the players must identify something perceivable, like a similarity, between a few objects.
    - The ‘cnvrt’ command’s output, visible by the onsite player, has both blue and red letters, while the note the remote player views has a password with blue and red spaces to signify missing characters. The players must accurately describe what they see to each other and correlate them.
    - In the final iteration of the last puzzle, which will be described shortly, the players must also correlate some credentials the remote player has, with a request for credentials made by a command the onsite player attempts to run at their own computer.

5.3.4.2 Formative Evaluation

5.3.4.2.1 First Phase

The first phase of formative evaluation for the prototype involved players with a computer science background. The remote player and their facilitator were located in the same space, an office outside of the museum, while the onsite player was followed to the museum by their facilitator. The play session provided valuable insights into both the puzzles and overall game design, uncovering areas for improvement while highlighting strengths.

While the puzzles were generally easy to solve, players struggled to grasp the objective of each mini-activity. This confusion was primarily due to the initial decision on allowing players to only communicate when about to solve puzzles. This resulted in abrupt interruptions in communication, which hindered the players' understanding of the overall flow. Players felt like they could not freely chat and reflect on the information they received, and would much prefer being able to control their voice chat experience through standard mute/deafen buttons to allow for focus if they so wished. Specific issues included:

- The "blue computer" in the museum, which players found difficult to identify from a distance. It was suggested that either the riddle associated with it should be reworked or more explicit guidance provided.
- The final activity suffered from general flow issues. The remote player found it somewhat anticlimactic, describing the process as overly automated. Meanwhile the onsite player experienced confusion, made worse due to the inconsistent voice chat availability, and believed they contributed insufficiently to the activity's outcome.

At this stage, the learning content had not yet been integrated, which the remote player specifically noted as a missing component. However, players thoroughly enjoyed the narrative elements of the prototype. They suggested that bonus narrative content be made available from the start of the game, allowing players to discover it organically while exploring.

The dialogue system UI underwent a significant change after this phase, transitioning to an interface styled like a messaging app (Figure 17). This redesign was believed to better allow players to easily review both Alan's educational content and hints, as well as naturally integrate controls for the voice and text chat interface with the other player that came up as a requirement. Additionally, the messaging app interface could be more adaptable across various mobile device sizes, improving usability and visual consistency.

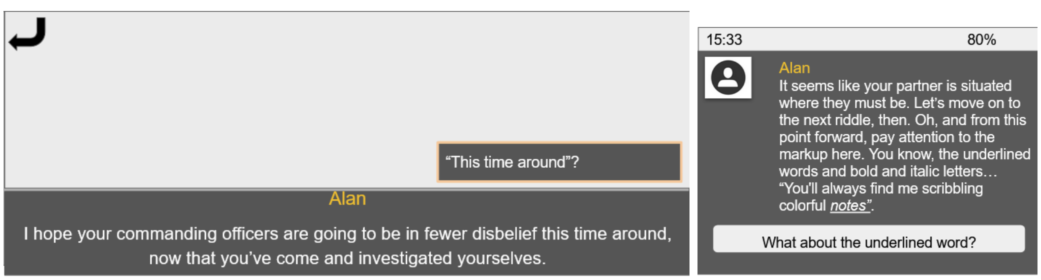


Figure 17: (Left) The old UI, where the mobile device ought to be held in landscape mode. (Right) The new UI, showing a message from Alan where the user can respond by clicking one (of possible more) buttons.

Overall, despite its mockup stage, the activity was described as engaging and held the players' attention. Notably, the remote player remarked, *"I hope there's more after that,"* before reaching the final activity, indicating a high level of immersion. Players expressed satisfaction with the alternating "helper" role, which allowed both participants to experience guiding and being guided. This dynamic contributed significantly to their enjoyment and sense of contribution. Finally, players emphasized the critical importance of maintaining communication at all times, even suggesting this take precedence over the implementation of a voiceover for Alan, which they thought would hinder their focus on the information he presents compared to a pure textual format. These observations provided a foundation for refining the prototype in subsequent iterations through addressing any flow issues and improving the overall clarity and engagement of the game.

5.3.4.2.2 Second Phase

The second phase of formative evaluation tested a revised version of the prototype, incorporating changes based on feedback from the first phase. This iteration aimed to examine whether free and continuous communication between players would allow for increased feelings of connectedness and a deeper understanding of the presented content, address flow issues, particularly around the last activity, and find out whether the game also caters towards players from the general public. This session featured two participants who, while not from a computer science background, closely work on the broader cultural heritage field, both colleagues and familiar with one another. The remote player participated fully remotely, while the onsite player and their facilitator were located at the museum. All communication occurred through a Discord call, as it did in the previous session, without any directions from the facilitators on the players muting themselves, ensuring consistent voice chat (VC) availability throughout the session.

Before we proceed with the feedback received, we will shortly describe the final activity, which underwent significant restructuring. It was divided into two halves, with control of the terminal where the ssh command runs transferring to the onsite player (Figure 18). This change aligned better with the narrative and introduced a new learning objective: understanding Secure Shell (SSH). In this revised activity, the onsite player helped the remote player fill in the password, as previously described, while the remote player's 'Notes' file contained credentials for logging in to a remote computer via SSH, which they had to assist the onsite player with.

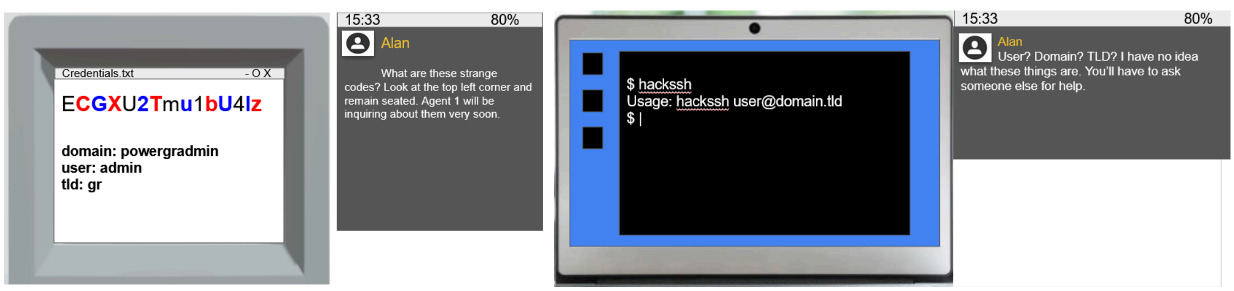


Figure 18: The view of the remote (left) and onsite (right) players' computers during the last activity.

Additionally, the prototype introduced the learning content, separated into two tiers to support players without a CS background:

- **Mandatory Content** (Figure 19): Focused on the differences between Command-Line Interfaces (CLIs) and Graphical User Interfaces (GUIs), alongside basic UNIX commands (arguments, input, output). This was intended to prepare players for experimenting with a custom command in the game, as part of the second activity.
- **Optional Content**: Provided deeper explanations of the activities, including ASCII, the binary system, and SSH (protocols, key files). Players could choose to engage with this material at their discretion after the end of the corresponding activity.

Figure 19: A sample of the mandatory educational content given before Activity 2.

We will present a sample of the bonus educational content coming after Activity 2. The highlighted terms contained more content the user could choose to read.

A character is basically an umbrella word for the letters, numbers and symbols you see on the computer. All the following, as well as letters from other alphabets and many more visible and invisible symbols, are characters. But the computer doesn't quite understand or discriminate between classic letters, or symbols, or numbers. The computer only understands numbers. Therefore, every character corresponds to a number. The first character set for a computer included the capital and lowercase letters of the English Alphabet, as well as digits 0-9, and some symbols such as the dollar sign ($). That character set is called ASCII, and it's essentially a table where each character corresponds to a decimal number. For example, C, the first character given as output by giving the present argument to the 'cnvrt' command, corresponds to the number 67. Decimal numbers are easy for humans to read, but the computer doesn't understand them either; it can only understand binary numbers. So every time you type the letter C, the computer only understands 0100 0011, which is the binary equivalent of 65. To sum up, the 'cnvrt' command stands for 'Convert'. It reads 5 decimal numbers from its arguments and converts them to the 5 characters they correspond to, according to the ASCII table, which it then returns as output.

Findings

The play session revealed both successes and areas for improvement. Starting from the educational content, which was the prototype's main issue, the mandatory content, instead of aiding the players, caused confusion. Players mistakenly believed they needed to use the example commands provided in the learning content, rather than focusing on the custom command for the activity. However, the in-game hint system proved sufficient in helping them progress through the puzzles, suggesting that it functions effectively as a guidance tool. Additionally, the volume of the optional material overwhelmed the remote player, due to its three-page length. The onsite player expressed a desire to read it alongside the remote one, and proceeded not to as to not have their partner wait. This indicates a need to significantly shorten the material, as well as rethink about its means of presentation. Additionally, the remote player found the prototype medium confusing but was able to acclimate themselves and complete the activities with guidance from their facilitator, indicating that this prototype medium has started to reach its functional limits.

However, this iteration of the prototype showed clear improvements in several areas. The revised final activity structure and continuous voice communication enhanced collaboration and player experience. Players enjoyed sharing Alan’s dialogue and felt time passed quickly, underscoring their engagement with the game. In particular, the remote player reported a high level of immersion, remarking that she lost track of her surroundings during the session—a strong endorsement of the experience’s potential for engagement. Finally, while the hint system had not been used much in the previous iteration due to the participants’ CS background, it demonstrated effectiveness in guiding players to completion without inducing frustration.

5.3.4.2.3 Third Phase

The third phase of the prototype's formative evaluation combined elements of expert evaluation and playtesting, allowing players to experience the game while pausing to provide comments, opinions, and suggestions. Both participants had a computer science background, with Player 1 also being an experienced escape room enthusiast. No changes were made to the prototype for this phase.

Beginning with the puzzles, several suggestions for improvement were received. The on-site player noted issues with the "blue PC" riddle, making this the second time in testing, highlighting the need for potential reworking of this element to improve clarity and accessibility. Player 1, with their escape room background, provided a detailed critique of the second activity. They identified specific areas for improvement, such as the misleading color-coding of text and ways to rephrase or expand hints for better clarity. For example, color coding between Figure 14 and Figure 19, that is, the instructional and puzzle screens is inconsistent. While red is used for notating command names in the educational screens, it is used for emphasis in the puzzle’s manual page. Yellow is used to notate argument names in the manual screen, while orange is used for the educational content, which could have possibly amplified the confusion of the two users in the previous session. The phrase ‘some things have to change’ (as shown in Figure 14), which refers to the fact that arguments change between the two command executions, confused Player 1. They also suggested adding helpful content, such as informational signs next to UNIX command examples to explain their functionality. Implementing these targeted changes could enhance the activity’s comprehensibility without requiring a major overhaul.

Moving on to social interaction, it must be noted that due to constraints with one facilitator’s schedule, both players were in the same physical space in a way that allowed a single person to facilitate the process and made sure they were unable to view each other's screens, maintaining the intended asymmetrical dynamic. They took significantly longer to complete the game, partly due to frequent pauses for discussion and analysis of design choices but also because they embraced the social aspect of the activity. Their interactions included joking and casual conversation, indicating that the game encouraged natural communication without feeling forced or contrived. Both players felt the game successfully fostered collaboration and found the design to be entertaining. They expressed enthusiasm for recommending the game to others, emphasizing its potential as a social and enjoyable experience.

In regards to the educational content, participants did not engage with the optional bonus content due to the notable issues that came up in the previous session. However, both participants agreed that the primary learning objective—a brief look into a different form of human-computer interaction—was effectively communicated and sufficient as a standalone concept. Player 1 suggested that the additional topics explored in the bonus content, such as ASCII, binary systems, and SSH protocols, might be better suited for a separate level or significantly condensed into a brief optional explanation for interested players. This feedback highlights the need to balance educational depth with player engagement and accessibility.

Finally, the participants praised the narrative, particularly the writing style and how the story's setting was seamlessly integrated into the activities. The story was engaging and contributed to the overall experience, effectively immersing the players in the game world.

Overall, this phase provided valuable insights into the prototype's strengths and areas for refinement. The narrative and social aspects were well-received, reinforcing the game’s appeal as a collaborative and entertaining activity. Targeted adjustments to specific puzzles and learning content, as well as a reevaluation of the bonus material's format, could further enhance the game’s clarity, educational impact, and overall player experience.

5.3.4.2.4 Key Design Insights and Lessons Learnt

Player-Game Interaction and UI Adjustments

The initial concept for the desktop player’s perspective utilized a first-person point-of-view with WASD-based navigation. However, feedback from the final expert evaluation raised concerns about the usability of this control scheme, particularly when combined with point-and-click mechanics for tasks like inventory management. As a result, the implementation is likely to adopt a fully point-and-click interface, reminiscent of classic adventure games, to streamline interactions and provide a consistent user experience.

Similarly, the dialogue system is intended to undergo a significant redesign. Originally inspired by RPG-style interfaces, it was reimagined as a messaging app interface. This change empowers players to control the pacing of their interaction with the game’s narrative content as well as making it more intuitive and adaptable across various mobile device sizes. For the remote player, a complementary on-screen overlay—mimicking ‘futuristic’ glasses— could be implemented. Visual effects like a subtle blinking indicator would draw attention to key elements while maintaining immersion.

Enhancing Player-Player Communication

A key takeaway from evaluations is the importance of maintaining natural, unregulated communication between players. Rather than imposing mute or deafen functions outside of puzzle solving moments, players should manage these tools autonomously to suit their needs for focus or clarity. This approach ensures the interactions remain fluid and enjoyable, fostering collaboration without unnecessary restrictions. Notably, players consistently reported high levels of engagement, enjoyment, and immersion. They appreciated the opportunity to help and interact with their counterpart, frequently sharing moments of casual conversation and humor during the game. This positive social dynamic significantly enhanced their overall experience.

Refining Educational Content

Feedback on the learning content highlighted the need for concise and targeted materials. While the bonus content added depth, it was deemed non-essential to achieving the primary educational objectives. Evaluations confirmed that the core learning goal—demonstrating command-line interfaces (CLIs)— was both clear and impactful. Future revisions will focus on simplifying and refining the content to ensure accessibility for players of diverse backgrounds. These insights provide a strong foundation for refining the prototype and offer valuable lessons for designing engaging, educational, and cooperative gaming experiences.

6. IMPLEMENTATION

In the following section, we will describe the project's technical development. While the current thesis focuses a lot more on designing a hybrid experience for a museum or otherwise cultural heritage site with a focus on sociality, parts of the experience have been developed, mainly its networking foundation and parts of its dialogue system. Additionally, we considered that it would be incomplete without describing a possible structure for the project's entirety, as the project's implementation is our main future work. We will begin by presenting the parts implemented so far, and we will conclude by describing the intended project structure of the complete project.

6.1 Chosen Technological Tools

Aside from the project's prototyping stage which was implemented using Google Slides and which has already been covered in the previous section, the implemented project modules are created using Unity, which is a popular game engine.

6.1.1 A brief introduction to game engines

A game engine is a software framework or platform designed to help developers create video games and interactive applications more efficiently by providing a suite of tools and libraries for common game development tasks. Instead of building everything from scratch, developers can use a game engine to handle essential and complex aspects of game creation, such as rendering 2D & 3D graphics, simulating physics, handling audio and animation, managing inputs and interactions, and enabling networking, all tied together by scripting systems for application logic. Many engines also support cross-platform deployment, making it easier to release games on multiple devices. Popular game engines like Unity, Unreal Engine, and Godot provide user-friendly interfaces, community support, and features that cater to developers of all levels, making development accessible to teams of all backgrounds and sizes. Game engines accelerate development, reduce costs, and make game creation more accessible. They enable creators to produce high-quality games efficiently, whether for indie projects, AAA titles, or experimental applications, bridging the gap between imagination and technology.

6.1.2 The Unity Game Engine

Unity is a powerful, cross-platform game engine used to create 2D and 3D interactive experiences, including games, simulations, and virtual reality (VR) applications. It offers a robust suite of tools for developers, such as a visual editor, scripting in C#, and a vast asset store for resources. Unity supports multiple platforms, enabling developers to deploy projects across PCs, consoles, mobile devices, and AR/VR systems, making it a versatile and widely used solution in the game development industry.

6.1.2.1 A typical Unity Project structure

A Unity project is built around **scenes**, which are like "levels" or "stages." Each scene contains **GameObjects**, which are the basic entities in the scene. such as characters, environments, lights, and cameras, which define the interactive world. **Components,** like **Scripts** that add application logic and functionality, are then attached to GameObjects in order to define their behavior. Unity uses **C#**, a versatile programming language developed by Microsoft, commonly employed for creating various types of applications, including games. Beyond C#'s standard features, Unity provides specialized classes and functions tailored for game development, including tools for managing game objects, processing input, and utilizing engine-specific features like audio, animation, and more.

6.1.2.2 Why Unity?

There are numerous reasons why Unity can be a good fit for a developer's project, starting with its ease of use. The Unity Editor (Figure 20), Unity's visual interface for designing, testing and tweaking the game, is very intuitive. Additionally, Unity comes with an extensive library of tutorials, making it beginner-friendly for new developers while still offering advanced tools for professionals. Another very important point is Unity's cross-platform support which allows for an application to be built for different platforms with minimal overhead. This was particularly important in our case as cross-platform support, particularly desktop and mobile platforms, is one of the project's most important requirements. Furthermore, Unity has one of the largest development communities, providing extensive documentation, forums, and mutual support. Finally, Unity offers a wide variety of tools and software development kits (SDKs) in addition to its base features that we think can support the project's main features, specifically the dialogue/hint system's UI, and the networking that is at the core of its social nature.

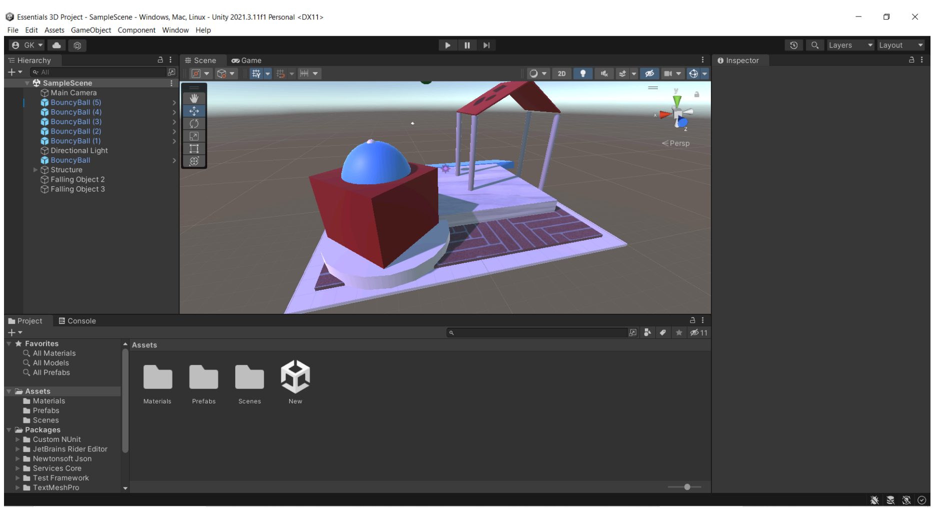


Figure 20: A screenshot of the Unity Editor

We will conclude this subsection by briefly presenting the main Unity SDKs and features that have been used so far for the project's implementation.

6.1.2.3 UI Toolkit

UI Toolkit is the most recent addition to Unity's collection of UI systems. It is a set of tools, resources, and features designed for building user interfaces and extending the Unity Editor. Its streamlined workflow allows for creating and troubleshooting application UI more efficiently. Drawing inspiration from web technologies, UI Toolkit includes the UI Builder (Figure 21) and UI Debugger to provide a user-friendly experience. The UI Builder enables visual design and editing of game and application interfaces directly within Unity, while the UI Debugger simplifies identifying and fixing issues. The UI Toolkit is used to create the entirety of the project’s UI, including the dialogue/hint system, the players’ inventory, etc.

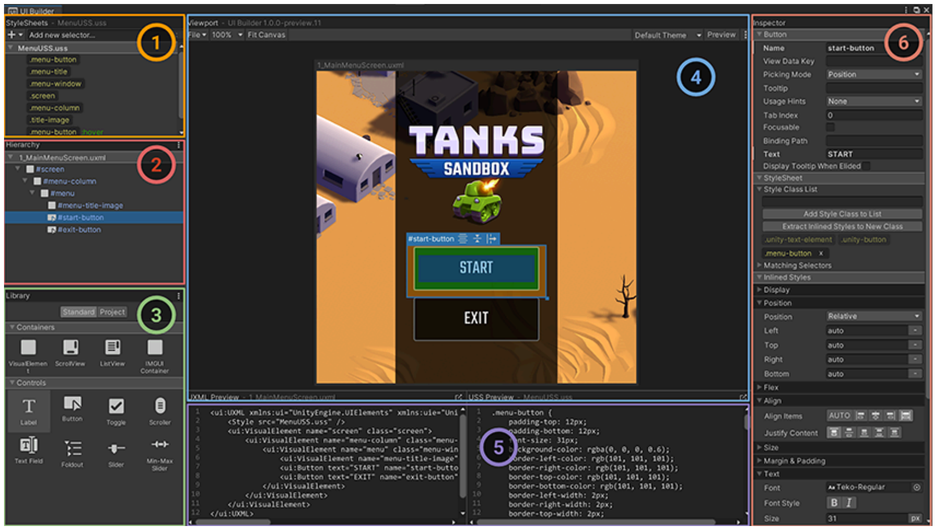


Figure 21: A screenshot of UI Builder from its official documentation.

The UI Builder draws inspiration from standard web technologies by defining the two following asset types:

- **Unity eXtensible Markup Language (UXML) documents:** UXML is a markup language inspired by HyperText Markup Language (HTML) and eXtensible Markup Language (XML), both foundational technologies of the Web. Similar to how HTML is used to define the content and structure of a web page, UXML is used to define the structure of UI and create reusable UI templates.
- **Unity Style Sheets (USS):** These are style sheets that apply visual styles and behaviors to UI. They’re very similar to Cascading Style Sheets (CSS), the main style sheet language used in web applications to specify the presentation and styling of the content. In fact, Unity Style Sheets support a subset of standard CSS properties, making any prior knowledge of CSS easily transferable.

6.1.2.4 Lobby

Lobby is a service dedicated for allowing players to connect to a game session. In multiplayer gaming, a **lobby** is an essential element, referring to a virtual space where players gather before starting a multiplayer game or activity. In some cases, the lobby may include features like chat, voice communication, and options to modify game rules or character loadouts. Unity’s Lobby SDK allows players to create public lobbies using simple game attributes which other players can then search, discover, and join. This service is used to allow players to create a username and a lobby where they can wait for their game partner, or conversely, search for a game lobby created by their game partner and join them. The SDK is also used to handle various connectivity issues, such as temporary disconnects.

6.1.2.5 Relay

Unity’s Relay service simplifies multiplayer gaming by enabling secure and cost-effective peer-to-peer or listen-server UDP communication between players, eliminating the need for expensive dedicated game servers and ensuring seamless gameplay experiences. This service is used to allow for connection handling between players, ensuring there will be no issues with the networking layer of the experience.

6.1.2.6 Network for Game Objects

Unity's Netcode for GameObjects (NGO) provides developers with tools to synchronize GameObjects, components, and player interactions across multiple clients in a networked environment. It allows for managing tasks like spawning and synchronizing GameObjects, handling input, and ensuring consistent state updates across all players. synchronizing variables between clients. In other words, it ensures real-time synchronization of any component that is shared across multiple players. While none of its functionality has been used so far in the game’s implementation, we have completed its basic integration into the game, expecting some of its functionality to require basic synchronization, such as maintaining that both players are on the same puzzle at the same time.

6.2 Project structure

We will now describe in more detail the project’s intended structure, beginning with its already implemented parts, and concluding with the rest of the proposed design. It is worth noting that the hybrid experience’s implementation is separated between two distinct Unity projects; one for the desktop and one for the mobile application. However, due to similarities in their core functionality, features that are shared across them, like the networking, have been implemented as standalone modules in the form of local unity packages, so code reusability can be maintained. A GitHub repository, complete with the two applications’ source code as well as the local packages, can be found here.

6.2.1 Implemented Modules

6.2.1.1 Networking Module

The networking module is the most complete part of the application so far, due to its importance as the facilitator of the experience’s social nature, one of its core elements. As mentioned previously, it is implemented as a local unity package to enable reusability across both applications. The networking module doesn’t only include the necessary scripting required to implement the netcoding logic, but also scenes that allow for username creation and lobby creation or search. These scenes appear in order before the experience starts to allow the players to connect to a session with their desired partner as well as set up anything related to their network connection in their background.

We will shortly present the module’s functionality through screenshots of the application, specifically the aforementioned scenes, and then we will get into more detail regarding its internal structure.

Module Walkthrough

Figure 22: User creation screen.

In the application's first screen (Figure 22), the user can choose the username they appear with to others. When searching for a lobby to join, a user can see the host's name and recognize that their intended co-player is the lobby's creator. After username creation, a player can choose to create a new lobby and be discovered by their co-player, or either search for an already created lobby to join their player two (Figure 23). Lobby creation is very straightforward and involves only naming the lobby (Figure 24).

Figure 23: Lobby options screen.

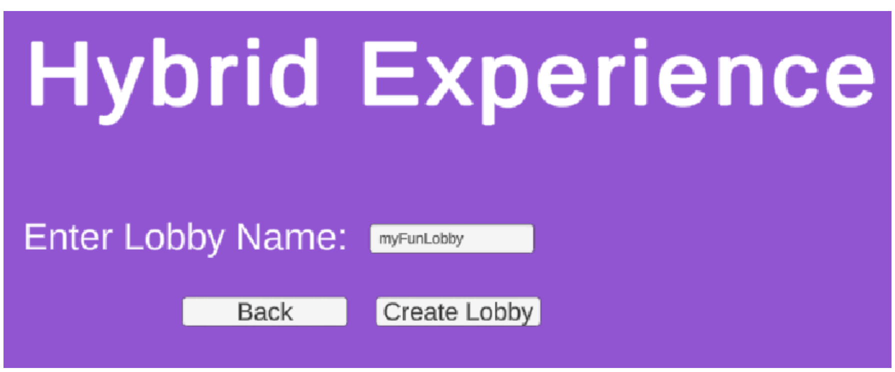


Figure 24: Lobby Creation Screen

If the user chooses to search for a lobby instead of creating one, they see a list of lobbies (Figure 25), complete with their names and the host's username. If the intended lobby does not appear, they can refresh the list, or go back to the previous screen to make a lobby of their own, otherwise they click the ‘Join’ button next to the lobby they wish to join. It must be noted that only lobbies where the user waiting in them has a device opposite to the current player’s are shown. That is, a desktop player sees only lobbies created by a mobile player. This ensures only eligible players appear.

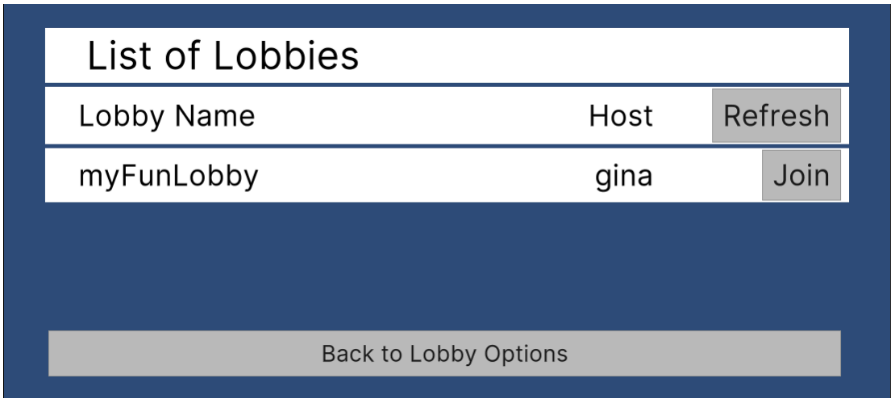


Figure 25: Lobby List Screen

Once the player joins the lobby’s waiting room (Figure 26 & Figure 27), they can set the status to ‘Ready’ or ‘Not Ready’. Both players must be ready before the host can press the ‘Start Game’ button, which takes them to their respective scenes.

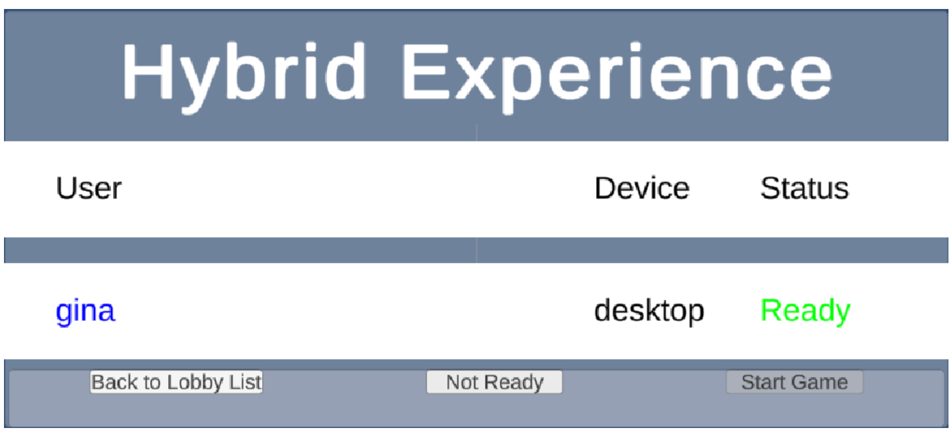


Figure 26: Lobby Waiting Room Screen. Currently, only the host is joined in.

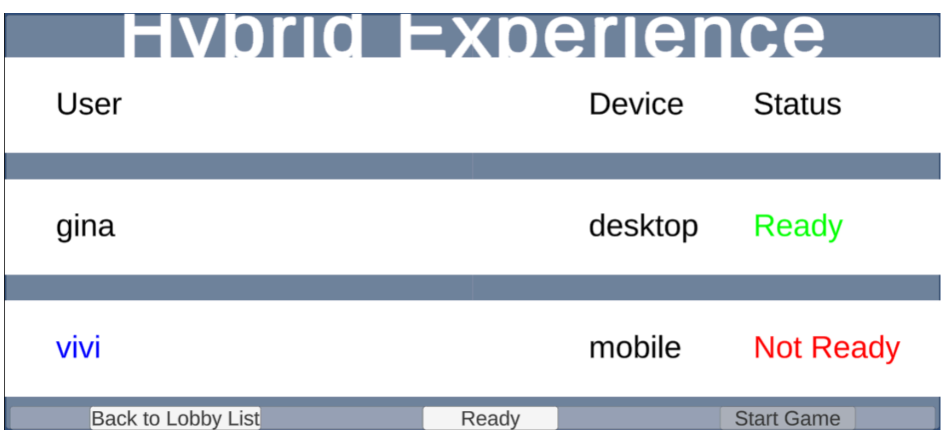


Figure 27: Lobby Waiting Room Screen, with both players joined in.

Module Structure

The module is comprised of five main scenes:

- UsernameScene
- LobbyOptionsScene
- LobbyCreationScene
- LobbyListScene
- WaitingRoomScene

The rest of the module is composed mostly of scripts implementing its logic. These scripts are roughly categorized as follows:

- **Managers**, scripts that oversee a specific aspect of a game's functionality, often acting as a centralized controller or coordinator for related operations. This module contains the following managers:
    - **SceneManager.cs,** that manages transitions between the module's five scenes
    - Networking managers, specifically:
        - **LobbyManager.cs,** responsible for handling creating and leaving a lobby, searching for one according to certain criteria, updates to the players' status (such as 'Ready' or 'Not Ready'), as well as keeping the lobby 'alive' by sending what is called a heartbeat ping, that is, a message to the service's servers to keep the lobby active.
        - **RelayManager.cs,** responsible for handling connecting to a relay allocation and server, necessary for ensuring good connection handling.
        - **ConnectionManager.cs,** responsible for starting a networking client or a server. This is a necessary setup for supporting Unity's NGO in a later version of the app.
        - **VivoxSetup.cs,** responsible for handling the necessary setup for voice (and in the future, text) chat. Specifically, this manager is responsible for handling the Vivox service's initialization, leaving and joining a voice channel, as well as requesting microphone permission in the case of an Android application.
            - **VivoxUserHandler.cs** is a complementary script to the Vivox manager, responsible for handling user actions such as muting.
    - Finally, the **MainManager.cs** is responsible for orchestrating operations that the other managers perform that must occur concurrently at a certain event. For example, when a lobby is created, the Main manager coordinates the following calls to other managers:

        - First of all, a call to RelayManager’s createAllocationId function is fired, resulting in the creation of a new relay allocation. This Id is then given as input to LobbyManager’s CreateLobby function. Once these two operations have been completed, the Vivox manager is prompted to create and join a voice channel. Finally, the SceneManager is then called to move on to the next scene, which is the WaitingRoomScene.

- **UI Controllers**, that is, scripts that manage the behavior, interactions, and logic of the UI, such as user input, serving as the intermediary between the UI elements (such as buttons, sliders, and text fields) and the rest of the game logic and triggering appropriate actions when users interact with the interface. Examples of a UI controller’s responsibilities will be presented below. The module’s UI controllers are:
    - **Username.cs,** which is responsible for adding logic to the Username scene’s UI. In this case, the script only performs the very simple task of making the ‘Start Game’ button interactable only if the username textbox is not empty.
    - **MySafeArea.cs,** which makes sure that all UI elements remain inside the mobile device’s safe area, in the case of the mobile application. A mobile phone or tablet’s safe area refers to the portion of the screen where content can be displayed without being obscured or cut off by physical or software elements of the device, such as notches at the top of the screen for the front-facing camera, rounded corners or ui overlays like the home bar at the bottom of the screen.
    - **UICreateLobby.cs,** which performs a similar operation as the Username.cs script, except this time for the lobby creation screen. Additionally, it alerts the SceneManager to proceed to the WaitingRoomScene.
    - **LobbyMembers.cs,** which is responsible for handling the waiting room’s UI. This is a more complicated task than the previous scripts’, as it requires communication with the LobbyManager for subscribing to the addition of a new member to the lobby, and displaying their information in real-time, as well as inform the LobbyManager of any other action the player wishes to perform, such as changing their status or leaving the lobby overall, and visualize the result of these actions (e.g. change the word ‘Not Ready’ to ‘Ready’ and the color from red to green when the ‘Ready’ button is clicked).
    - **LobbyListController.cs**, which is responsible for populating a ScrollView, a UI element containing a list of elements complete with a scrollbar, with the results of LobbyManager’s SearchForLobbies function, as well as add interactivity to each entry’s ‘Join’ button and the ‘Refresh’ and ‘Back’ buttons.

6.2.1.2 Dialogue System Module

The dialogue system module is a crucial component of the application, as it is the backbone of its hint system, an attribute that has proven to be robust and help players progress through the experience without experiencing frustration. The dialogue system involves the medium of communication between the player and Alan, the main NPC and mediator of the experience. Any information given by Alan -including bits of narrative, educational content such as that in Activity 2 or hints on puzzles- is supported by this part of the application.

The module is composed of two parts: a conversation parser, and the actual dialogue system logic. The conversation parser is intended to read the entire dialogue of the game, complete with branches depending on the hints a user chooses, markup instructions required by certain hints in the game, etc. This content is currently parsed from a simple text file, where anything outside of regular dialogue lines is marked with special notation. Then, this content is converted into an appropriate custom data type and stored in the disk along with the other game files. During runtime, the dialogue system's controllers read the stored dialogue and present it on the screen according to the logic they implement.

While this module might not be entirely developed yet, we will proceed by a demonstration of its current state and a description of its internal structure, as we believe its core functions have already been implemented.

Module Demonstration

Conversation Parser

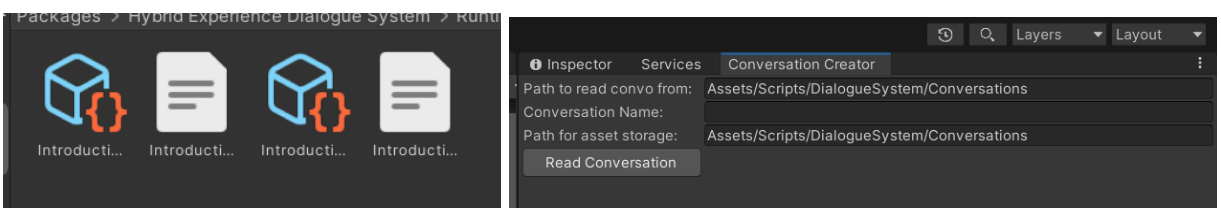


Figure 28*: Screenshots of the Unity Editor. (Left) A folder with the .txt files of the dialogue and their corresponding stored conversations used as input for the module's controllers. (Right) The custom Editor interface for the conversation parser.*

The conversation parser is composed of a single script, **ConversationParser.cs.** As seen in Figure 28, the script is responsible for creating a piece of custom Editor UI, where the user can input the path of the folder the dialogue text files are stored in, which file they intend to parse as well as where they would like to store the parsed data. The following is a snippet of a text file containing a sample conversation. The first line contains the name of the character that 'speaks' the relevant dialogue. Every other line is a message. A break line indicates a separate message must be demonstrated. Special characters include:

- Square brackets ('[ ]') that indicate the user needs help, complete with the message to be displayed on the button the player must click to inquire about the hint.
- Curly brackets ('{ }') that indicate Alan's response to the hint.

- Common markup characters, such as asterisks (‘*’) to indicate that a word or phrase surrounded by them must have the corresponding markup applied. For example, asterisks correspond to bold letters.

Alan // Character name

Hello, I am Alan and this is a message.

This is the next one, where there will be a hint.

*This one has a bit of *markup*.*

This one has a hint.

[I need more help] // The hint button is displayed with the previous message

{Here's the help you needed} // Hint answer

Here's another message.

Here's another message.

Here's another message.

Here's another message.

Here's another message.

Each character is associated with a name and a profile picture that the parser assigns to the conversation while parsing it. The parser converts the text to a corresponding **ScriptableObject,** a data container that allows for storing and organizing data independently of scenes and GameObjects and is used to define custom data types or configurations.

Dialogue System Logic

We will now present the realization of the conversation parsed in the previous section through the application’s controller scripts. The following screens present a bare-bones appearance intended for the onsite user’s device, that is, similar to how a messaging app would appear on a mobile device. Given the modularity of Unity’s UI Toolkit system, changing the UXML and USS files used in Figure 29 & Figure 30, will visually upgrade the application without needing to interfere with the implementation so far.

The player is first presented with a list of conversations to choose from, similar to a messaging app’s home screen. By clicking on a conversation, they move to the next screen where the character begins chatting with them. It must be noted here that the same interface will be used for chatting with their co-player in future versions of the application, in the form of a second conversation thread, complete with voice chat control buttons. The player can click the ‘Back’ button (as seen in Figure 29b) to return to the home screen. When returning back to the conversation, it will continue from where it left off.

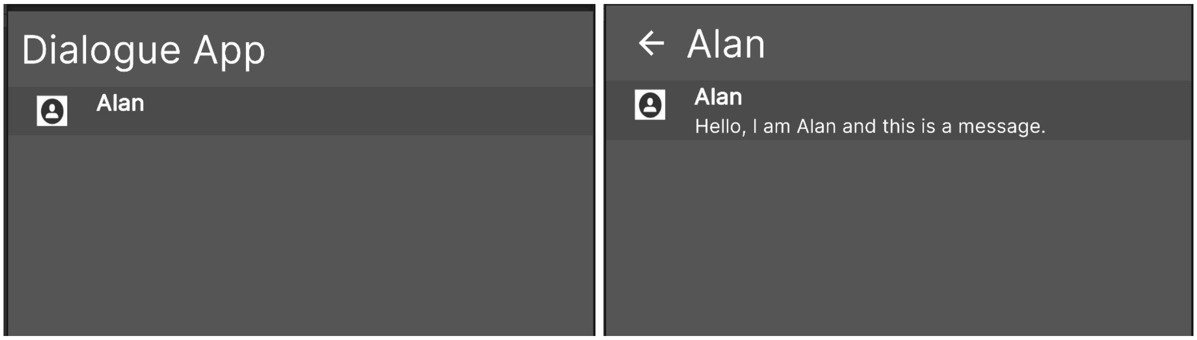


Figure 29: (Left) The dialogue system's homescreen, with a list of available conversations. (Right) The first message of the user's conversation with Alan.

When Alan gives a player an obscure direction, he will also present them with two choices: asking for a clarification, or confirming that they've understood and completed the task.

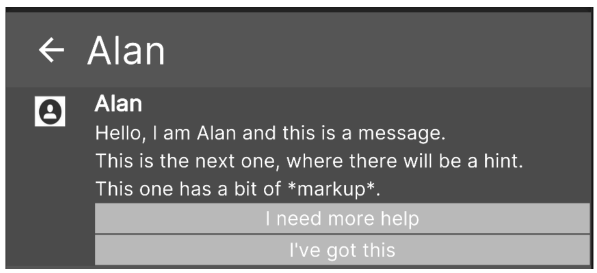


Figure 30: A message from Alan, complete with buttons for needing and not needing a hint button.

In the future, this will be extended to multiple choice questions for hints requiring multiple explanations. One such example is from a task the remote player must complete in Activity 2, as seen in Figure 31.

Figure 31: An example of a multi-question hint from Activity 2.

The player's response will appear as a message from the player once they click the corresponding button. Depending on their answer, the corresponding button label appears in their message's body (Figure 32).

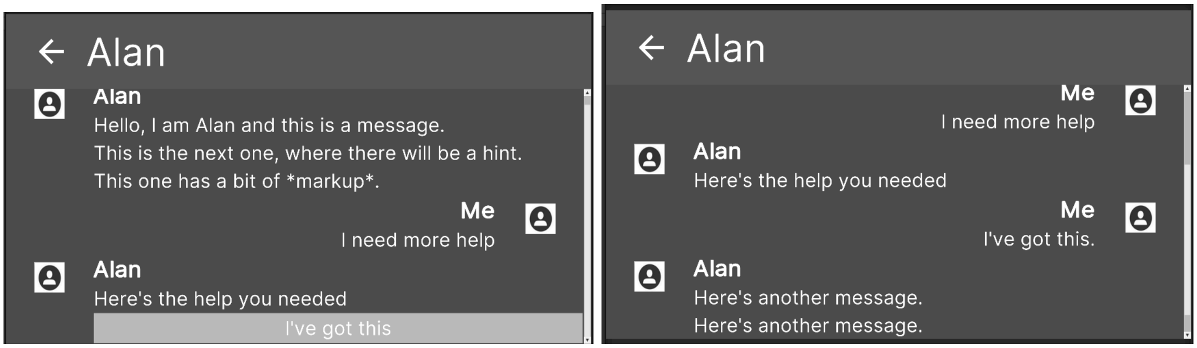


Figure 32: (Left) Alan's response to a user's request for help. (Right) Alan continues the conversation after the player confirms completion of the task.

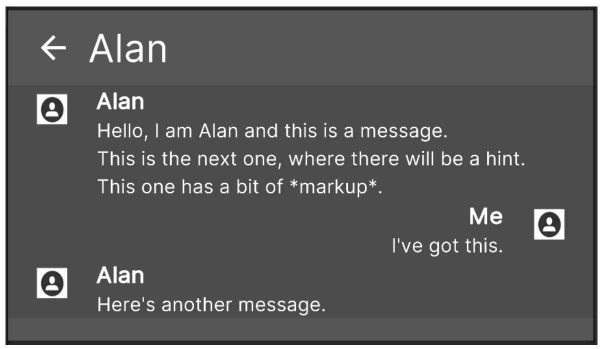


Figure 33: Alan continues the conversation after the player confirms they do not require help and have completed the task.

Module Structure

Aside from the **ConversationParser.cs,** which for now is a singular script, the module's structure includes

- **Controllers**, specifically:
  - **HomeScreenController.cs,** which is responsible for populating the home screen with all chat previews.
  - **ChatController.cs,** which is responsible for populating the chat with messages and applying any effects such as time between messages and for invoking corresponding controllers for various message types depending on the type of message to be displayed.
  - **MessageController.cs,** which does the very simple task of handling the message's text. The following controllers build on this:
    - **FirstMessageController.cs,** responsible for adding a character's name and profile picture to either their very first message, or their first message after the other party finishes chatting with them (for example, Alan's name and profile picture reappears after the player asks for a hint or sends a confirmation).

        - **HintController.cs,** responsible for handling the functionality of a hint being requested.
- **Views,** which are composed of UXML files and the corresponding USS files styling them. There exists a view for each of the aforementioned controllers, that is, the following templates:
    - **MessageTemplate**
    - **HintTemplate**
    - **HomeScreenTemplate**
        - **ChatPreviewTemplate**
    - **ChatTemplate**

It must be noted that the aforementioned views are essentially the views for the mobile application. There remains a need for designing corresponding templates for the desktop application. Due to the way the module is designed, there will be no need to change the controllers. Finally, we believe that a good feature would be redeveloping the parser to read from a JavaScript Object Notation (JSON) file, instead of only a text file. This is due to retaining the same ease of use for humans while allowing for hierarchical data structure, which is ideal for nesting hints and their answers, while remaining extremely lightweight.

6.2.2 Pending Development

In this final section, we will be briefly presenting the project structure for the rest of the desktop and mobile application functionalities. This is not an exhaustive design, as it is subject to change during implementation iterations, however we believe it is a good foundation for the development that will follow. Finally, a separate subsection for the mobile application is not included, as most of its functions are implemented in the two aforementioned modules as well as the scripts described in the following subsection.

6.2.2.1 Shared Game Logic

In order to achieve seamless communication between the two applications and ensure that both players progress through their respective tasks at the appropriate time and synchronized with each other, we propose a small 'Core' module containing the following three scripts.

- **SynchronizationManager.cs:** This manager will be responsible for handling any synchronization required between the two players. The main priority of this script is to ensure that the information given to the players (such as educational content, hints or simply dialogue) is in sync, that is, that no player sees any information before it would make sense for their partner to no about it and that no player moves on to another activity without their partner following. This script is the most likely to utilize the already integrated NGO service.
- **UIManager.cs:** This could be a manager for handling global UI, for example, a pause function.

- **GameManager.cs:** This will serve as a global game manager. Similar to the MainManager script in the Networking Module, this GameManager would be responsible for orchestrating communication between other manager scripts, coordinating logic across multiple components of the application.

6.2.2.2 Desktop App

The remote player's application, aside from the additional scripts required to implement its game logic, includes a new scene, essentially the virtual version of the MI&T museum developed in [8].

This project was also developed in Unity, but was originally a VR project. The museum scene has been imported in the desktop application project, with any GameObjects relevant to its VR controls removed. Figure 34 presents some parts of the virtual museum that were included in the evaluation prototypes and will be visited as part of the implemented experience.

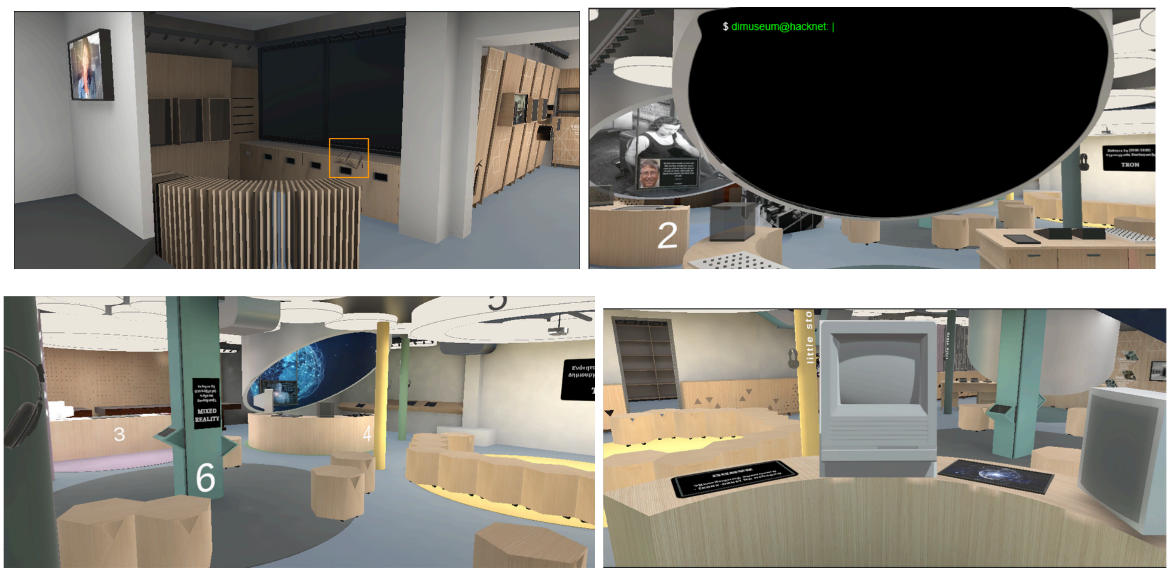


Figure 34: Views of the virtual museum scene. Top left: the entry. Top right: One of the four domes included in the architectural design, with another one in the background. Bottom left: Another dome, with the surrounding space clearly visible. Bottom right: A computer existing in the physical museum on one of the virtual museum's counter spaces.

We conclude the 'Implementation' section with describing the applications' intended scripts:

- Script that control the **Player**'s behavior, namely:
    - **CameraController.cs,** which would control how the scene's camera moves around in the virtual space, thus shaping what the player sees. This script will implement part of the point-and-click adventure game logic by controlling the camera viewpoints.
    - **DesktopPlayerController.cs,** which would be in charge of handling the player's interactions with objects (such as typing into the terminal from Activity 2, opening their inventory to store their scrap of paper and turning the guest book's pages in Activity 1, etc.), as well as the player's

movement across the different viewpoints through the point-and-click interaction.

- **Puzzle-specific scripts** that are responsible for controlling the functionality of a specific puzzle's components. This could include:
    - A dedicated puzzle manager for that puzzle, such as **FirstPuzzleManager.cs** and so forth.
    - A dedicated controller for each component of the puzzle, complete with its corresponding UXML/USS view asset. This would translate to scripts such as **GuestBookController.cs, ManualTerminalController.cs, MacintoshPCController.cs, NotesAppController.cs**, and so forth, as well as their respective UI templates.
- Finally, we conclude with **Core** scripts, whose functionality spans across the entire application:
    - **PuzzleManager.cs,** responsible for ensuring that the activities are executed in order and orchestrating communication between the rest of the scripts, such as when a specific puzzle's manager requires a function that the camera controller performs.
    - **Utility** controllers, for utilities that ought to be accessible from all puzzles, such as the player's inventory, the UV light, etc. A separate controller would be required for each utility, resulting in scripts such as **InventoryController.cs**, **UVLightController.cs,** etc.

7. CONCLUSIONS & FUTURE WORK

Motivated by the lack of social digital solutions for remote access to cultural spaces, we explored the iterative design process of a hybrid visit experience for the Museum of Informatics and Telecommunications (MI&T) at NKUA which aimed to facilitate social interaction and engagement between remote and on-site visitors. By leveraging principles of asymmetrical multiplayer game design, the project aims to enhance co-presence and promote informal learning about foundational concepts and historical milestones in Computer Science, a primary mission of MI&T.

Designing for this type of experience was a deeply experimental and iterative process, due to the novelty of this design, which resulted in a multitude of different prototypes with different educational objectives. Early prototypes revealed a multitude of factors that needed to be taken into consideration, such as activity length, scope and difficulty, content clarity, and importantly integration with the museum's physical (and virtual) space and connection. Despite these issues and the evaluation findings' preliminary nature, the game's social and narrative strengths were consistently highlighted by players, who reported enjoying the collaborative dynamic and immersive storytelling. Early testing revealed challenges with communication, as well as additional challenges with puzzle clarity, and the integration of educational content. Final improvements to voice communication, puzzle design, and the overall flow led to a more cohesive and engaging experience for the last two phases of the evaluation. Finally, refining the educational material (both mandatory and optional) and ensuring a balance between educational depth and accessibility remain key considerations for future iterations. Overall, the prototype effectively fostered sociality and enjoyment, fulfilling its core objectives while providing a foundation for further enhancement.

We acknowledge that the number of users is not yet adequate, however we believe that there is a lot more sense in continuing with a complete and thorough playtesting process once the game's basic implementation has been completed. This evaluation phase will include, among others, validating our User eXperience (UX) objectives, specifically how well the chosen interfaces for the remote and onsite users work in addition to other standard UX metrics such as a game's look and feel. Evaluating the feelings of sociality and connectedness, as well as the impact of the reworked educational content, will be more systematic through the use of well-established methods of user-centered evaluation methods such as questionnaires and interviews. In addition, we aspire to design more levels to ensure this design is extensible, evaluate its learning impact regarding different concepts and explore different elements the game could include such as those described in the Design Choices section. This includes experimenting with ludic multimedia content (such as journal entries, cutscenes, etc.), as well as leveraging different technologies, such as mixed reality for the onsite player. As a final point, we wish to include not only a great quantity of users, but also users from multiple and diverse backgrounds, including but not limited to prior gaming experience and age, to ensure that this experience design can be accessible to as wide a reach as possible, hoping to lessen feelings of social isolation and promote informal learning, especially on a domain as influential to our daily lives as Computer Science is.

ABBREVIATIONS - ACRONYMS

MI&T	Museum of Informatics & Telecommunications
NKUA	National and Kapodistrian University of Athens
MDA	Mechanics, Dynamics and Aesthetics
VR	Virtual Reality
AR	Augmented Reality
IDN	Interactive Digital Narrative
IT	Information Technology
CS	Computer Science
NPC	Non-Playable Character
HMD	Head Mounted Display
BoC	Bot of Conviction
RPG	Role Playing Game
LARP	Live-Action Role Playing
TTRPG	TableTop Role Playing Game
ARG	Alternate Reality Games
GUI	Graphical User Interface
ASCII	American Standard Code for Information Interchange
NFC	Near-Field Communication
QR	Quick-Response Code
PC	Personal Computer
3D	Three Dimensional
CHM	Computer History Museum
CTSS	Compatible Time Sharing System

TTY	Teletype
VDT	Video Display Terminal
URL	Uniform Resource Locator
SSH	Secure Shell
AI	Artificial Intellgence
UI	User Interface
VC	Voice Chat
SDK	Software Development Kit
UXML	Unity eXtensible Markup Language
USS	Unity Style Sheets
HTML	HyperText Markup Language
XML	eXtensible Markup Language
CSS	Cascading Style Sheets
NGO	Networking for Game Objects
JSON	JavaScript Object Notation
UX	User eXperience

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