

MSc Interaction Technology
Final Project

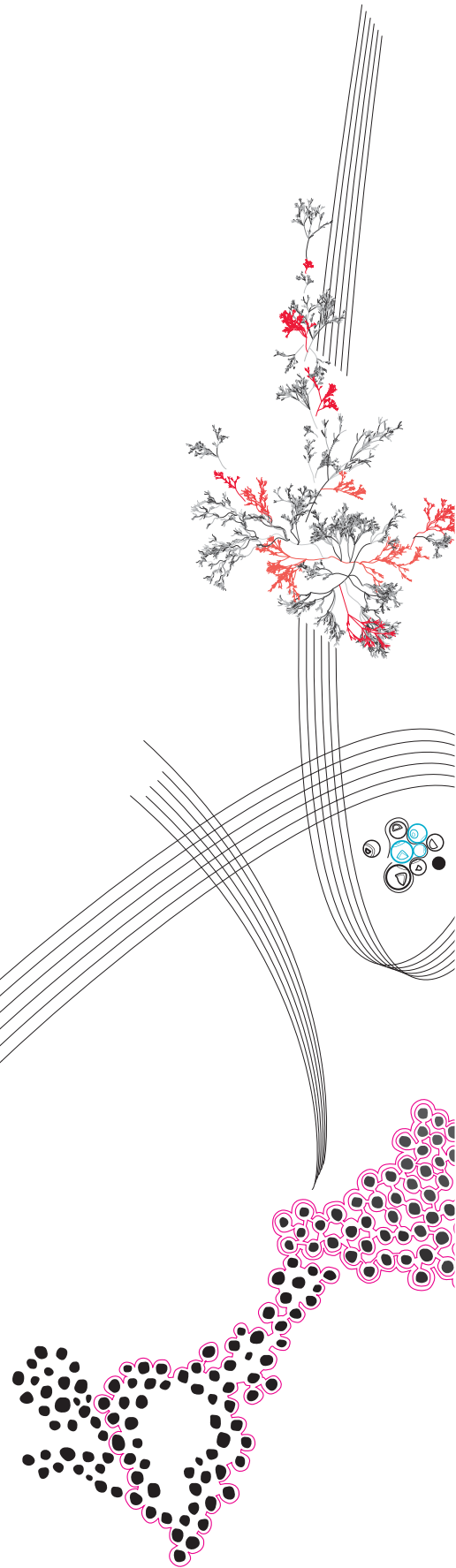
Creating a collaborative Mixed Reality experience

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Abstract

As technology evolves, its integration into various industries continues to expand, particularly with Mixed Reality (MR) applications in gaming, entertainment, engineering, and medicine. Despite the growing use of MR, current systems are predominantly designed for individual use, thus lacking collaborative opportunities, especially in gaming and entertainment. This project aims to bridge this gap by developing an MR system that fosters engaging collaborative play.

We explored various MR applications, inspired by an interactive MR pinball game, to design a system that promotes social interaction and engagement. The project was significantly supported by a graduation internship at Alten, a leading engineering and technology consultancy firm, providing invaluable supervision, workspace, and opportunities for user testing.

We defined MR as a system integrating both virtual and physical environments, allowing interactions between them, with the virtual world affecting the physical world and vice versa. The primary objective is to develop an MR system that facilitates collaborative play, validated through field studies and controlled user tests. Our findings underscore the potential of AR-based MR experiences to enhance social interaction and engagement, providing a foundation for future research and practical insights for designers and researchers.

Keywords: Computer, Science, Mixed Reality, Augmented Reality, Collaborative, HCI

Chapter 1

Introduction

As technology evolves, its integration changes, facilitating the increasingly common and favourable use of Mixed Reality (MR) in various industries, including gaming and entertainment, engineering and construction, and the medical field [29, 25, 80]. Despite its growing use, MR systems often remain designed for individual use, lacking opportunities for collaboration, particularly in the gaming and entertainment industry.

For this project, we explored various MR applications within these fields. Our immersion into the practical realm of MR was significantly nurtured by our graduation internship at Alten, a leading engineering and technology consultancy firm. Alten provided invaluable supervision, a dedicated working space, and opportunities to conduct user tests and surveys. The inspiration for our project stemmed from an interactive MR pinball game at Alten, which led to the idea of incorporating MR into our own project. This report is the second in this field; the first report [54] focused on exploring existing projects and games within or close to MR, a portion of which is included in Chapter 3.

1.1 Mixed Reality

Before exploring existing projects, it is important to define MR. Generally speaking, MR merges the physical and virtual worlds, but interpretations vary, potentially causing confusion. Therefore, we will first review a few definitions before adopting a concrete one for the rest of the paper.

[71] investigated MR definitions by interviewing ten AR/VR experts and reviewing 68 research papers. They found no single definition but identified key aspects of reality: visual, audio, motion, haptics, taste/flavour, and smell. Visual aspects can be as simple as integrating a screen. Audio examples include Spotify's audio aura, which uses song data to create a colour combination based on mood. Motion, though challenging to replicate digitally, is crucial for bridging physical and virtual realities, achievable through motion capture technology for manipulating 3D models. Haptics allow users to feel virtual objects. AR can enhance eating experiences by projecting virtual overlays onto food and manipulating flavours. Smell can be incorporated in cinemas to enhance movie experiences [71].

Adding to the above, [47] also agrees that the term "mixed reality" is not yet well known. While more recent publications exist, this seminal paper from 1994 remains significant as it discusses six classes of MR, including what we now recognise as virtual reality (VR) and augmented reality (AR). Another class highlighted involves interactive graphical environments where real physical objects in the user's surroundings are seamlessly incorporated or interact with computer-generated scenes, allowing users to interact with virtual objects physically.

[31], on the other hand, defines MR by combining previous definitions from [47, 11].

While the earlier definitions are broader, [31] makes it more concise with three elements: the system should combine physical objects in at least one physical environment and virtual objects in at least one virtual environment; it should run in real-time; and it should spatially map the physical and virtual objects to each other.

For this report, we define MR as a system that integrates both virtual and physical environments, allowing interactions between them. The virtual world can affect the physical world and vice versa, with complexity determined by the system designer. The surroundings should be integrated into the virtual world.

1.2 Objectives

This project aims to develop an MR system that allows for an engaging collaborative play experience, addressing the gap within the gaming and entertainment industry. We also aim to validate the system through a field study and controlled user tests and to showcase Alten's technological capabilities to potential employees, such as senior and graduate students.

1.3 Research question

To achieve these objectives, we defined the following main research question and a sub-research question:

Main research question: *How can an engaging digital-physical play experience be realised that promotes collaborative play among individuals?*

Sub-research question: *What kind of experience do individuals have with the resulting system, such as playfulness, engagement, and social multiplayer interaction?*

The main research question includes two terms that require further explanation, as their meanings can vary across different domains. These terms, engagement and collaborative, will be explained in more detail in Chapter 2. In short, engagement is closely related to concepts such as attention, immersion, involvement, presence, and flow. Collaborative play involves various forms of interaction between players and learners, including collective competition, collaborative learning, and cooperation.

1.4 Structure of this thesis

In order to answer the main- and sub-research questions, we will first explain these terms in Chapter 2: Background, we will then showcase the state of the art in Chapter 3: State Of The Art. After exploring what has already been done, we will form a final concept for the project in Chapter 4: From Global to Final Concept. Followingly, the resulting final concept will; be further developed and evaluated in Chapters 5: Puzzle Design and Chapter 6: Puzzle Design Evaluation. We will then discuss the resulting system in 7: Final Implementation and Enabling Technology. We will validate the resulting system and answer the research questions in Chapters 8: Validation, Chapter 9: Discussion and Conclusion. Lastly, we will provide a brief explanation about the use of AI in Chapter 10.

Chapter 2

Background

This chapter will explore and clarify the terms "engagement" and "collaborative play" as the remainder of the project will further explore these concepts, along with Mixed Reality, to aid in answering the research questions.

2.1 Engagement

[18] describes engagement as a broad range of interactions between people, including one-sided communication, active decision-making participation, and collective efforts within groups [18, 19]. Engagement elicits intense emotions during gameplay, both positive and negative, forming a tight, positive feedback loop. Processing these emotions requires debriefing, which itself must be engaging. Lack of debriefing can lead to reduced learning and increased stress, confusion, or anger [18].

Additionally, [14] notes that engagement has multiple definitions across different domains, such as marketing, communication, human-robot interaction, web applications, digital games, education, and game-based learning. They reviewed various papers [27, 82, 61, 10, 15, 64, 59, 24, 65, 22] and concluded that each domain views engagement differently. In web applications, engagement includes emotional, cognitive, and behavioural aspects. In human-robot interaction, it is more psychological and behavioural. In education, it is similar to web applications, encompassing behavioural, emotional, and cognitive dimensions. Bouvier et al. [14] focus on engagement in digital games, highlighting its context-dependency.

In digital gaming, engagement involves attention, immersion, involvement, presence, and flow. Attention is vital for concentrating on relevant information. Immersion means deep engagement, losing track of time, and feeling part of the game world, though its definition varies. Some studies suggest it involves sensory and interactive aspects making players feel like they are in the game world. Involvement is the willingness to exchange information with the system, depending on the interaction tools. Presence is the genuine feeling of being in a world other than the physical one, a subjective user experience. Flow is the balance between user skills and challenge, a subcomponent of presence.

Engagement also includes readiness to experience emotions, feelings, and thoughts directed by a mediated activity towards a specific goal, depending on the activity's nature and player expectations. Engagement occurs when players' expectations are met, akin to the "suspension of disbelief" concept, where users immerse themselves in an activity. This state can continue after the activity as individuals reflect on past experiences and anticipate future ones. This definition applies not only to digital games but also to other mediated activities like web use and online social networking [14].

Henry et al. [30] discussed findings in previous studies [17, 67, 68, 22] and suggests that the use of digital games has a positive effect on language learning behaviour of students. Upon studying these positive effects, Cornillie [17] developed a framework of engagement with digital games specific to Computer-Assisted Language Learning (CALL), that defines engagement as when learners are intrinsically motivated to use L2 in a meaningful and communicative way.

Although there is no universal conceptualisation of engagement, there are three commonly accepted key aspects of the student engagement concept acknowledged by researchers. The first one is that student engagement is related to specific targets. Meaning, that the nature of what students are engaged in influences the outcome or consequences of their engagement.

The second one is that student engagement is multidimensional. It entails various dimensions, such as behavioural, affective (related to emotions and feelings) and cognitive (related to thinking and mental processes). Suggesting that engagement is not just one-dimensional but rather more complex.

The last one is that student engagement fundamentally involves observable behaviours directly related to the learning process. This can be in the form of "participation" or "task focus". Engaged behaviour can vary in intensity ranging from basic attentiveness and compliance to more concentrated effort and persistence [30].

2.2 Collaborative play

According to Romero, there are three ways of collaborative game-based learning mechanics due to different types of interactions between players and learners. The first one is called collective competition by playing against others. This can also be seen in for example online video games where individuals play against other individuals. They all have the same goal but have to achieve that goal on their own. Others can however comment and view player rankings. The second one is games supporting collaborative learning by playing together for learning. With this type of collaboration, players develop skills such as negotiation, collaborative decision-making and creative problem-solving. The third one is playing together against other groups or as Romero calls it "coopetition" [62].

[41] notes that puzzles are typically single-player games. Their study investigates issues in collaborative puzzle design through the game eScape, highlighting that traditional single-player concepts don't always apply. While the study shows promising results, improvements are needed, particularly in enhancing collaboration by increasing pressure, risk, or creativity. Manninen and Kova [41] conclude that designing constructive games is harder than destructive ones. Game designers can choose to design collaborative games, but players must decide to play collaboratively. Designers can also force collaboration by creating tasks that require teamwork, such as pressing four buttons simultaneously [41].

[35] states that interest in collaborative games is growing in both the gaming industry and academia, driven by the internet and social media enabling wireless connectivity and collaboration. The game industry influences technology development, often aiming for global games and sometimes overlooking local contexts, leading to the creation of location-based games that include contextual elements.

[35] identifies three main areas of investigation: learning environments, interaction, and in-gameplay experience. Learning environments focus on how games support learning, especially through location-based applications. Interaction examines game mechanics that facilitate player communication. The in-gameplay experience explores how commercial games promote collaborative activities.

Research on collaborative play has shifted from studying individual functions within a group to analyzing the group itself [21]. Initially, the goal was to see if collaborative learning yielded better results than individual learning by controlling variables like group size, composition, and task nature. However, the interaction of these variables made it impossible to establish causal links. Thus, studies now focus on how these variables moderate interaction.

[21] notes that different fields understand learning and problem-solving, as well as collaboration and cooperation, differently. In psychology, learning and problem-solving are considered the same, while computer scientists see them as separate. According to [63], collaboration involves mutual engagement in solving a problem together, while cooperation involves dividing labour among participants, with each responsible for a part of the problem-solving [21].

[36] researched the benefits of cooperation, suggesting that teachers learn from each other through practice rather than memorisation. Cooperation, where members work together for joint goals, was compared to competitive, intergroup, and individualistic learning. Results show that while competitive learning has some advantages over individualistic learning for adults, intergroup competition decreases overall productivity. Cooperation fosters more positive relationships than competitive or individualistic efforts. [36] also found that cooperation provides greater social support among adults and tends to foster higher self-esteem than competition, though there is no significant difference between cooperation and individualistic learning. Some studies suggest individualistic learning can promote higher self-esteem than competitive learning. They conclude that cooperation among adults supports achievement, positive relationships, social support, and self-esteem. Therefore, organising teachers into collegial support groups enhances expertise, relationships, cohesion, social support, and self-esteem [36].

[9] argues that collaboration can reduce productivity and motivation when contributions are unequal. However, it benefits learning outcomes by enabling information sharing, idea development, and providing opportunities to ask questions. Collaboration also aids memory recall and serves as quality control for detecting errors. Insufficient preparation can lead to less cooperation, more off-task behaviour, and poorer learning outcomes in high school students. Proper preparation improves results, especially for complex tasks, as students perform better collaboratively on complex tasks than simple ones. [9] concludes that collaboration's advantages are evident when: 1) all group members' inputs and cognitive abilities are effectively harnessed, 2) obstacles to effective collaboration are reduced, and 3) critical assessment and discussion-based argumentation are enabled. Thus, collaborative activities should be designed accordingly [9].

2.3 Conclusion Background

In this chapter, we explored the terms "engagement" and "collaborative play" by looking at different literature. From this literature, we can conclude what engagement and collaborative play entail for the remainder of the project.

Engagement is dependent on the domain in which the term is used. For digital gaming, there are several concepts including attention, immersion, involvement, presence, and flow. Attention involves focusing on relevant information, immersion means deep engagement and losing track of time, involvement refers to interacting with the game system, presence is feeling part of the game world, and flow is achieving a balance between challenge and skill. These concepts will also be considered during later stages such as in setting up

requirements, designing a concept, and user tests.

The most important aspects of collaborative play that we consider for upcoming stages contain three points. First, collaborative puzzles require high interaction among players, differing from single-player puzzles. Second, enhancing collaboration can involve increasing pressure, risk, or creativity. Third, game design can force collaboration by requiring tasks that need teamwork. To conclude, our exploration of "engagement" and "collaborative play" has provided a comprehensive understanding of these concepts, which will be crucial for the remainder of the project.

Chapter 3

State Of The Art

Mixed realities can be realised in different ways. This chapter will look at what some of the many possibilities are in four sections. The first section will talk about projects people have realised. The second section will talk about existing games. We grouped both sections into different types of installations by looking at their common main characteristics, including Tabletop, Rube Goldberg machine, AR Sandbox, Escape room, Spatial, and Parkour. All of these installations are either within the field of MR or projects that are relevant within the field of MR. The third section explores a bit of technology which could make MR possible. The last section talks about single- versus multiplayer experience.

3.1 Projects

3.1.1 Tabletop

[72] created a portable mixed reality game using standard equipment like a computer, projector, and webcam. Their goal was to develop an intuitive augmented reality platform that's portable, works with common hardware, interacts with real objects, and supports various applications. They tackled challenges such as image quality, projector-camera misalignment, real-time constraints, and hardware-software integration by employing C++ and libraries for tasks like object recognition, calibration, physical calculations, and user interface. In gameplay, the computer connects to the projector, displaying the game on a table or whiteboard, where players interact by moving their hands to control a virtual ball, with the option to include real objects or drawn shapes in the game environment [72].

Next, the Augmented Cafe Table, developed by [48], enhances group interactions in a museum cafe setting. While not strictly MR, it offers insight into interactive tabletop engagement. It utilises a standard cafe table with top-projected graphics and sensors like cameras and microphones to capture data on head movements and voice activity, shaping visual stimuli accordingly. By highlighting content like water drops or fish movements, it aims to stimulate museum-related conversations. A strategic planner module selects the best communication strategy based on gathered data to foster engaging interactions. In summary, the Augmented Cafe Table is a configurable platform promoting meaningful discussions and increased participant engagement [48].

Moreover, [53] devised an AR game utilising marker-based tracking. Players wear a head-worn display and a wireless backpack while gripping a driving controller. A 3D user interface offers options like starting the game, adjusting settings, viewing credits, or seeking help, navigated by pointing for three seconds. The game commences with a countdown, placing the car on the board. Players aim to complete three laps by following specific way-

point sequences, guided by animated arrows and markers. Game difficulty adjusts based on factors such as object number, size, arrangement, and influence from other players setting waypoints and obstacles. Falling off the board prompts the car to reappear at the center, and realism is enhanced by occluding objects using the ground plane.

On the other hand, [76] investigated the use of Spatial Augmented Reality (SAR) in classrooms for individuals with visual impairments. Traditional tactile maps are limited by their lack of interactivity and reliance on braille, which caters to only 20% of the visually impaired population. To address these issues, Thevin et al. [76] aimed to create a more inclusive system. They compared a Graphical User Interface (GUI) with a SAR-based system, finding that while the GUI offered greater precision, participants preferred SAR for its user-friendliness and faster map creation. The SAR system allows users to draw on any surface using a projector, depth, and RGB cameras, effectively turning it into a touch-screen. Interaction points, like cities on a country map, can be created and programmed to offer audio cues when touched, which can be prerecorded by the teacher. After creating the map and interaction points, students can interact with them accordingly. While currently used in educational settings, the SAR system holds potential for multiplayer games or sandbox environments [76].

CARDS, a MR system designed for group collaborations in schools, combines the advantages of both paper-based and digital collaborations. Researched by [26], CARDS is dynamic with digital content yet easy to manipulate as it utilises physical pieces of paper. It allows multiple individuals to use it simultaneously, and users, especially children, find no noticeable distinction between projected and printed images. CARDS surpasses traditional printed materials by integrating various multimedia elements like video content. Additionally, creating and modifying mind maps is straightforward with a stylus, allowing users to draw and break connections effortlessly. Supplementary tokens, such as a magnifying tool for zooming in on projections, enrich the collaborative experience [26].

The ReacTable, developed by [37], features a circular translucent surface equipped with a computer vision system to track the position and orientation of physical objects like blocks or tokens. These objects represent various musical components such as synthesizers or filters. Users manipulate these objects to create and modify sounds in real-time. Visual feedback is provided through a GUI displayed on the table, representing objects as icons and visualising their connections and interactions. Objects can be connected by proximity or by drawing virtual connections. Multiple users can engage with the table simultaneously, each contributing to the music-making process. A camera beneath the table detects hand movements and tokens, preventing shadows and occlusion that would occur if the camera were placed above the table [37].

[50] developed a system enabling users to play an instrument on any surface by projecting a user interface (UI) onto it. The user wears a wristband containing an Arduino Nano to detect hand movements, while a depth camera detects surface taps. Although the system's accuracy varies, user tests suggest it functions effectively overall. Communication between the wristband and server occurs via Bluetooth, with processed movements translated into music notes corresponding to the chosen instrument and sent to the speaker [50].

3.1.2 Rube Goldberg machine

The Amuseum project team collaborated with the MuseumLab at the Children's Museum of Pittsburgh to integrate AR elements into a Rube Goldberg machine [51]. They aimed to enhance visitor experience with interactive AR features, overcoming challenges of inte-

grating AR into an existing physical and digital environment. The final machine taught guests how to send letters through snail mail, combining logic and absurdity. Unconventional objects and AR-enhanced animal elements enriched the installation. Visitors could participate simultaneously by scanning an AprilTag with any web XR-capable browser. Raspberry Pi sensors and servers enabled interactions between physical and virtual realms, with special speakers and sounds guiding visitors' attention [51].

3.1.3 AR Sandbox

Reed and his team [58] developed an Augmented Reality Sandbox, using a depth-sensing camera like the Microsoft Kinect to detect changes in sand height and project corresponding colour-coded topographic contours onto the sand in real time. As users shape the sand, updated depth information is captured and processed to create a dynamic topographic map, forming the basis for projecting terrain features onto the sand surface. Moreover, the system simulates water flow by detecting surface changes and projecting virtual water, allowing users to create rivers, lakes, and other water bodies, with realistic flow patterns generated in response [58].

3.1.4 Escape room

In a game developed by [38], two distinct rooms are featured: one for player A and the other for player B. Player A occupies the On-Site room wearing a Vive VR headset, where they interact with physical objects and perceive player B's hand gestures and head position. Meanwhile, player B is in a remote location wearing Holo Lens [32] AR glasses, viewing a virtual world along with animated representations of their hands and player A's head position. The On-Site room acts as an escape room, necessitating specific tasks for a final code and successful escape. While player A physically carries out these tasks, player B guides them, with access to virtual elements like laser beams. Notably, only player B can perceive these virtual aspects. This game innovatively merges AR and VR technologies, blending real-world and digital experiences [38].

3.1.5 Spatial

In their work, [16] introduce two innovative games that blend the virtual and real worlds using mobile computing, wireless LAN, ubiquitous computing, and motion-tracking technologies. The first game, "Human Pacman," sees players embody Pacman characters or Ghosts, navigating real-world spaces while interacting with virtual elements. They tap on physical objects or people to consume virtual enemies and collect items. The game employs a client-server architecture, wearable computers, laptops, and Bluetooth-embedded objects connected via wireless LAN. Players, divided into Pacman and Ghost teams, can have remote Helper players join through the internet, mirroring the original Pacman objective of collecting cookies while avoiding Ghosts. The game operates across physical, augmented, and virtual reality modes, with real-time position data updating wearable computers and virtual item locations. Tangible interactions like holding objects and tapping sensors are encouraged, with each Pacman or Ghost paired with a Helper in virtual reality for guidance and collaboration.

The second game, "Touch-Space," revolves around rescuing a princess captured by a witch in a castle. Players navigate a large room-sized area, interacting with real objects to progress in the game space, similar to traditional non-computer games. The physical space can be augmented with virtual objects, seamlessly blending computer entertainment with the real environment. Multiple players can participate simultaneously, maintaining social interaction, and players can transition between immersive virtual environments and

physical reality through a traversable interface [16].

[66] used the Holo Lens to build the first level of Super Mario. He mapped the whole first level into 3D objects and replicated the game in AR. The game can be played both inside and outside, but it is recommended to play it outside. The game includes jumping to either avoid things or collect items. All of the interaction is only happening in the virtual world, e.g., collecting items. The game is a personal project and can not be downloaded or purchased anywhere [66].

ARLooper is an application, designed by [55], that allows multiple users to collaborate on making music without verbal communication. On the app, the user can press a button in order to start recording the sound they want. At the same time, the sound is displayed as a 3D tube-shaped waveform, where the size and brightness of the tube are influenced by the audio’s amplitude. Additionally, the centre points of the waveform align with the device’s spatial position, creating a visual representation that corresponds to the device’s movement in space. Every user has their own user ID colour. And all users are in the same room while making music [55].

3.1.6 Parkour

In their work, [40] developed an augmented reality (AR) game to teach individuals with motor disabilities how to control an intelligent wheelchair. The system comprises two main modules. Module 1 involves configuring the system, offering two operating modes: O1 and O2. O1 utilises cloud anchors, accessible via smartphone or computer, to link virtual objects. These objects can be positioned intuitively using gestures like dragging, rotating, and pinching/spreading. O2 performs the same functions but without storing cloud anchors.

Module 2 introduces the AR Scenario Game (ARSG) for robotic wheelchairs. The scenario experienced depends on the chosen operating mode. In O1, the system recognises saved cloud anchors, instantiating virtual objects accordingly. In O2, virtual objects appear in the smartphone’s field of view, aligning with the device’s position during configuration. Game objectives vary based on the mode selected, ranging from following a white line to pursuing a moving car. Users must adhere to game features to maximise scores [40].

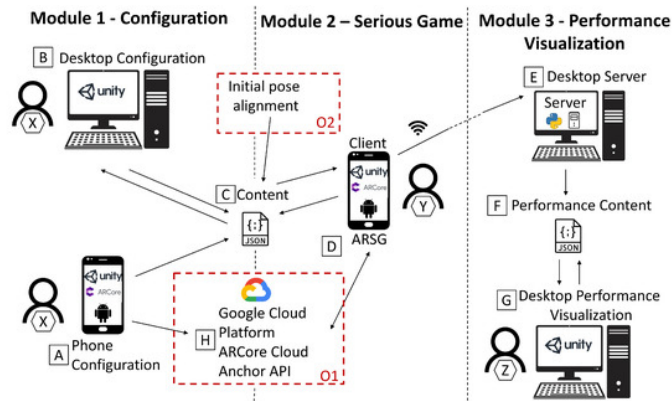


FIGURE 3.1: Architecture overview: O1—requirement for motion tracking using the cloud anchor operating mode; O2—requirement for offline motion tracking operating mode. [40]

3.2 Games

3.2.1 Tabletop

Mirrorscape [49] is an AR gaming company enabling multiplayer experiences in immersive 3D environments that blend reality with digital elements. Traditionally, tabletop gaming has been limited to physical setups or 2D virtual tabletops (VTTs) online. Mirrorscape bridges this gap by offering interactive 3D terrains, dynamic miniature movements, and social engagement, akin to physical gaming, while providing the flexibility of VTTs to play anywhere, anytime. Gameplay requires a phone or tablet directed at the table, though this may pose inconveniences if the device must be continuously held.

Spatial [70] provides a holographic AR platform for tabletop gaming, creating an immersive experience where players interact with virtual objects in the real world. It transforms a physical tabletop into a dynamic AR gaming environment, projecting virtual game elements onto its surface. In tabletop gaming, Spatial allows for projecting game boards, cards, tokens, and more onto the tabletop, enabling players to manipulate these virtual objects as if they were real. Moreover, Spatial facilitates multiplayer experiences by connecting players in the same virtual space. They can see each other's avatars, communicate through voice chat, and collaborate or compete in real-time gameplay.

3.2.2 Rube Goldberg machine

Gadgeteer [23] is a VR puzzle game where players become inventors in a workshop, tasked with constructing intricate Rube Goldberg-style machines using a variety of gadgets. These gadgets, including ramps, dominoes, balls, and conveyor belts, offer unique properties and interactions. Players progress by unlocking new gadgets as they solve puzzles. The game features intuitive controls for manipulating and connecting gadgets in the virtual space, allowing for experimentation and refinement of machine designs. With levels ranging from simple tasks to complex puzzles, players can explore open-ended creativity or tackle specific objectives. Gadgeteer also offers a community aspect, enabling players to create and share their own levels, enriching the game's content and promoting collaborative play.

3.2.3 Escape room

In the game "I Expect You To Die: Home Sweet Home" [33] the player becomes a secret agent in the comfort of their living room, by creating a mixed reality environment. In the game, the player is implanted with an ocular implant. With this, they can decipher puzzles, evade dangerous threats, battle robotic hornets, and utilise an assortment of spy gadgets. The evil character Dr. Zor has planted a trap in the home of the player and it is up to them to save themselves from it. The game has several key features. First of all, the home of the player is transformed into an escape room, using mixed reality. Second of all, it involves solving a mini-mission before the villain of the game can craft an evil plan. Lastly, by using the AR glasses, the player can "see" hidden objects in the wall [33].

"Keep Talking and Nobody Explodes" [1] is a cooperative multiplayer VR game. In the game, one player is tasked with defusing a bomb, while the other players, who cannot see the bomb, provide instructions on how to defuse it using a manual. The game emphasises communication and teamwork, as the defuser must describe the bomb's components accurately and the instruction-givers must interpret the manual correctly to guide the defuser through the disarmament process.

3.2.4 Spatial

Minecraft Earth [8] brought the beloved Minecraft universe into the real world through AR technology. Players used their mobile devices to interact with virtual Minecraft elements projected onto their surroundings, enabling them to build, gather resources, and engage in activities akin to the original game. Leveraging geolocation and surface detection, players could place virtual blocks and objects in their physical environment, fostering collaborative building experiences and allowing them to showcase creations. Minecraft Earth introduced new features like Adventures—location-based challenges and puzzles for collaborative play. Players could also collect Minecraft mobs, customise characters, and participate in special events and seasonal content.

The goal of the game VRTuos [81] is to learn to play the piano. The game can recognise the size of the piano and the keys on it. In the game, the player can choose a song to learn. They can also upload songs to learn. In the game strokes in different colours fall down on the right key to indicate which key needs to be pressed when and for how long. This allows the player to learn to play the piano in a fast way. The player can still see their hand and the rest of the environment while playing [81].

3.2.5 Parkour

[73], developed by Joy Way, is a VR game centred on parkour-style gameplay. Set in an urban environment filled with skyscrapers and obstacles, players navigate using dynamic parkour moves like running, jumping, climbing, and swinging. Agility, timing, and precision are key as players execute jumps, leaps, and wall runs to progress through multiple paths. The game encourages creative movement, offering freedom to choose different approaches. Using motion controllers, players simulate authentic parkour movements, fully immersing themselves in the experience.

Mario Kart Live: Home Circuit [43] merges physical remote-controlled cars with virtual elements using Nintendo Switch consoles. Players control a physical kart equipped with a camera, driving it through AR-generated racetracks and obstacles in their real-world environment. They set up gates to create custom courses at home or elsewhere. The kart's camera feeds live footage to the Switch screen, offering an MR experience with virtual opponents, power-ups, and environmental elements. The game retains classic Mario Kart gameplay, allowing players to collect items, use power-ups, and compete against AI or other players in multiplayer races. The physical kart reacts to in-game actions, providing an immersive blend of real-world and virtual racing.

3.3 Technologies

This section will begin by providing an overview of commercially available headsets. It will then talk about hand detection as a potential form of interaction.

3.3.1 Headsets

There are a lot of VR/AR headsets available for commercial use. It's essential to examine the most common options, considering their specifications and prices, before potentially deciding to use a headset. The specifications are crucial for understanding their capabilities, while the prices are important to consider due to potential budget constraints for the project. A few of them which are relevant in terms of creating an MR space are listed down below.

The first one is Meta Quest Pro. It is a headset designed by Meta and is listed for €1,199. It comes with 2 controllers to enable controls within applications. The headset itself is transformable into a VR headset by attaching rubber attachments to the side of the eyes. The AR option with the pass through is done by using cameras showing the user a camera feed of the room rather than then the room itself, directly through the glasses [46].

The second one is the Nreal Air AR [52] glass. These are glasses that look like normal sunglasses. It is a lot lighter than a normal VR/AR headset. They are available for around €360. The glasses require a USB-C connection to your phone, which may pose a limitation for certain Apple users, as they may need an adapter for direct usage. There are 3 options that you can choose from while wearing the glasses. The first option is to mirror the screen on your phone. The second option is to use the screen of the glasses itself. There is also an option to connect it to your laptop to be able to work on multiple screens at the same time. The glasses are adjustable to the user's head shape and size and there are lenses available for people who need glasses to attach to the AR glasses [52].

The third one is the HoloLens from Microsoft [32]. There are three different options one can choose from, being HoloLens 2, HoloLens 2 Industrial edition and Trimble XR10 with HoloLens 2. The latter two are used in work fields, but the first one can be used for daily use such as games. It is currently available for 3.5K euros, making it a quite expensive headset. The experience however is everything one would expect from an AR lens in terms of immersiveness. The user is still able to see the normal world while using the headset. Giving the idea that the virtual world is actually present in the real world [32].

The last one is the MagicLeap [39], similar to Air AR glasses from Nreal and HoloLens. These glasses are not only for gaming purposes but have a wider range of uses, such as in medical settings and industrial environments. Their motto is: "We seamlessly integrate the digital into the physical world to amplify human potential". The headset comes with a controller and a licence is needed to be able to develop. It can be purchased online for almost 3.5K euros, with an additional €797 for the license [39].

3.3.2 Hand detection

[20] developed a hand detection system applicable to human-computer and smartphone interactions. This system, using OpenCV and C++, segments the hand from the background by setting a threshold for pixel values. This technique enables two applications: a gesture-controlled robot and a pick-and-place robot. The former interprets hand orientation and finger counts to control robot movements, while the latter tracks finger movement to manipulate objects. Users interact with the pick-and-place robot by selecting objects and their destinations through fingertip overlays on the robotic arm's camera feed [20].

According to Thwe and The [77], hand gesture recognition encompasses various techniques primarily aimed at designing systems for controlling electronic devices. They reviewed common methods and tools for hand gesture recognition, analysing their strengths, weaknesses, and associated challenges. Several papers from their literature survey are discussed, each offering unique approaches to hand recognition.

One such paper [57] achieved 92.4% accuracy in recognising 55 static and non-static hand gestures using depth data. However, issues arose when users wore bracelets, suggesting the need for improved adaptation methods. Another paper [12] employed deep learning to recognise small hand gestures without segmentation, achieving 97.1% accuracy with simple backgrounds but requiring enhanced robustness for outdoor use. A third paper

[69] utilised a Faster Region-Based Convolutional Neural Network, achieving 86.12% accuracy with real-time webcam images but facing limitations in detecting very small hands. The fourth paper [56] attained 94% accuracy on Cambridge dataset and a 98% of accuracy on Sebastien dataset using Hough Transform and Neural Network [77].

Overall, describes two main stages in general hand gesture recognition: training images and testing images. Both involve pre-processing, hand region detection, and feature extraction. Training images additionally include database formation and feature matching, while testing images proceed directly from feature extraction to feature matching without database involvement [77].

[42] proposes a novel approach to Human-Computer Interaction (HCI) by introducing hand gesture recognition as a means of controlling video games. Unlike traditional devices such as keyboards or mice, this method offers real-time responses in an unconstrained environment. Using a webcam, users interact with a 3D video game solely through hand gestures, without the need for uniquely coloured gloves or markers on hands or a controlled background. This inclusive approach led to the development of an algorithm that works for most individuals without additional tools.

Manresa et al. [42] achieve their objective through three key steps. Firstly, they segment the hand by locating the region in the image based on skin colour, which remains consistent during natural hand movements, scale, and rotation. Secondly, they track hand position and orientation using pixel-based tracking to provide continuous updates and prevent segmentation errors. Lastly, they recognise gestures by utilising the estimated hand state and extracting features for gesture recognition.

3.4 Single versus multi-player

[74] examined the impact of single and multiplayer video games on gamers' mental well-being. Through online questionnaires, 260 responses were collected, with 132 indicating a preference for single-player games and 128 for multiplayer. During the pandemic, there was a notable increase in both single-player (105%) and multiplayer (129%) gaming sessions exceeding 5 hours daily compared to pre-pandemic levels. Motivations for gaming differed between the two groups: single-player gamers cited reducing anxiety, stress, and escapism as primary reasons, with percentages increasing from 40% to 70%, 76% to 89%, and 69% to 90% respectively. Conversely, multiplayer gamers cited socialising, stress reduction, and escapism as key motivations, with percentages rising from 43% to 76%, 45% to 47%, and 61% to 66% respectively. Despite a slight decrease in stress reduction during the pandemic (from 74% to 70%), Su [74] concludes that single-player games generally aid in relaxation, stress reduction, and potentially improving mental health during such times, while multiplayer games enhance social interaction and possibly social well-being [74].

Vella et al. Vella et al. [79] explored the impact of social context in video game play on player experience and well-being. Through four studies, they examined factors like solo versus multiplayer, competitive versus cooperative play, and relationship dynamics. The first study focused on player experience and well-being, finding that playing with others predicts greater social well-being, though this effect diminishes when considering other player experience factors.

The second study highlighted differences between playing alone and with others: solo play emphasised autonomy and presence, while playing with others increased feelings of relatedness. Cooperative play with familiar individuals enhanced relatedness, whereas competitive play with strangers decreased it. Additionally, mixed play showed the highest bridging social capital. Single players' well-being correlated with autonomy and related-

ness, while multiplayer players' well-being was influenced by playing with strangers and bridging social capital.

In the third study, player motivations varied by social context: solitary players sought relaxation and autonomy, while social players sought challenge and relatedness. Mixed play was deemed most enjoyable and least dissatisfying, with players primarily considering practical and psychological factors when choosing their social context.

The final study, a laboratory experiment, compared cooperative play with avatars (human-controlled characters) to play with agents (computer-controlled characters). Cooperative play with avatars enhanced positive affect, presence, enjoyment, connection, and cooperation compared to play with agents.

3.5 Conclusion of State Of The Art

This chapter first examined the state of the art in two sections: projects and games. These sections provide a diverse range of examples demonstrating how MR can be realised, forming a foundation for the final concept's design process. We then reviewed two types of technology: headsets and hand detection. Despite being commercially available, headsets remain too expensive for the scope of this project. Hand detection offers a highly interactive MR experience with high accuracy, but it requires substantial computing power to recognise gestures. Lastly, we examined single-player versus multiplayer games, finding that both types help reduce anxiety and stress and provide an escape from reality. Additionally, multiplayer games offer opportunities for social interaction. Solitary players seek relaxation and autonomy, while social players seek challenge and connection. In conclusion, these findings will inform the design of the final concept.

Chapter 4

From Global to Final Concept

This chapter will first set the project requirements, then talk about the different methods used to generate ideas, such as a persona, mind map, a mood board, the 100-idea technique, asking peers, story boarding. Finally, one idea will be selected to continue with for the remainder of the project.

4.1 Persona

Initiating the ideation process involves creating a persona. The persona represents the potential user of the to-be-made experience. The persona can be found in Figurefig:Persona.



FIGURE 4.1: Persona of a potential user

4.2 Mind map

Based on findings from the previous report [?] we made a mind map to illustrate the main concept along with its surrounding facets. This is done to gain deeper insight into the facets. See Figurefig:MindMap.

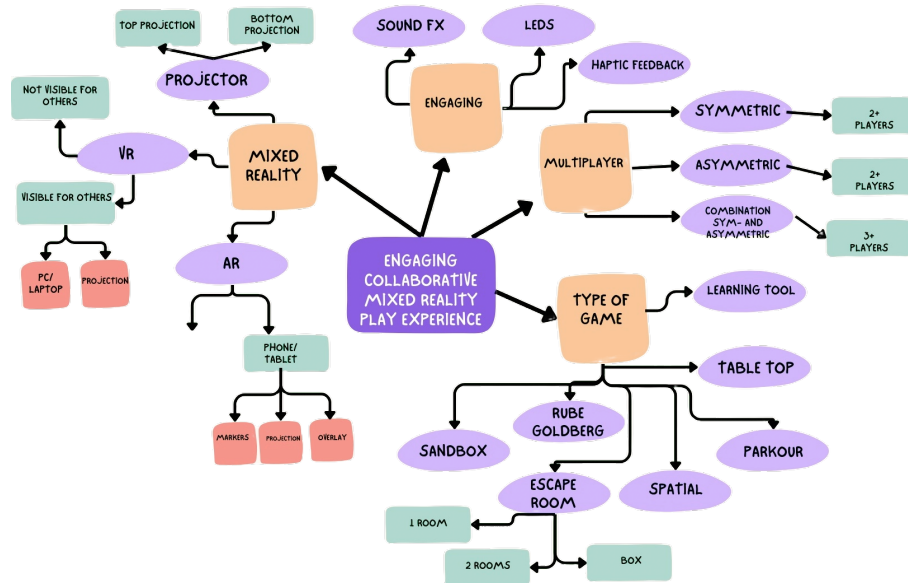


FIGURE 4.2: Mind map

4.3 Mood board

To visualise the mind map and to gain a greater understanding of the project a mood board is made using Canva. Canva is an online tool with which one can design things like posters, flyers, social media posts, etc. but also a mood board. The tool also allows the user to generate images using AI. To do this, the user needs to fill in a prompt for the AI to work with. The user can also select different themes for each prompt. The prompts used for this mood board are:

- AR game collaborative
- MR escape room collaborative
- AR collaborative riddle
- Collaborative AR
- Collaborative MR escape room

Each prompt allows the user to choose from four different pictures, but the results can also be refreshed to generate new images from the same prompt. We made a mood board, from the results the AI provided, see Figure 4.3.

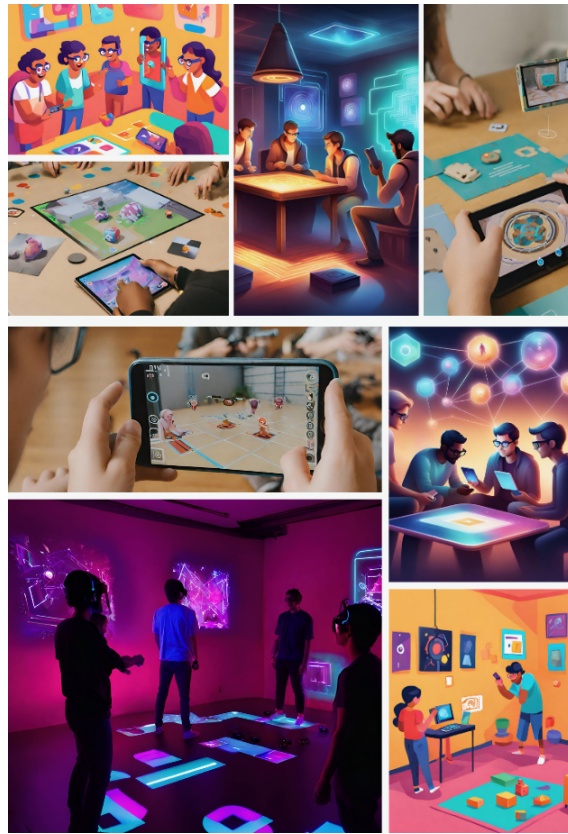


FIGURE 4.3: Mood board Mixed Reality

4.4 100 idea technique

The 100 idea technique promotes creative thinking by encouraging the generation of ideas without filtering them beforehand. While this approach can yield numerous ideas, many may not align with the project's scope. However, the primary goal is to initiate the creative process. Figure 4.4 showcases the ideas generated using this technique, amounting to 45 over several days. The discrepancy between the actual number of ideas and the intended 100 could stem from subconscious pre-selection during ideation. Despite this, most ideas were conceived with criteria such as MR environment or collaborative play in mind.

- 100 Ideas
- 1) Football table top game
 - 2) Ping pong table top game
 - 3) 2 player escape room
 - 4) Hide and seek
 - 5) Hot or cold? Hide and seek object?
 - 6) Making music piano
 - 7) Digital-physical drawing (to learn)
 - 8) Mario cart game
 - 9) Quiz/Match/Trivia
 - 10) Solving puzzles
 - 11) Escape room box
 - 12) Marble track
 - 13) Karaoke
 - 14) Chess with real pieces followed by virtual opponent
 - 15) Boardgame with virtual obstacles
 - 16) Puzzle with virtual obstacles
 - 17) Pointing virtually on physical wall/object
 - 18) Upgrade version of Wii sports with feedback
 - 19) Interactive art with camera, user being the artist
 - 20) Lego physical/digital
 - 21) Tick tick toe draw physically play digitally
 - 22) 4 in a row " " " " " "
 - 23) Pokemon training card game + virtually appearing Pokemon animation etc

(A) Ideas 1-23

- 24) Building a city sand box
- 25) DJ table turning everyday objects into instruments
- 26) Sound box; send a sound from an app to the box, the box becomes something you can make music with
- 27) Shatters game in space table top
- 28) Interactive room; Draw an environment digitally and the room is transformed into that environment. The environment can be manipulated physically & digitally. Or vice versa physically.
- 29) Multi player
- 30) Fake Goldberg MR
- 31) Interactive drawing table (learning tool)
- 32) A table/surface suggesting recipes based on the product(s) on the table
- 33) Table top maze game with real physical objects
- 34) Interactive pingpong table, table shows points to him for extra points or "no" points
- 35) Air plane simulator
- 36) AR pacman game (with like setting)
- 37) AR pacman 2 separate rooms
- 38) Bowling with projectors
- 39) Midget golf with MR elements

(B) Ideas 24-38

- 39) MR Angry birds type of game
- 40) Interactive drawing table (learning tool)
- 41) Fireboy & Watergirl game with capacitive sensor on the floor for some controls
- 42) IKEA building game with AR guide and feedback
- 43) 2 player game where 1 draws something digital and it appears on a wall (using a projector). The other one has to catch the items with a net/basket etc.
- 44) Scavenger hunt
- 45) Tag game with interactive floor

(C) Ideas 39-45

FIGURE 4.4: 100 idea technique

4.5 Asking peers

To generate even more ideas, we posed two questions. First, we inquired whether they knew about MR. For those unfamiliar, we provided an explanation: "MR integrates virtual and physical worlds, allowing interaction in both directions, distinguishing it from VR and AR." (See Figure 4.5).

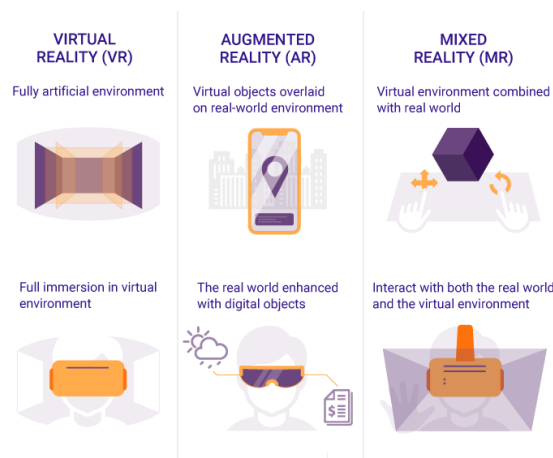


FIGURE 4.5: Illustration of Mixed Reality

After this, or if they already knew about MR, we asked them to name three MR-related ideas without specific guidance, encouraging completely free thinking. While this approach yielded diverse responses, not all were project ideas; some were simply associations with MR. We received 17 responses in total, which can be found in Figure 4.6.

ID	Do you know what MR e	Name 3 Ideas that come to mind when thinking of MR?
1	No	making running more interesting, cause that is boring design products using fusion360 or solidworks, but being able to walk around the products
2	No	Navigation. Recipe when cooking Ordering items and trying to find a specific item
3	No	Gaming (like Pokémon GO), team meetings in MR, attending concerts in MR
4	Yes	1. Creating/modelling prototypes of physical objects 2. Remote office meetings 3. Virtual desk with virtual computer screens
5	Yes	Create a 3d render of a machine where a senior can explain the ins and outs of the machine. Simulate an emergency situation like fires in a building. Creating a new layout and design for your house Training an AI model, a human could demonstrate what to do in a real environment from which the AI model could learn
6	No	Even more emersive gaming experience
7	No	Lijkt op de werkelijkheid Meerdere versies/werelden beschikbaar Machine Learning
8	No	Force generation proportional to position A game with a ball where the env changes Typing with your hands in the air instead of keyboard - Virtual scoreboards or game statistics in physical games and sports - Ability to draw 3D models with physical drawing activity - realtime subtitles when somebody is speaking to you
9	No	
10	No	Online Meetings Games AI glasses (buddy)
11	No	People learning how to fight with vr on that tells them where to go - a vr coach with a real person. A way to eat dinner with friends or family far away in a more realistic setting. Enjoying a theater show with more diverse and different backgrounds. Like watching a live movie in which the sets change. The Mandalorian film set method (used huge TV screens as background to let the actors know how it looks like instead of green screens) AR glasses from Google. Being able to draw in AR while still seeing the space around you.
12	Yes	
13	No	Tele-interaction; long-distance execution of certain specialised tasks, e.g. drone/plane piloting or performing surgery when at a different location. (Customisable/adaptable) art installations and experiences
14	No	Rehabilitation, fobia treatment, learning tree names/nature things by using glasses outdoors
15	Yes	AR VR Glasses/Headphones
16	No	Hologram Fun Future
17	Yes	Gaming, medical applications and education

FIGURE 4.6: Survey results for Ideation

To effectively analyse this data, we first organised the responses into a clear list (Appendix A.1). Similar ideas were merged to create groupings, which were further organised into subgroups for clarity (Appendix A.2 and Appendix A.3). From these, we selected ideas based on their potential for playful development. The following are ideas deemed suitable for playful implementation.

1. Teaching X

- (a) Education

2. Leisure

- (a) Games

- (a) A game with a ball where the environment changes

3. Meeting Leisure

4. Designing/Drawing X

5. Making X more interesting

6. Simulation

Lastly, from those ideas, we looked at whether collaboration is possible or not and all of the ideas mentioned above could also be made collaborative, which makes those six ideas the final six ideas from the survey.

4.6 Top three ideas

To choose the top three ideas, we analysed concepts from the 100 idea technique and survey results. Initially, we categorised ideas into nine groups based on characteristics like tabletop games, physical activity, and music-related concepts. Similar ideas were merged for clarity. We considered common themes from the survey, including Teaching X, Designing/Drawing X, and Simulation. While peer input is valuable, discovering novel ideas remains our priority. From the survey, two standout ideas emerged: a dynamic ball

game with changing environments and enhancing experiences with MR. Ideas were selected based on attributes such as engagement, digital-physical integration, play experience, and testability in relation to our research questions. This approach yielded a selection of 13 ideas, emphasising cooperation over competition and feasibility within our timeframe. The resulting shortlist includes:

1. Maze game with real & virtual objects
2. 2 player escape room
3. Solving puzzles
4. Escape Room Box
5. Hide and seek
6. Hot and cold -> hiding objects
7. Fire boy water girl with capacitive sensor on the floor for some of the controls
8. 2 player drawing —> catching game

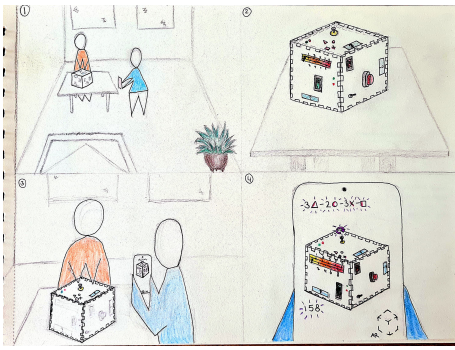
Lastly, from these ideas, a top 3 is made based on personal preferences, as all research-related qualities are already covered. Those ideas are the following:

1. Escape Room Box
2. Fire boy water girl with capacitive sensor on the floor for some of the controls
3. 2 player drawing —> catching game

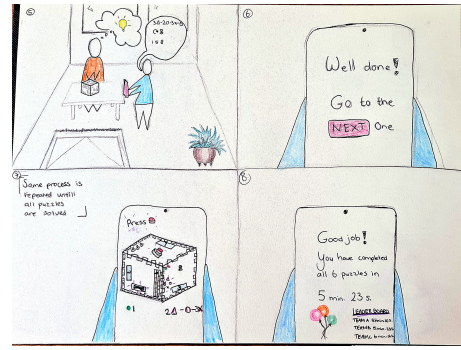
Since the ideas are listed in Figure 4.4, we wrote descriptions of the top three ideas to provide a better understanding. This review also allowed us to modify concepts as needed. We revised the second idea to focus more on an MR environment and generalised its name, which was previously based on an existing 2D game. We then created storyboards to illustrate the concepts, breaking down each idea into scenes and sketching them on paper. While not hyper-realistic, the illustrations effectively convey the essence of each idea. We added colour to highlight important elements like characters and objects and outlined key attributes with a fine liner for enhanced visibility. This process was applied to all three concepts, resulting in detailed storyboards that provide a better understanding of each idea.

4.6.1 Escape Room Box

A box with a puzzle or riddle on each side that users must solve to proceed to the next side. After solving the last side, the box opens and records a time. The fastest times are recorded in a top three to provide a sense of competition for higher engagement. The game is played by two people. One user scans AR markers on the box with their phone to get hints, while the other person executes the solution. Interaction flows both ways: from digital to physical using AR markers and from physical to digital using sensors/buttons that send information to the app. The storyboard for this idea is shown in Figure 4.7.



(A) Part 1



(B) Part 2

FIGURE 4.7: Escape Room Box

4.6.2 2D multiplayer

The game is a 2D game displayed on a main screen (TV/monitor) that both players can view. One player controls the game using hand gestures, such as moving forward, backward, jumping, or ducking. All obstacles and extra points are visible in an AR environment. The player controlling the avatar must avoid or collect these items and complete the levels with guidance from the other player. The idea is illustrated with a storyboard shown in Figure 4.8.

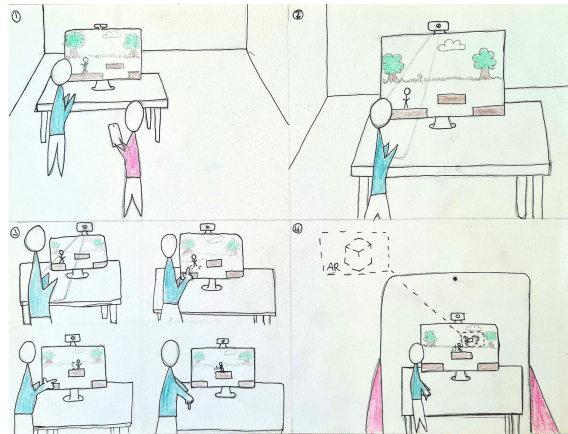


FIGURE 4.8: 2D multiplayer

4.6.3 Two-player drawing and catching game

This game is also played by two people. Objects are hidden in the room and can only be found using AR on their phone. After collecting all the objects, one person draws them on a tablet. These drawings are then projected onto a wall using a projector, with the items falling from top to bottom. The other player needs to catch the items before they hit the ground. The goal is to collect and catch as many items as possible within a specific time. Figure 4.9 shows the storyboard of this idea.

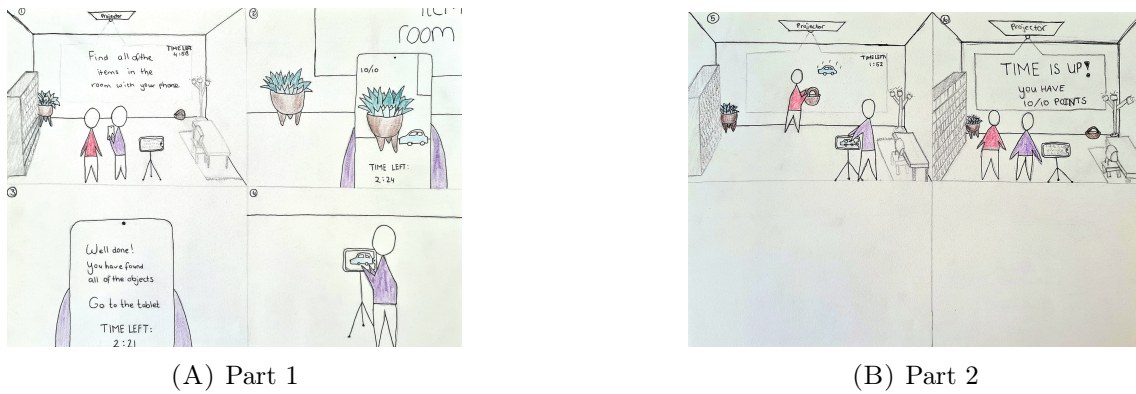


FIGURE 4.9: Two-player drawing and catching game

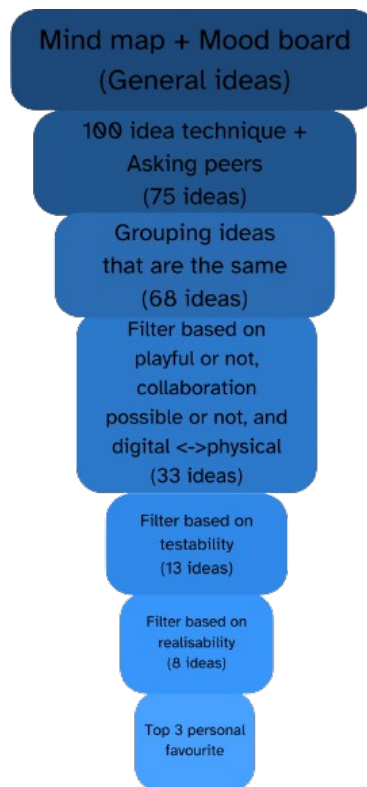


FIGURE 4.10: Funnel graph of ideation phase

4.7 Storyboard evaluation

The storyboards are evaluated using an online survey. The complete survey can be found in Appendix B.1.

4.7.1 Survey

The survey first requires a consent form the participant has to sign to continue with the survey, which can be found in Appendix B.1: Survey questions .

If consent is not given, the survey goes to the final page where the participant is thanked for their participation. If consent is given, the survey proceeds to the next question, asking

for the participant's age to ensure the target group, those with the potential to work at Al-ten, is reached. The survey then continues with the first concept, providing the storyboard and description for each concept, as detailed in Chapter 4.6: Top three ideas. For each concept, participants are asked four questions about their initial thoughts, engagement, innovative elements, and suggestions for improvements. After the three concepts, a set of general questions follows.

All questions are open-ended, encouraging participants to share their unfiltered thoughts about each concept. This approach aims to provide a comprehensive understanding of participants' perspectives, including general impressions, suggestions for improvements, and perceptions of engagement and innovation. Further details of the questions can be found in Appendix B.1.

We distributed the survey via WhatsApp group chats within our study network and through our personal LinkedIn profiles. The LinkedIn post was shared multiple times, reaching several hundred individuals. 13 respondents completed the survey, providing valuable insights. As the survey is regarding qualitative research this amount will suffice [75, 34].

4.7.2 Survey analysis

The raw survey data is first colour-coded for clarity, then grouped by question. Each question includes answers for the different concepts, allowing a separate evaluation of each concept per question. Data analysis is conducted question by question, with notes taken from each answer. Repeated answers are merged into one note for conciseness. These notes can be found in the Appendix B.2: Raw data.

From the first question, "Please share your initial thoughts and impressions about the concept," we gathered the following insights:

Escape Room Box: Participants found it fun, interesting, cool, and challenging. However, some likened it to the existing game "Keep Talking and Nobody Explodes" (see Chapter 3). The puzzle-solving aspect was well-received, with many seeing potential in it. Concerns were raised about replayability, and the MR component was particularly liked by several participants.

2D Multiplayer Game: Initial impressions were generally negative, with comments about confusion, annoyance, and the second player's role seeming less fun. Suggestions included preventing the phone user from seeing the main screen. Some found the AR element unnecessary or too complex, though teamwork was appreciated, and the game was seen as fun and interesting by some.

Two-Player Drawing and Catching Game: Feedback was mixed, with some finding the game disjointed, leading to confusion. While some enjoyed it, others did not. The game was seen as more active and engaging, involving multiple activities and senses. Concerns included the balance of playtime between players. However, the hide-and-seek aspect was generally liked.

From the second question: "What elements do you find most engaging or captivating? Please explain.", we conclude the following.

Escape Room Box: The most engaging or captivating parts were the puzzle-solving aspect, the collaborative/cooperative problem-solving, and the MR part using AR, sensors, and buttons.

2D multiplayer: The most engaging or captivating parts were the fact that movement translates to game movement, the MR using gesture control, and AR, the asymmetric multiplayer aspect, teamwork, interactivity, and familiarity with known games.

Two-player drawing and catching game: The hide-and-seek using AR was found most engaging. Next to that, the search in combination with time pressure, drawing items, catching digital items with a physical item, bringing own drawings to life, and the variety of elements.

According to the third question: "Does the idea introduce innovative elements or unique features that caught your attention? Please describe.", Concept 1 was seen as the least innovative, with 4 participants answering "no." However, participants mentioned:

- Physical aspect of the game compared to "Keep talking, nobody explodes"
- The technology used in the game
- The amount of thinking and collaborating
- Using digital and physical elements that are meant to go together
- Each side of box having riddles

Concept 2 was seen as the most innovative since only two participants answered "no". The parts mentioned as innovative were;

- Mix of AR and gesture control
- Ability to move with 3D effects
- Asymmetric multiplayer
- Real-time setting determination
- Bringing real movement to digital movement
- Combining game world and obstacles perspectives
- Clear collaboration
- Unique execution of AR

Concept 3 had three "no"s as an answer. The innovative parts can be concluded as follows;

- Combining existing technology
- Physical elements
- Merging multiple games
- Projecting drawings
- Digital-physical interaction
-

The fourth question: "Can you provide suggestions for improvements or features you would like to see added?", provided a lot of insight in terms of improving the concepts. All of these suggestions can be found in Appendix B.1 for each of the concepts. These improvements will be considered in the further development of one of the concepts. Therefore, further analysis of this question will be discussed in Chapter 4.9: Final concept.

After analysing the concept-specific questions, we examined the general questions. Question five asked which of the ideas stood out the most and why. Several participants gave more than one answer, in such a case both were counted separately. The concept that stood out the most was Concept 1, then Concept 3, and lastly Concept 2.

Concept 1

- Most tangible interaction
- Collaborating setting
- Most captivating
- Can be played on its own and in a larger environment
- Not much equipment needed
- Easy to coordinate for players

Concept 3

- A lot of creative and interactive potential
- Active physical activity
- Many opportunities

Concept 2

- Highest chance of playing out of the three concepts
- Provides more interaction with AR
- Level of interaction and teamwork required to play the game

Concluding from question six, Concept 2 was the least resonating with the participants. This was attributed to its static nature, the desire for increased player interaction, and potential challenges with player synchronisation.

The answers provided for question seven can also be found in Appendix B.1. As the question again asks for enhancements for any of the concepts, this question will be discussed in Chapter 4.9: Final concept as well.

Question eight asked about the most viable concept, and both concepts 1 and 3 were seen as most viable. Participants again gave multiple options several times. Both concepts were seen as most viable six times.

Question nine asked which concept participants would suggest for further development. While it directly indicates a preferred concept, responses to earlier questions are equally

relevant in shaping the final ideation. Participants considered various aspects of each concept before answering, making their responses highly thoughtful. Thus, the question was placed towards the end. Most participants recommended Concept 1 for development, citing the following reasons:

- Might be the easiest to implement
- Most tangible interaction
- Most possibilities to explore
- Most attention-grabbing
- Due to the puzzles
- Dynamic between the players
- Funny
- Challenging

The survey ends with a final recommendation question. The most important recommendation perhaps is the fact that there was not enough context provided of why these experiences are designed. This seemed to have influenced the answers of the participants, as some parts of the experiences were found confusing for the participants.

4.8 Requirements

Based on the storyboard evaluation and the three initial concepts the following requirements have been identified for the final concept. These requirements integrate insights from each of the three initial concepts, focusing on aspects such as simplicity, interaction, dynamics, replayability, and collaborative problem-solving. The system must meet the following requirements, designed specifically for potential employees at Alten, such as Senior or graduate students.

4.8.1 Functional Requirements

- The system must be simple and easily comprehensible.
- The system must include tangible interaction elements to ensure an engaging user experience.
- The system should facilitate collaborative problem-solving with existing technology.
- The system must feature asymmetric multiplayer dynamics with clear player roles.
- The system should be designed for replayability, incorporating varied levels, or randomness to maintain user engagement.
- The system should include familiar elements from popular games to enhance user resonance.
- The system should incorporate multi-sensory elements such as sound, aroma, or mist.
- The system should enable enhanced teamwork and collaboration among players, accommodating more than two players if possible.

4.8.2 Non-Functional Requirements

- The system must avoid the use of hand gestures for control due to concerns about potential control and latency issues.
- The MR experience should facilitate collaboration between users. This can include cooperative problem-solving tasks, shared virtual environments, and real-time interaction between participants. The collaboration should be meaningful and enhance the overall experience.
- The system should maximise interaction between the physical world and AR, creating a cohesive and immersive experience.
- The system must be visible to all players during use, ensuring that gameplay elements are easily seen and understood by participants.
- The system should be designed to attract attention from a distance, making it apparent to observers that an engaging activity is taking place. This can include visual cues such as bright colours, dynamic lighting, or other attention-grabbing features.

These requirements form the foundation for the design and implementation of the final concept, ensuring that it meets user needs and incorporates the best aspects of the initial concepts.

4.9 Final concept

With those requirements in mind, the final concept is an Escape Room Box similar to Concept 1. The name remains the same, but the interaction type and technology use differ. This box features puzzles on each side with physical elements, requiring collaborative problem-solving. To incorporate more physical activity, players use a phone and AR. The AR component not only offers tips but becomes essential for solving puzzles. For example, one person holds the phone to see a figure through AR, while the other matches it with a physical figure.

This setup incorporates cooperative gaming, enhancing interaction between the physical and digital worlds, and creating clear player roles for an asymmetric gaming experience, as suggested earlier in Chapter 2: Background. The game involves solving three puzzles as quickly as possible, earning more points for faster completion. Each puzzle has its own timer, adding penalty time if not completed in time. The game ends when all parts are finished, showing a record time to add competitiveness, encouraging players to replay to beat records. Randomness in puzzles keeps the game interesting for multiple playthroughs. Details such as feedback provision and puzzle types will be discussed in the next section of this report.

Chapter 5

Puzzle Design

The previous chapter talked about the final concept, the Escape Room Box, which consists of a set of puzzles and challenges. This chapter will discuss the design process for these puzzles and challenges, involving a co-design session and user tests.

5.1 Theme

Inspired by valuable feedback and recommendations from section 4.7: Storyboard evaluation, we designed a wizarding theme for the Escape Room Box to enhance engagement, immersiveness, familiarity, and innovation. This theme supports unbounded creativity and a wider range of puzzles and challenges. Although we considered other themes like Prison Break or Ancient Egypt, the wizarding theme best aligns with our criteria. A wizarding theme allows for defying real-world constraints, facilitating novel interactions not bound by realistic settings. Its widespread recognition from popular books and movies fosters familiarity, enhancing engagement and immersiveness.

5.2 Co-design of concrete puzzle elements and challenges

To define concrete puzzles and challenges, we organised a co-design session aimed at generating general puzzle ideas, combining concepts, identifying enabling technologies, and promoting collaboration in the game. Participants for the session were recruited from within Alten, fitting the project's target audience. The session involved two participants and the researcher, who primarily led the session but also participated when needed. To prevent language barriers, the session was conducted in Dutch, the native language of the participants.

The co-design session followed a detailed plan, outlining steps prior to the design thinking process, the overall session goal, and the design thinking steps. Before the session, we prepared necessary equipment such as stationery, snacks for breaks, and idea prompts to aid participants. The session comprised four steps: an introduction, a warm-up, an MR concept demonstration, and the design thinking process. Refer to Appendix C.1: Session plan for the detailed session plan.

Before initiating, the Ethics Committee of the faculty approved the co-design session. Participants provided their consent after reviewing an information letter, which detailed the purpose of the co-design, the session plan, and how their input would be documented and used in the study. The consent form covered participation in the study, use of the information in the study, and future use and reuse of the information by others. The information letter and consent form can be found in Appendix C.2: Information letter and

consent form.

5.2.1 Introduction to the Escape Room Box Concept

The first step of the co-design session is the introduction, which briefly explains the concept of the Escape Room Box and outlines the session plan. This explanation includes an overview of the thematic elements, gameplay structure, and intended user experience. The introduction aims to foster a shared understanding among participants and establish a solid foundation for collaborative ideation and design discussions. For a detailed explanation, the session plan in Appendix C.1: Session plan can be referenced.

5.2.2 Warm-Up Activity for Creative Thinking

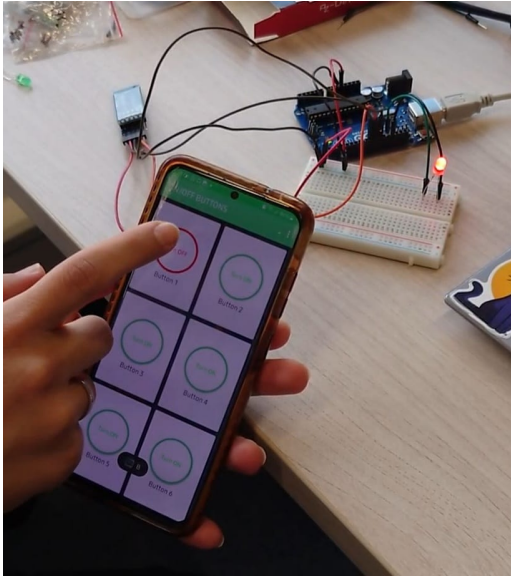
The second step of the co-design session is the warming-up activity to facilitate the creative thinking process. The activity is conducted using mood-setting cards as introduced by [2]. The specific card selected for this purpose called "Move to Words" is detailed in Appendix C.3: Mood setting cards for warming up, and contains information about the duration, body awareness, creativity, exertion, playfulness, and how to execute the warming up. This choice of card is deliberate for two reasons. First, since participants are not familiar with each other, initiating physical contact might be uncomfortable. Instead, the focus is on establishing a comfortable and collaborative environment through verbal and gestural interactions. Second, the chosen warm-up activity facilitates creative thought without excessively fatiguing participants. Insufficient engagement might fail to prepare them adequately, while excessive exertion could tire them before the design thinking process. The duration of the warm-up is also tailored to the participants.

5.2.3 Demonstrating MR Technology

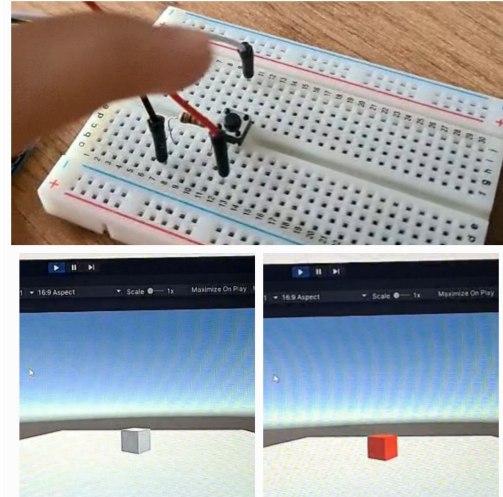
The third step of the co-design session explains the concept of MR by presenting two types of technology. The technology demonstrates two-way interaction, allowing engagement between the physical and digital worlds in both directions. It is emphasised that the shown technology is solely for illustration purposes, and participants are not bound to those two technical options.

The first technology demonstrates interaction from the digital to the physical world using a phone application with a button to trigger an LED. Clicking the button turns the LED on/off, showcasing wireless interaction. The interaction is realised by an Arduino and a Bluetooth module. A signal is sent from the application to the Bluetooth module and from the Bluetooth module to the Arduino.

The second interaction involves a physical button changing the colour of a 3D object on a screen. The interaction demonstrates how a physical object can influence a digital one. This is achieved by connecting an Arduino with a push button to the Unity game engine, which contains a simple scene with a grey cube. Pushing the physical button turns the grey cube on Unity into red and back to grey when released. Figure 5.1 shows the presented technology for the two-way interaction. By showing these two interactions, the participants are sensitised about what to design for.



(A) Digital to physical world interaction



(B) Physical to digital world interaction

FIGURE 5.1: The presented technology for the two-way interaction

5.2.4 Design Thinking Session

The fourth step is the design thinking session, which is done in four stages; general idea, combination/link, enabling technologies, and collaboration. The participants are guided through the stages one after another. The ideas are all written down on a whiteboard in the form of a mind map. Each stage is represented by a different colour. The participants were encouraged to freely share ideas across stages during the design thinking session, allowing flexibility for contributions that might better align with a different stage.

Stage one is the general idea thinking process which allows for broad ideas and divergent thinking. The first stage starts with individually writing down general puzzle/challenge ideas on a piece of paper. This ensures that more introverted people can share their thoughts as well. Followingly, the individually created ideas are shared and written down on the whiteboard by the researcher. Writing the ideas down in this way stimulates brainstorming as ideas are shared, explained and broadened.

Stage two is combining the existing ideas and creating links where possible. During this stage, new ideas are created by critically looking at the ideas and thinking about new possibilities by combining them. These combinations can vary from fusing two ideas into a new one to adding only an aspect of an idea to another idea. Introducing the wizarding theme for inspiration added a new perspective to the brainstorming, like new ideas including dressing up, and the use of magnetic wands.

Stage three is incorporating enabling technologies such as identifying possible sensors, defining methods for AR interaction, and exploring ways to engage with the box. Identifying one sensor can lead to multiple enabling technologies which can be used for different puzzles/challenges. Specifically looking at AR interactions broadens the perspective of utilising AR for different purposes, including AR as part of a puzzle or AR as a tool to solve a puzzle. Exploring ways to engage with the box mainly comes forth from writing down different sensors.

- Navigation and directional challenges, like pointing to the North and navigating through mazes.
- Themed challenges, such as embodying a security guard or dressing up as a member of a Harry Potter house.
- Collaborative and sequential actions (e.g., coordinating responses to AR cues or physical elements).
- Consequence-based challenges (e.g., 'take a step back or your turn ends').
- Dynamics with music (e.g., red light/green light with musical cues).
- Problem-solving and puzzle challenges, including digit codes and a miniature Rubik's cube challenge.

The result of the first stage is a good starting point for the second stage as it contains a broad variety of 19 general ideas.

Stage Two: Idea Combinations

The second stage combined three pairs of general ideas, resulting in three new concepts.

1. **Red Light/Green Light + Security Guard:** This combination adds a control element where a security guard ensures no one moves when the music stops.
2. **Performing Subsequent Actions + Correct Gesture = Correct LED:** A correctly performed gesture becomes part of a sequence of actions.
3. **AR Line on Screen + Following the Line with Finger + Maze:** A maze can be solved using finger gestures in the air, displayed on the screen through AR.

Combining ideas not only generates new concepts but also fosters creativity during the thinking process.

Stage Three: Enabling Technologies

The third stage led to the generation of 13 new ideas in the form of enabling technologies. These enabling technologies are the following; Interactive perspectives and size control, Box movements and gyroscope interaction, spatial measurement and navigation, e.g. measuring angles, heights, and distances, and utilising a compass, audio interaction for speech recognition or measuring dB, connection mechanisms such as the use of magnets or NFC, multi-sensory interaction by adding smell, colour detection, or light detection, and user-driven customisation, e.g. selecting elements they cannot do in the room.

Stage Four: Promoting Collaboration

The fourth stage resulted in five ways to promote collaboration. While most of the ideas were already enforcing collaboration, explicitly thinking about it provided deeper insights into the possibilities. One way is by requiring users to perform actions on the phone and the box simultaneously. Another approach involves task-dividing roles, with one user performing a certain action as the other holds the phone to either provide hints, check on the completion of the task, or keep a certain distance from the Escape Room Box. The task-dividing roles can also be seen as three different approaches. Lastly, imposing time constraints makes it challenging for participants to perform actions on their own. These five approaches can all be individually incorporated or combined to promote collaboration.

5.2.7 Interpretation of Co-Design Session Results

The co-design session successfully generated many general puzzle/challenge ideas, combinations, enabling technologies, and collaboration strategies. AR can be used for clear role division and as part of the puzzle, serving as both a general idea and enabling technology. Different sensors, like microphones, colour detection, and light detection, offer new insights into multi-sensory design. Previously focused on buttons, knobs, and LEDs, interactions can now include innovative possibilities like box rotation and height differences. The phone promotes collaboration by dividing roles, imposing time constraints, and specifying distances. In conclusion, the session provided numerous ideas for developing complete puzzles, including puzzle aspects, flow, enabling technology, and collaboration.

5.2.8 Future Directions

These interpretations suggest promising directions for concrete puzzle designs. AR can promote collaboration by enabling role division, maintaining physical distance, and providing feedback or hints. It can also be integrated into the puzzle itself. Time and distance constraints can further enhance collaboration. Sensors like microphones can broaden interaction types, such as incorporating speech recognition. Music can also be used to diversify interactions and enhance engagement, aligning with the Escape Room Box theme. In conclusion, various aspects for enabling puzzles have been derived, including puzzle ideas, interactions, enabling technology, and collaboration strategies. These can be utilised in designing puzzles for the Escape Room Box.

5.3 Puzzle design

To develop an MR experience, we will design a set of three puzzles based on two main features: enabling technology and the puzzle element itself. While most escape rooms have eight to 15 puzzles, three puzzles will suffice for the Escape Room Box, aligning with the project goal of efficient completion as outlined in Chapter 1.2: Objectives.

Starting with enabling technology, we used insights from the co-design session. Technologies beyond the project's scope, like compass use, angle measurement, and adding smell, were filtered out. The selected enabling technologies include AR image tracking and object placement for puzzle integration or hints, and app UI for hints and feedback. Hardware elements include physical buttons, capacitive and pressure sensors, LEDs, and sound for feedback.

For the puzzle elements, we conducted extensive research on existing designs and implementations, drawing from Chapter 3: State Of The Art, blogs, and YouTube videos.

Combining these aspects, we developed our puzzles. The first puzzle, "Button Sequence," emerged from analysing available technologies and existing designs. The second puzzle, "Casting Spell," was inspired by the wizarding theme and co-design session results. To incorporate more MR elements, the third puzzle features a maze with themed characters, integrating AR and physical elements. Given the theme and nature of the Escape Room Box, we named it "Enchanted Escape."

5.3.1 Button Sequence

"Button Sequence" combines physical buttons with hints provided through AR. The core concept of this game involves users pressing physical buttons in a specific sequence. Once the correct button sequence is achieved, the game ends. To assist users in finishing the game, they can request hints through AR on the provided phone. The player is provided with feedback using LEDs to inform them whether their answer is correct or not.

5.3.2 Casting spell

"Casting Spell" consists of an LED, two capacitive sensors functioning as buttons, and an application. The goal is to solve a Morse code to cast a spell using speech recognition. The capacitive sensor buttons have icons to indicate their role in the puzzle. The application, themed around wizardry, has three screens. The first screen provides instructions, the puzzle goal, and a start button. The second screen is where users solve the Morse code, activating the LED to blink in the spell's pattern. Navigating away from this screen stops the LED, and returning reactivates it. The final screen is for casting the spell using speech recognition. Users must press three buttons simultaneously: the two capacitive sensors and one on the application, all marked with the same icon. When the correct spell is recorded, the puzzle is completed.

5.3.3 Maze

"Maze" is an AR game where players navigate a physical image of a maze, aiming to reach the finish as quickly as possible while collecting items along the way. The AR application provides an explanation of the game's objective and instructions on how to move through the maze. Users hold the device camera towards the physical maze image, where a 3D model of the maze, the player, the finish, the timer, and collectables appear in AR. The physical image shows only the maze and the starting point, represented by a witch who wants to reach her cat (the finish). Along the way, there are several collectables that users can choose to gather, benefiting them in the next puzzle. A countdown timer is displayed above the maze. Points are awarded based on how quickly the user finishes the maze. If time runs out, the game is over, and the user receives no points and loses their collectables. To move the witch through the maze, users must turn the physical maze around. The AR witch reacts to the real-world physics of the maze's angle, moving faster or slower depending on the angle.

To conclude, in developing the "Enchanted Escape" MR experience, we designed three puzzles centred around enabling technology and engaging puzzle elements. The "Button Sequence" puzzle integrates physical buttons and AR hints, requiring users to press buttons in a specific order, with feedback provided through LEDs. "Casting Spell" involves solving a Morse code puzzle using capacitive sensors and speech recognition. The "Maze" puzzle leverages AR to navigate a physical maze image, challenging players to reach the end quickly while collecting items. These puzzles were designed to contribute to a cohesive and immersive escape room experience, showcasing the potential integration of enabling technologies and creative puzzle design.

Chapter 6

Puzzle Design Evaluation

This chapter talks about the interim user tests conducted to evaluate the three puzzles/games designed for the Enchanted Escape. Each puzzle/game is evaluated by their own user test. The chapter will first explain the methods used to conduct the user tests, it will then highlight the results per user test, and lastly present a discussion and conclusion derived from the tests.

6.1 Method

The three puzzle/game ideas are evaluated separately, but there are overlapping aspects in the method of conducting the user tests. Figure 6.1 provides an overview of these overlapping aspects. All three user tests are conducted at Alten with employees or other interns. Participants are enlisted either by email or by direct approach. The recruitment criteria require that participants have no previous exposure to the puzzle and were not involved in its creation. A time schedule is used for the Maze user test to provide more structure and efficiency, as detailed in the Appendix D.7: Recruitment of participants.

	Participants enlisted through email to Alten employees	Participants enlisted by directly approaching them at the office	Use of a schedule for the user tests	Information letter + Consent before user test	Amount of participants
Button Sequence	Yes	Yes	No	Yes	10
Casting Spell	No	Yes	No	Yes	10 (5 individual, 3 paired with researcher, 2 as a duo)
Maze	No	Yes	Yes	Yes	11 (5 individual, 3 duos)

FIGURE 6.1: An overview of the method used in the interim user tests

For all user tests, participants received prior information about the test, including its objectives, the type of data recorded, and the methods used for recording and storing the data. Participants also signed a consent form regarding the recording methods and data usage. The information letter and consent form for each user test are specific and can be found in Appendix D.1: Information letter and consent form Puzzle 1, D.4: Information letter and consent form Puzzle 2, and D.8: Information letter and consent form Puzzle 3.

Each user test consists of two parts: the primary user test and a survey. The primary user test for "Casting Spell" and "Maze" was conducted with two groups, A and B. Group A conducted the test alone, while Group B conducted the test in pairs. For the "Casting Spell" test, some employees paired with the researcher, who refrained from knowing the

answers or how the game/puzzle worked to keep it fair. For the "Maze" test, all pairs consisted of employees or interns.

The game/puzzles involve several aspects to consider, including solvability, the need for AR, the added value of collaboration, and individual interest in interacting with the game/puzzle. Each user test assesses different aspects identified as critical for ensuring a successful game/puzzle design. Figure 6.2 shows which aspects are assessed for each game/puzzle.

	Solvability	Need for AR	Added value of Collaboration	Interest of individuals in interacting with the game/puzzle
Button Sequence	X	X		X
Casting Spell	X		X	X
Maze	X		X	X

FIGURE 6.2: Aspects assessed during the user tests

6.2 Button Sequence

6.2.1 Objectives

We set the success criteria for the user test as follows.

- **Solvability:** Average solving time should be one to five minutes. Less than one minute: the game is too easy. More than five minutes: the game is too hard. At least 60% of participants should be able to solve the game.
- **AR Component:** Considered necessary if participants use it for hints and see it as a valuable addition to enhance interactivity.
- **Engagement:** At least 60% of participants should be willing to engage with the game.

6.2.2 Setup and procedure

The primary user test features a game prototype that includes essential elements for evaluating the test's objectives. However, the Bluetooth module connecting the phone and physical buttons was not finalised, so the researcher's laptop facilitated communication between the physical and virtual components. The buttons and AR functioned as intended.

The game includes four coloured physical buttons on a breadboard and provides feedback through an 8x8 red LED matrix, displaying a checkmark for correct answers and an X for incorrect ones. Participants have four lives; each wrong answer deducts one life, and losing all lives results in a sad face on the matrix. The game involves a nine-step button sequence, and a participant is deemed a solver if they complete it correctly. Otherwise, they are non-solvers. Participants receive no feedback on the number of lives, current step, or buttons pressed, requiring them to track these themselves.

Four Harry Potter character pictures are displayed on the table. Participants can request unlimited hints via the AR app on the phone. After clicking 'Hint,' the app opens the camera with instructions to type 'a' and press 'enter' on the laptop. The hint, shown on the laptop, involves pointing the camera at a picture to reveal a coloured cube indicating the correct button. Each phrase corresponds to a picture: Sirius Black, Dumbledore, a dementor, and Padfoot the dog:

- "They are looking for Sirius Black, do you know where he is?"
- "Dumbledore can help you out."
- "Someone has used magic outside of school, the dementors are going to punish them, find the dementor."
- "A dog is a human's best friend."

Before testing, the researcher explains the game's objective, components, rules (lives and hints), and the procedure, including timing and note-taking. Participants start the game when ready, and the researcher starts the timer and notes the use of hints, quotes, game progress, end time, and other remarks. The test ends when the participant either solves or fails the game.

After the game, participants complete a survey with nine open-ended questions in four sections: general questions, AR, collaboration, and final remarks. The detailed survey questions are available in Appendix D.2: Survey questions with answers. Participants are then thanked, and the setup is reset for the next participant.



FIGURE 6.3: Test setup user test puzzle 1

6.2.3 Results

The results of the user test comprise two parts: user test notes and survey responses. The user test notes cover game solvability, hint usage, feedback and tracking, and general remarks. The survey results include general engagement, the role of AR, suggestions for improvements, collaboration enhancement, the perceived value of AR, and final remarks. Although the survey data is based on nine participants instead of ten, this did not affect the quality of the data, as one participant was unable to complete the survey due to time constraints. A detailed overview of the results is available in Appendix D.3: Detailed notes user test Puzzle 1, and D.2: Survey questions with answers Puzzle 1.

User test notes

First, game solvability was measured by completion time and the number of solvers. There were five solvers in total. Among the non-solvers, one faced technical issues towards the end, potentially impacting their ability to complete the game. The average completion time for solvers was two minutes and 58 seconds, while non-solvers averaged three minutes and 51 seconds, skewed by an outlier who took nine minutes. Most non-solvers completed the game in about two minutes, excluding the outlier.

Second, hint usage was summarised as follows: every participant used a hint at least once. All solvers used hints for each step, while most non-solvers tried to solve the game independently initially but turned to hints after losing two or more lives.

Third, the feedback provided by the system had limitations. Participants had to mentally track their lives, the current step, and buttons pressed, which added to the challenge. Additionally, a two-second delay in the feedback system led to unregistered inputs if participants responded too quickly, causing unnecessary mistakes.

Fourth, general remarks included issues with character recognition and confusion during the user test. Some participants did not recognise the characters in the images, making it difficult to understand the hints. Detailed explanations of the game’s objective and tools were essential for understanding. The delay in the feedback system also caused confusion and unnecessary errors.

User test survey

First, participants found the hardware, MR interaction, AR elements, and the puzzle’s restart mechanism after an incorrect answer to be the most engaging aspects. The most challenging parts included keeping track of steps and lives, understanding the puzzle’s goal, and solving it without using hints. Opinions on the puzzle’s difficulty varied: some found it easy due to unlimited hints, while others felt it was appropriately challenging or desired more information on solving it without hints.

Second, regarding the role of AR, most participants felt AR enriched their experience, especially when used with pictures. Some felt AR seemed like a gimmick but saw potential if enhanced with features like movement, varied shapes, or different orientations. A few noted that AR was essential for knowing the correct steps, as there was no other way to progress without it. There were no outright rejections of AR, although the perceived value varied, with some seeing it as needing improvement.

Third, suggestions for improvements included reducing the number of hints to increase the challenge, introducing varied AR shapes while maintaining consistent sizes to prevent confusion, and incorporating a storyline or questions for each step to provide alternative ways to solve the puzzle without relying on hints.

Fourth, participants suggested ways to promote collaboration, such as increasing puzzle difficulty to encourage discussion and cooperation, distributing small tasks within the group to manage the workload more effectively, and defining clear roles (e.g., one person managing the phone and offering hints while another engages with the puzzle). They also recommended incorporating biometric features like speech or facial recognition for personalised tasks and introducing competitive elements between players to increase engagement and collaboration.

Fifth, regarding the perceived value of AR, most participants stated that it added a meaningful layer to the experience, although some felt it needed enhancement to be truly valuable. One participant did not find AR to add significant value, while another saw potential but found the current implementation simplistic.

Sixth, as a final remark, participants appreciated the concept of an escape room in a portable format with minimal steps. Some found the concept cool and interesting, while others felt it was a bit simple.

6.2.4 Discussion

The results of the user test can be interpreted by examining the three user test goals: solvability, the need for AR, and participant interest in engaging with the puzzle. These goals are discussed in detail below.

First, the average solving time of two minutes and 58 seconds meets the success criteria. However, 50% of participants solved the puzzle, indicating the puzzle is slightly too challenging. It is generally perceived as non-solvable without hints, suggesting the need for adjustments such as changing the puzzle's goal or adding a narrative.

Second, while the role of AR is currently primitive, it adds value to the experience. AR is used to provide direct hints, but this could be expanded by making hints more challenging or displaying various AR objects. Currently, AR is the primary tool for solving the puzzle due to the unlimited hints. Limiting the number of hints can prevent over-reliance on AR for every puzzle step.

Third, the final goal of the user test was to gauge participants' interest in engaging with the puzzle. Recruiting participants was straightforward, and all completed the test without withdrawing. Feedback from the test notes and survey was overwhelmingly positive, suggesting that most participants would engage with the puzzle outside the test setting. To further increase engagement, several improvements were identified:

- Increase the difficulty level of the hints.
- Provide clear feedback on the number of lives and the current step.
- Enhance the puzzle with a story or modify it to be solvable without hints.
- Introduce a collaborative aspect by assigning clear roles or dividing tasks among users. For instance, one user could handle the phone and provide hints, while another solves the puzzle. As discussed in Chapter 2.2: Collaborative play.

6.2.5 Future considerations

Based on these interpretations, we propose several future considerations regarding the solvability, AR aspect, provided hints and feedback, and collaborative play.

1. **Enhance Solvability:** Modify the puzzle so it can be solved independently without hints while maintaining a challenging difficulty level. The difficulty level should promote collaboration through communication between the players, which can also be seen in Chapter 2.2: Collaborative play.
2. **Improve AR Hints:** Increase the difficulty level of AR hints and enhance the AR experience by adding different types of AR objects.
3. **Limit Hints:** Introduce a limit on the number of hints available to prevent over-reliance on them.
4. **Clear Feedback:** Provide clear feedback on the correctness of answers, the number of lives remaining, and the current step in the puzzle.
5. **Foster Collaboration:** Introduce a collaborative aspect by clearly dividing roles among users, such as one user handling the phone for hints while another solves the puzzle.

Implementing these considerations in the design of Button Sequence and other puzzles will enhance user interaction and experience with the Enchanted Escape.

6.3 Casting Spell

6.3.1 Objectives

The interim user test is an A/B test, group A participants solve the puzzle alone (control group), while group B participants solve it as a duo (test group). Success criteria for the test include:

- **Solvability:** The puzzle is considered solvable if the average solving time is six to 10 minutes, with less than six minutes indicating it is too easy and more than 10 minutes indicating it is too hard. Additionally, at least 60% of Group B and 40% of Group A should be able to solve the puzzle.
- **Collaboration:** Collaboration is deemed valuable if Group B solves the puzzle more easily than Group A and reports an enhanced experience due to collaboration.
- **Engagement:** The goal is met if at least 60% of participants express interest in engaging with the puzzle.

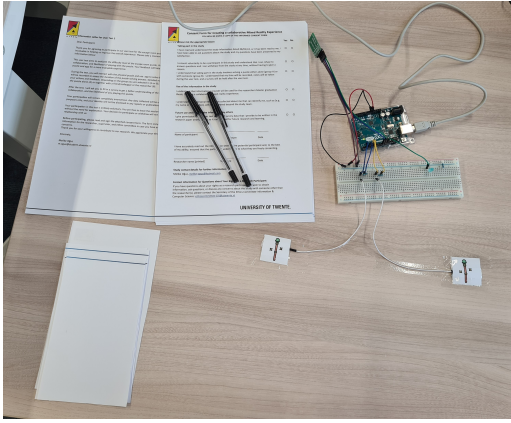
In summary, the interim user test, designed as an A/B test, aims to evaluate the solvability of the puzzle, the impact of collaboration, and user interest, setting success criteria based on solving time, success rates, and engagement levels to guide further development efforts.

6.3.2 Setup and procedure

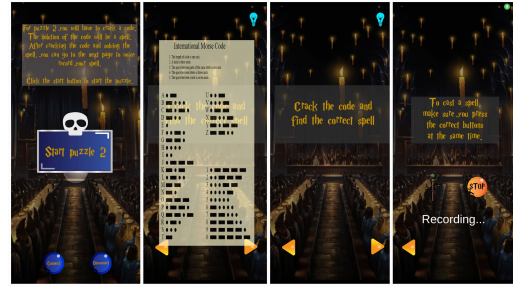
The primary user test includes a hardware setup and an application interface. The hardware comprises an LED, two capacitive sensors as buttons, pen and paper for note-taking, and a Bluetooth module connecting hardware to software. The application has three screens: the first provides puzzle instructions and a start button; the second offers an instruction text and a Morse code cheat sheet toggle button, activating the LED to blink Morse code. Participants decipher the code using the cheat sheet, write down the sequence, and form a spell for input on the third screen, which facilitates voice recording with instructional text, a wand icon button, and a stop button. Capacitive sensors with the same wand icon start the recording when pressed simultaneously. Correct spells prompt "Well done!", while incorrect ones prompt "Try again." The setup is illustrated in figure 6.4.

The test starts with providing participants an information letter and consent form, followed by assignment to Group A or B. Participants are informed about the groups and reminded that their time is being recorded while notes are taken throughout the test. Once ready, the timer starts (hidden from participants), and the researcher documents observations, including spoken phrases, steps taken, and end time. In Group B, participants solve the puzzle with the researcher, who only executes tasks instructed by the participant and offers hints if needed. This assistance is also available to Group A participants. The test concludes upon correct spell identification, with additional time due to technical issues deducted. Detailed test notes are found in Appendix D.6: Detailed notes user test Puzzle 2.

The secondary user test involves filling a survey with 13 open-ended questions in three sections: general questions, group-based questions about collaboration, and likelihood of playing. Detailed survey questions are in Appendix D.5: Survey questions with answers Puzzle 2. Finally, participants are thanked, and the test setup is reset for the next participant.



(A) The test setup of Puzzle 2



(B) Screenshots from the application of Puzzle 2

FIGURE 6.4: The test setup of Puzzle 2

6.3.3 Results

We summarised the results of the user test in two parts, the user test notes and the survey. The user test notes consist of puzzle solvability, the added value of collaboration, the interest of individuals playing the puzzle, and general observations. The survey results include common challenges, individual versus collaborative experience, and the interest of participants in playing the puzzle. More detail can be found in Appendix D.6: Detailed notes user test Puzzle 2, and D.5: Survey questions with answers Puzzle 2

User test notes

First, the solvability of the puzzle is evaluated based on solving time and the challenges encountered. All participants successfully completed the puzzle. The average solving time was 9 minutes and 28 seconds, with Group A averaging 10 minutes and 32 seconds, and Group B averaging 8 minutes and 16 seconds. A significant challenge was deciphering Morse code, particularly recognising the need to decode it. Many participants skipped the Morse code scene, resulting in errors when recording the spell. Additionally, there was common confusion regarding the functionality of the capacitive sensors and app buttons.

Second, Group A participants struggled more compared to Group B, with more mistakes in writing down and deciphering the code. Group A participants were more doubtful about their answers compared to Group B. Most Group B participants had clear role divisions, which improved their problem-solving approach. Initial attempts by some Group B participants to solve the puzzle individually were followed by collaborative efforts.

Third, Overall interest in playing the puzzle was high, as evidenced by participants' willingness to participate and positive reactions during testing. Specific notes on individual interest were lacking, but Group B participants showed more engagement through discussions on puzzle-solving strategies.

Fourth, observations from both the user test notes and survey data highlighted aspects of the UI, theme, and hardware. Participants often skipped the Morse code screen and went directly to the final screen. While the UI was praised for being nice and intuitive, some participants suggested making the hint bulb less obvious. There were also suggestions to improve the coherence of the puzzle's theme, particularly regarding the spell and hardware. Additionally, a recommendation was made to shorten the duration of the light indicating a Morse code dot, which the researcher also noted.

User test survey

First, the survey highlighted participants' struggles with tasks such as keeping up with and deciphering Morse code, the app recognising the spell, and determining the correct buttons to press before recording the spell. The perceived difficulty level was deemed appropriate as identifying Morse code is considered straightforward however, some challenges included technical difficulties with pressing three buttons simultaneously, and the inability to pause the Morse code. Despite these hurdles, participants found the user interface intuitive.

Second, tailored survey questions assessed collaboration's value based on group assignments, groups A and B. Both groups shared experiences in solo (A) and collaborative (B) settings, analysing their impact on problem-solving and strategies for overcoming challenges. Group A focused on potential partner influence, while Group B examined collaborative problem-solving. Despite efforts to ensure reliability, one Group A participant mistakenly responded to Group B questions, possibly impacting response accuracy.

Working alone on the puzzle yielded varied experiences among participants, with some finding it enjoyable, while others found it challenging, such as writing down the Morse code or lacking the opportunity to discuss solutions. A participant expressed doubt about the benefit of having a second person, showcasing diverse impacts on problem-solving approaches and task difficulties. In overcoming challenging aspects, participants from Group A employed different strategies, including waiting for the Morse code sequence to repeat, practising patience, trial and error, or seeking help from the researcher. Most participants believed that having a partner would make problem-solving easier by enabling double-checking, accelerating the solution process, and allowing for discussion.

Collaboration in Group B was described as useful, helpful, and necessary by many participants for various reasons. Key benefits included the ability to divide tasks, enabling discussion, and aiding in the pronunciation of the spell. Almost all participants highlighted the positive impact of collaboration on problem-solving, emphasising the essential role of task division in accelerating puzzle-solving, boosting solution confidence, and fostering broader thinking. Participants also cited complementing each other's efforts as an effective method for overcoming challenges.

Third, the survey assessed participants' interest in playing the full version of the puzzle, focusing on aspects such as prototype features, personal connections to the theme, and recommendations to others. Main aspects of interest included deciphering the code and speech recognition, alongside collaboration, hardware-software integration, UI, and sensors. While personal connections to the theme varied, they did not significantly affect participants' likelihood of playing, with some enjoying the puzzle regardless and others feeling enthusiastic due to a personal connection. Suggestions for enhancing personal connection included incorporating theme music. Recommendations for others highlighted aspects like vocalising the spell, the collaborative experience, thematic puzzles, and the integration of hardware and software.

6.3.4 Discussion

Interpreting the results based on the user test goals gives further insight into the solvability of the puzzle, added value of collaboration to the experience, and interest in engaging with the puzzle.

First, the puzzle's solvability is evaluated based on solving time and success rate, with the average solving time falling within the desired range of six to ten minutes. Group A took longer than Group B, suggesting collaboration aids in faster puzzle-solving. Although the success rate is 100%, Group A made more mistakes than Group B.

Second, collaboration positively impacts the overall experience and problem-solving process. Group A faced challenges without collaborative discussion, resulting in slower

progress, while Group B demonstrated confidence and efficiency. Group A relied more on trial and error, whereas Group B effectively divided tasks for quicker solutions. Challenges faced by Group A, such as app recognition and button identification, could potentially be alleviated through collaboration or UI/technology redesign.

Third, despite technical difficulties, participants reported a positive overall experience. Despite encountering speech recognition issues, participants expressed a desire to include it in the full version experience. This suggests that despite challenges, the puzzle's overall experience is engaging. Enhancing thematic coherence and implementation in each step could further enhance engagement.

6.3.5 Future considerations

The current puzzle's solvability is satisfactory, with the nine-letter Morse code being a key factor. Collaboration significantly enhances the experience and should be maintained, with clear task division improving efficiency. Physical buttons with icons improved the user experience, despite some technical issues with touch registration. Shortening the LED's dot duration could clarify Morse code distinctions. The UI maintains theme coherence but requires adjustments to prevent skipping the second screen. Enhancing theme coherence with theme music and sound effects could further improve the experience. Incorporating these considerations into the design process for all puzzles can enhance user interaction and experience with the Enchanted Escape.

6.4 Maze

6.4.1 Objectives

The interim user test is an A/B test, group A in the user test is the control group and plays the game on their own, group B plays the game in duos and is the test group. The user test success criteria are the following.

- **Solvability:** Appropriate if at least 80% of participants finish within three minutes. At least 60% should take more than 1.5 minutes to finish. If less than 60% finish faster than 1.5 minutes, the game is too easy. If fewer than 80% finish, the game is too difficult. Qualitative data on difficulty will also guide further development.
- **Collaboration:** Valuable if Group B's experience is enhanced by collaboration compared to Group A's.
- **Engagement:** At least 60% of participants should be willing to engage with the game.

6.4.2 Setup and procedure

The primary user test involves an application with a start screen, an AR screen, and a cardboard maze image. Instructions feature a witch, the main character, who needs to navigate the maze to reach her cat, collecting useful items along the way. Participants turn the physical maze to move the witch, viewed as a 3D AR version on the app with a countdown timer of three minutes. The physical maze must be visible to the camera at all times to display the 3D maze in AR. The witch's movement in AR adheres to physics laws, utilising gravity to navigate from start to finish. A picture of the primary user test setup can be seen in figure 6.5.

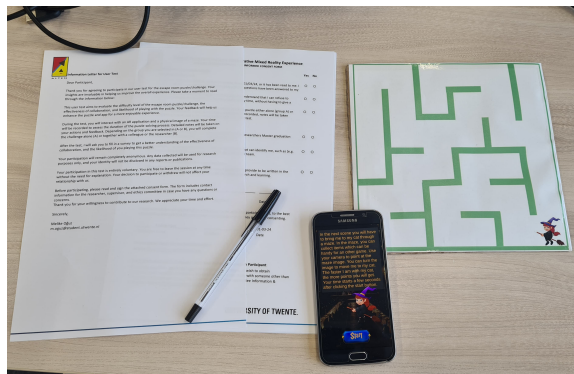
The test begins with participants reading an information letter and signing a consent form. Participants, who self-assigned to Group A or B during recruitment, are reminded

that their time will be recorded and notes taken during the test. Timing starts after the instruction screen. The researcher records the end time, the number of collectables collected, participants' comments, steps taken, and other observations. The test concludes when participants either finish the maze or run out of time.

Following, the secondary user test consists of a survey with 11 open-ended questions regarding the prototype consisting of three sections; general questions, group-based questions about collaboration, and interest in engaging with the game. All of the survey questions can be found in Appendix D.9: Survey questions with answers Puzzle 3. Last, the participant/duo is thanked for their participation, and the game is restarted for the next participant/duo.



(A) The AR application of Puzzle 3



(B) The test setup of Puzzle 3

FIGURE 6.5: The test setup of Puzzle 3

6.4.3 Results

We can note the user test results in two parts, the user test notes and the survey. The user test notes include solvability, the collaborative experience, and individual interest in engaging with the game. The survey results state the most challenging aspects, individual versus collaborative experience, the interest of participants in playing the game, and final remarks. Both the notes and the survey questions and answers can be found in Appendix D.10: Detailed notes user test Puzzle 3, and D.9: Survey questions with answers Puzzle 3.

User test notes

First, most participants completed the game within the designated time, despite one technical issue. The average completion time was about two minutes and 30 seconds. Initially, participants struggled to control the witch, trying methods like swiping or moving the phone, but they eventually grasped the controls. Participants debated between rushing for points or pausing to collect items, risking running out of time. Group A uniformly controlled the witch by holding the phone in one hand and navigating with the other. In Group B, strategies varied initially: one duo had one member hold the maze while the other managed the camera, later transitioning to both using AR. The remaining duos followed this pattern, with the third duo eventually shifting to one navigating while the other offered verbal guidance.

Second, both groups exhibited comparable experiences in solo play and collaboration. Group A participants expressed frustrations or achievements, while Group B participants offered directives and motivation. Despite these differences in communication style, there was little disparity in average completion times or the number of collectables collected. Both groups showed similar solo versus collaborative experiences in terms of verbal interaction, finishing times, and collectable collection rates.

Third, participants showed great interest in the game, mainly due to the interaction between AR and the physical maze. User test notes indicate participants enjoyed the game, with smiles, chuckles, and exclamations of joy. There was no clear difference between the groups in expressing joy during the test.

User test survey

First, survey responses indicated that participants found controlling movement, judging angles, and navigating lag to be the most challenging aspects of the game. Although the overall difficulty was described as moderate, manoeuvring the maze stood out as particularly tough. Once participants grasped the controls, the game felt less daunting, but the lag remained an additional challenge.

Second, participants in both Group A and Group B had differing experiences with solo and collaborative play. Group A generally enjoyed solo play, while Group B's experiences varied. Some in Group B found collaborating enjoyable and challenging, while others questioned its benefits. Solo play was seen as neutral or more efficient and relaxed, with suggestions for dual-handed control. Both groups overcame challenges through trial and error and adjusting movements, with Group B also adjusting their task division.

In collaborative play, Group B had varied experiences, with some enjoying it and others stressing the need for assigned roles. Verbal instructions from partners affected goal attainment for some, while others noted benefits like facilitating extra movement. Some participants were uncertain about the impact of collaboration. Group A's opinions on partnering differed, with concerns about decision-making time and others seeing potential time savings and collectable benefits. Group B provided examples of collaboration facilitating gameplay strategies, including increased speed, faster idea generation, quicker understanding, and problem-solving.

Third, participants were interested in aspects that would attract them to play the full version of the game, including the physical maze and AR, collectables with future benefits, beating time records, and playing with a partner. Survey questions highlighted these factors. The theme's impact was mostly neutral, though some noted positive influences like the cat, while one was negatively affected by the inclusion of a witch. Participants recommended AR, the physical maze, the time versus collectables dilemma, and the physical-to-digital interaction.

Fourth, participants provided several recommendations during the user test regarding the maze, timer, and instructions. They suggested increasing the maze's difficulty for greater appeal and adding handles to hold the physical maze. For the timer, they recommended indicating when the time is almost up (e.g., 30 seconds remaining) to help users decide whether to go for a collectable. Another suggestion was to introduce consequences for not reaching the cat in time to increase motivation. Lastly, they advised making the instructions clearer on how to move the player through the maze.

6.4.4 Discussion

Analysing the results with respect to the user test objectives provides a deeper understanding of the puzzle's solvability (difficulty level of the game), the enhancement collaboration

brings to the experience, and the level of interest in interacting with the puzzle. We summarised the key findings from this analysis in three points.

First, most participants (individuals or duos) completed the maze in time, with average finishing times between 2.5 and three minutes. While manoeuvring the maze was challenging, finding the path was easy. Therefore, the game’s difficulty level is considered satisfactory.

Second, despite having 11 participants, only five individual sessions and three collaborative sessions were conducted, making definitive conclusions challenging. However, collaborative play was seen as clumsier and harder than solo play but enhanced communication and motivation. Some participants found the struggle of collaboration positively impacted their experience. Collaboration was not necessary to complete the game, as Group A (solo) and Group B (collaborative) had similar average completion times. Group A collected slightly more items on average, suggesting solo play may make item collection easier. Group B perceived quicker movement, faster idea generation, and accelerated learning, even though their completion times were not faster than Group A’s, indicating collaboration may have subjective benefits beyond completion times.

Third, the AR component and physical maze were the most engaging aspects, despite app lag issues. The timer increased interest, motivating participants to beat their records. While the witch/magic theme did not significantly increase interest, adding consequences (e.g., something happening to the cat) could enhance engagement. Clear role division during collaborative play was mentioned positively and could be leveraged to increase interest.

6.4.5 Future considerations

Expanding on these interpretations allows for future considerations regarding the solvability of the puzzle, the collaborative aspect, and potential improvements to both hardware and software. We noted these considerations in three parts.

First, the current maze difficulty is slightly easy, but manoeuvring through it is challenging. The difficulty level can remain as is, but if manoeuvring is improved, the maze path could be made harder to maintain balance. The three-minute time frame is appropriate and should be maintained.

Second, collaboration currently feels clumsy and does not significantly enhance the experience. To improve, the game’s goals could be adjusted, specific roles assigned, or clearer instructions provided. As suggested by a participant, the system could be modified to require two hands to manoeuvre and a third hand to use AR. Enhancing collaborative play could make it a rewarding challenge and improve user experience.

Third, upgrade the hardware from cardboard to a sturdier material, making the maze one side of the Enchanted Escape. This design would require two hands to hold the box, keeping hands out of the way and encouraging collaboration. Improving pre-game instructions with clearer text or adding images/animations can aid better understanding. Lastly, engagement can also be increased by adding consequences for not finishing on time. All in all, these considerations regarding solvability, collaboration, and hardware and software improvements can enhance the final implementation of the Enchanted Escape.

Chapter 7

Final Implementation and Enabling Technology

This chapter will first talk about the final implementation of the Enchanted Escape including the flow of the system, and a description of the three puzzles. The descriptions mainly include implemented changes, if any, inspired by Chapter 6: Puzzle Design Evaluation. It will then talk about the enabling technology such as the hardware and the software used to realise the final Enchanted Escape, used in Chapter 8: Validation.

7.1 Final Implementation

In the final implementation of the Enchanted Escape, we designed the system to start with a screen to connect the phone to the box via Bluetooth. After connection, an explanation of the system, including the games/puzzles and the use of AR, is provided. The system tracks time in minutes and seconds in the background. Players aim to complete the Enchanted Escape as quickly as possible to earn points, ranging from 10 to 1050. Points can be earned or deducted throughout the games/puzzles. After completing the Enchanted Escape, players can view their total points.

The sequence of games begins with the Maze, followed by the Button Sequence, and concludes with the Casting Spell. To maintain smooth progression, players can collect items in the Maze, which provide valuable hints for the Button Sequence. The Enchanted Escape concludes once the correct spell is cast. Finally, players can view their earned points, input their team name into the leaderboard, and see the top five players. Please refer to Appendix E: Final Implementation Software, for screenshots of the software implementations.

7.1.1 Maze

Looking at the future considerations of the Maze design evaluation, we implemented four changes to the game. First, the physical maze is engraved on the box of the Enchanted Escape instead of a piece of cardboard, enhancing collaborative play. Second, a clearer explanation of how to manoeuvre the box is provided in the UI. Third, a consequence is added by removing all collected items when the maze is not finished in time, to enhance engagement. Fourth, the duration of the Maze is increased from three to five minutes to compensate for the encountered bugs. Figure 7.1 shows the final hardware implementation of the Maze.



FIGURE 7.1: Final hardware implementation of the Maze

7.1.2 Button Sequence

Based on the proposed future considerations of the Button Sequence design evaluation, we implemented four design changes. First, the feedback system now uses an LED strip divided into nine sections, each representing a step. Correct steps light up the strip in the corresponding colour, while incorrect inputs turn off the strip, requiring the player to start over. Figure 7.2A shows an example of six correct inputs. Completing all nine steps correctly triggers a rainbow animation, which can be seen in Figure 7.2B. This allows for feedback on both the current step and previous steps. Second, the sequence resets before starting the Button Sequence and after finishing it, with the order randomised by the system each time. Third, a time element has been added: the sequence must be completed within three minutes, or a 20-second penalty is added at the end. Fourth, players have a limited number of hints, equal to the number collected in the maze, with a maximum of five. Incorrect inputs add a 10-second penalty each time, with a maximum of 60 seconds, and no maximum number of lives.



(A) Representation of six correct inputs in the button sequence



(B) Final implementation of the Button Sequence after solving the sequence

FIGURE 7.2: The final hardware implementation of the Button Sequence

7.1.3 Casting Spell

Considering the future recommendations of the Casting Spell design evaluation, we carried out four changes in the design. First, the UI is made more intuitive, e.g. on how to close the cheat sheet. Second, a better explanation is provided on which buttons to press to cast the spell. Third, the physical buttons are changed to two pressure plates instead of capacitive sensors, for higher accuracy. Fourth, when the correct buttons are pressed, an LED turns on to indicate that the buttons are pressed correctly. Refer to Figure 7.3 for the final hardware implementation.



(A) LED used for the Morse code



(B) One of the pressure plates on the side

FIGURE 7.3: The final hardware implementation of the Casting Spell

7.2 Enabling Technology

This section provides an overview of the hardware and software used for the Enchanted Escape.

7.2.1 Hardware

The hardware is built, using the materials listed below, in five steps.

First, we connected all the necessary components such as the buttons, the LEDs, the Bluetooth module, and the wires needed for the pressure plates to an Arduino UNO via a breadboard. For a detailed description of this setup please refer to Figure 7.4.

Second, assembling the necessary components provides a clearer indication of the required box size, and placement of the components on the box. The dimensions of the box are not only based on these components but also on ensuring that an average person cannot hold the box with one hand, while still keeping it manageable for one person.

Third, we created the design document for laser-cutting and engraving the box. At this stage, we also cut and engraved the box. Details of this design can be found in Appendix F: Laser-cut Design.

Fourth, the Arduino, the breadboard and all the other components are placed securely in the box. The box is then glued together, keeping the side with the maze unglued to access the components when needed.

Fifth, each pressure plate side is constructed using a 1kOhm resistor, three jumper wires, two pieces of aluminium foil, and an extra wooden plate. The assembly process is as follows: Glue a piece of aluminium foil into the extra wooden plate, leaving a one-centimetre margin. Attach a wire to the foil with tape, connecting it to the Arduino's 5V, as shown in Figure 7.4. Glue another piece of aluminium foil to the side of the box, also leaving a one-centimetre margin. Attach two thin vertical wood pieces on the left and right to create a gap between the plates. Connect a wire from the Arduino's ground to the resistor, and from the resistor to the foil on the box side. To register a "push," the two plates must make contact, requiring sufficient pressure due to the thin wood pieces separating them.

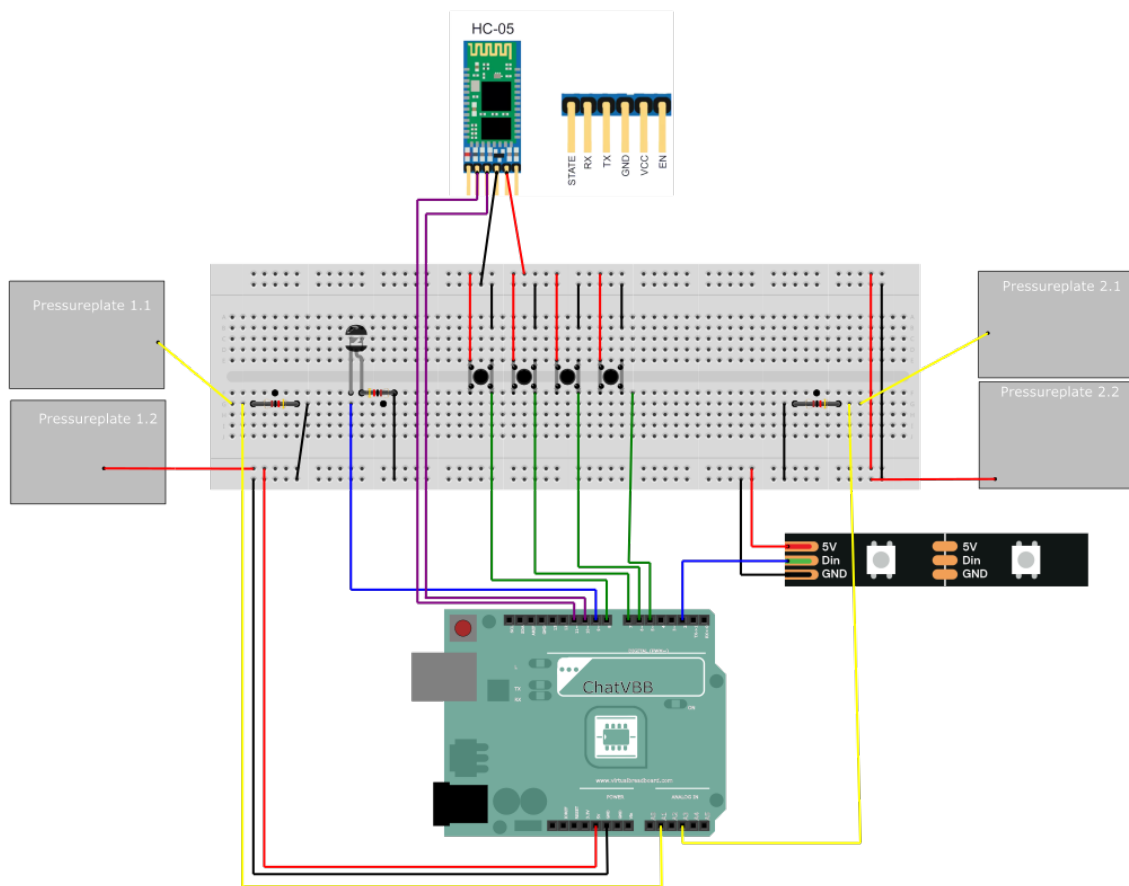


FIGURE 7.4: Arduino circuit diagram used for the hardware implementation

The hardware of the Enchanted Escape consists of the following materials:

- Four tactile push buttons and button caps
- WS2812B Digital 5050 RGB LED Strip - 144 LEDs 1m
- Single LED
- HC-05 Bluetooth module
- Arduino UNO
- USB-A to Arduino UNO power cable
- Re-load powerbank 12 watt | 5.000 mAh
- Breadboard 400 points
- Jumper wires
- Resistors
- Aluminium foil
- Soldering supply
- Laser-cut box

– Dimensions in cm: W25 x L15 x H15

7.2.2 Software

To realise the software, two main programs are used, Unity [3] and Arduino IDE [4]. Unity is used to build the app, including the UI, the AR, speech recognition, a leaderboard and Bluetooth communication. Arduino IDE is used for the push buttons, LEDs, pressure plates, and Bluetooth module.

Unity

Different packages are used to build the UI, AR, speech recognition, and leaderboard in Unity. The UI is designed with a magical theme, incorporating background, buttons, fonts, characters, and sound effects. A package is used for uniform button design.

The AR system is built using Vuforia Engine AR [5], which is downloaded and installed in Unity. Vuforia allows for image tracking by uploading an image into the desired scene. The system then recognises the image and displays a designed 3D object, such as a cube or maze, on it. For the Button Sequence, AR uses four different coloured cubes. The maze, however, needed to be designed using an online tool as a guideline and built in Unity with ProBuilder [6].

Speech recognition is implemented using Hugging Face [7], an online machine-learning platform. The open-source API for speech recognition was downloaded into Unity and modified to include the required spell recognition and adapt the record buttons to pressure plates.

The leaderboard is built using an example game by Tran [78] in Unity. It utilises Dreamlo [28] to track points and names. Unity sends the information to Dreamlo, which stores it and allows Unity to retrieve it as needed.

To allow for a Bluetooth communication between Unity and Arduino we used an Asset from the Asset store. This Asset includes examples scenes which provided code to use in our system. The code is modified to our needs, such as sending and receiving specific messages to and from the Arduino.

Arduino

The Arduino code consists of three parts, the Button Sequence, the Morse code, and the pressure plates.

The button Sequence uses a randomised array as input, consisting of a total of 9 inputs, with each input being zero to three. The numbers zero to three correspond to one of the buttons, and each button corresponds to a colour. The code checks an incoming input and compares it to the current step in the array. If the input corresponds with the current step, the according colour and step on the LED strip turns on. The LED strip consists of 27 LEDs, divided by nine steps resulting in three LEDs per correct input.

The Morse code functionality integrates LED flashes to represent the Morse code for "Ignis Nova". The Morse code sequence consists of characters, dots, dashes or a space, and is stored in a string. Depending on the character the duration of the LED turning on changes, short for dots, longer for dashes, and even longer for spaces, ensuring an accurate representation of the Morse code.

The Pressure plates are each connected to the ground, 5V, and an analogue pin, as the only information the Arduino reads from the pin is HIGH or LOW. When both sides of a plate are touching, the Arduino reads it as HIGH, and when both pressure plates are HIGH, the system sends a message to Unity to inform that both plates are pressed.

The Bluetooth module facilitates real-time communication between Arduino and Unity. Data is sent from the Arduino to the Bluetooth module via serial communication, which then forwards the message to the device running the Unity program through Bluetooth. Similarly, messages from Unity through Bluetooth are received by the Bluetooth module

and relayed back to the Arduino through serial communication. However, this system is limited to a single character, such as a letter or a number.

To conclude, this chapter outlines the final implementation of the Enchanted Escape, detailing the system flow and describing the three puzzles: Maze, Button Sequence, and Casting Spell. The chapter also discusses the enabling technologies, including both hardware and software components, that were used to realise the final version of Enchanted Escape. The implemented changes, inspired by the Puzzle Design Evaluation in Chapter 6: Puzzle Design Evaluation, are highlighted to showcase the enhancements made. The chapter concludes by emphasising the integration of various technologies, such as Bluetooth communication, Arduino controls, and Unity software, to create a seamless and engaging user experience for the Enchanted Escape, which is used in the next Chapter 8: Validation.

Chapter 8

Validation

This chapter validates the research methods and findings from previous chapters, addressing the main research question: *"How can an engaging digital-physical play experience be realised that promotes collaborative play among individuals?"*. It also tackles the sub-question: *"What kind of experience do individuals have with the resulting system, such as playfulness, engagement, and social multiplayer interaction?"*. Validation is structured into two categories: the first examines how well the Enchanted Escape promotes collaborative play through field studies, while the second assesses user experiences—playfulness, engagement, and social interaction—via controlled tests. Subsequent sections will detail the findings from each category, starting with field study results and then controlled user test outcomes.

8.1 Field Study

The field study aimed to determine if the Enchanted Escape system could effectively promote collaborative play among office consultants. The study focused on two key questions: does the system encourage spontaneous play, and does it foster collaborative play? Over four days, we observed consultants during their coffee and lunch breaks. It became evident that employee interest in engaging with the Enchanted Escape system decreased over time. To ensure reliable validation, we set up the test so that the system itself was the only inviting element for interaction. The system was placed prominently in the coffee or lunch rooms with a sign saying, "Feel free to try out (unlock the phone to start)" (see Figure 8.1).



FIGURE 8.1: Field study test setup

To minimise our presence and interference, we observed from about 1.5 meters away, discreetly taking notes on a form designed for quick and unobtrusive data collection (see Figure 8.2). The notes included the date, time, location, number of employees present and interacting, session duration, and whether consent was obtained for using their data. Data from brief glances or sessions without obtained consent are disregarded.

Consent was verbally obtained post-session to ensure participants agreed to data use and maintain spontaneity. Participants also completed a survey for deeper insights into their experience, spontaneous play, collaborative versus solo play, engagement, and additional remarks. The survey questions are detailed in Appendix G.3: Field Study Survey Questions and Results.

Field study

Test Nr.	Comments/Observations	Extra
Date:	<input type="checkbox"/> Initiation of Interaction: Instances where individuals approach the game without any external prompting. Phrases such as "What's this?" or "Let's check it out." <input type="checkbox"/> Expressing Curiosity: Verbal expressions of interest or curiosity about the game. Phrases like "This looks interesting!" or "I wonder how it works." <input type="checkbox"/> Engagement with Physical Components Actions like touching the box, rotating it, or examining the details <input type="checkbox"/> Use of Mobile Application: Phrases indicating interaction with the app, such as "Let me try scanning this" or "I think the app does something." <input type="checkbox"/> Expressing Enjoyment or Satisfaction: Phrases like "This is fun!" or "I like how it combines physical and digital elements." <input type="checkbox"/> Seeking Others to Play: Phrases such as "Hey, come check this out!" or "Want to solve this puzzle together?" <input type="checkbox"/> Revisiting the Game:	Location:
Time:		
Employees present:		
Employees interacting:		
Engagement duration:		
Consent:		

FIGURE 8.2: Field study notes form

8.1.1 Observation Results

The field study findings offer valuable insights into participants' interactions and experiences with the Enchanted Escape system. Observations highlight curiosity, enjoyment, satisfaction, and the inclination to seek others for play. These insights are summarised in four parts, with detailed notes provided in Appendix G.2: Field Study Observation Results. Figure 8.3 provides an overview of the Field Study results.

Field Study Results

	Observation	Survey
Interaction Initiation	8	Curiosity, amusement, and fun cited as engaging; physical box and note inviting; AR and button sequence found engaging
Curiosity Expression	6	Some participants found gameplay unclear or not easy; curiosity sparked by observing others
Physical Engagement	6	Design and aesthetics praised; bugs and unclear instructions noted as discouraging
Mobile App Use	6	Use of mobile application seen as an inviting aspect despite some hesitation due to bugs
Enjoyment and Satisfaction	3	Positive comments on overall experience; some found the game interesting despite challenges
Social Interaction	3	Collaboration found enjoyable and beneficial; joint problem-solving appreciated; some difficulties with task division noted
Game Revisiting	2	Memorable moments included the timer and AR implementation

FIGURE 8.3: Overview of the Field Study Results

Firstly, over four days, there were eight interactions recorded with consent. Five of these occurred during lunchtime, and three took place at the coffee corner. While lunchtime and the office layout are consistent for most employees, the coffee break location and time can vary. Therefore, the system was positioned at different coffee corners before and after lunch to ensure diverse participant interactions throughout the day.

Secondly, employee attendance varied during lunch and coffee breaks. On average, 20

employees attended lunch sessions, but two sessions had fewer attendees. Coffee break attendance ranged from one to four employees. Participant numbers varied from one to eight, with five sessions having one participant each, and the rest having two, three, or eight participants. In sessions with three participants, one left while another joined, maintaining three participants. In the session with eight participants, three were active initially, but five bystanders provided verbal input by the end.

Thirdly, session durations ranged from a few seconds to a maximum of 12 minutes. Lunchtime sessions varied slightly, with three lasting from two to 10 seconds, one lasting 10 minutes, and the longest lasting 12 minutes. The 12-minute session involved initial interaction for two minutes, followed by a return for further engagement, adding ten minutes. Coffee break sessions lasted from four to ten minutes. Most sessions longer than a few seconds focused on solving the first puzzle, while two sessions completed the Enchanted Escape entirely. No discernible trend in session duration was observed between individual, group, or pair sessions.

Fourthly, interactions during each session varied, ranging from mere initiation to revisiting the game. Most sessions included expressions of curiosity, engagement with physical components, and interaction with the mobile application. We summarised the results of these interactions in Figure 8.3.

8.1.2 Survey Results

The field study survey results provide insights into overall experience, spontaneous play, solo versus collaborative play, engagement, and final remarks. Despite eight sessions with varying participant numbers (one to eight), only eight respondents completed the survey. We summarised the findings into seven points: four general questions for all participants, separate sections on solo and collaborative play, and final questions on engaging aspects, memorable moments, and additional remarks. Refer to Figure 8.3 for an overview of the results. See Appendix G.3: Field Study Survey Questions and Results for more details.

First, participants' feedback on the overall experience varied. Positive comments included "Good" and "Interesting to play," while some found it "Unclear" and "Not easy to play." The design was appealing to some, and the system's placement was inviting. Observing others play and struggle sparked curiosity. Despite challenges, most found the experience engaging and enjoyable, citing curiosity, amusement, and fun

Second, participants highlighted various engaging aspects of Enchanted Escape, such as the physical box, the note on the table, AR, and the button sequence.

Third, factors encouraging spontaneous participation included the physical box, design aesthetics, the note next to the system, and AR functionality. Discouraging factors were system bugs, gameplay uncertainty, and hesitation to use the phone despite the sign.

Fourth, prompting moments to engage with the system included coffee and lunch breaks, visual appeal, observing others struggle, the game timer, and AR movement

The following point addresses three questions about playing alone with the system. Five participants interacted alone, but three of them had only brief interactions, such as looking at the system or touching a few buttons, each lasting no more than a few seconds. Consequently, most of the subsequent questions were not answered by these participants.

Fifth, solo participants reported uncertainty about gameplay and system bugs preventing game completion. They struggled with multitasking and navigation. Some missed crucial information due to not reading instructions carefully. They suggested that having a partner could help divide tasks and improve understanding.

The succeeding point addresses three questions that are asked to participants playing in collaboration. There were in total three participants who collaborated and filled in the survey.

Sixth, participants found playing with a partner enjoyable, entertaining, and full of communication. Collaboration enhanced their experience, facilitating joint problem-solving. They appreciated idea-sharing, task division, and teamwork, although some puzzles were complicated by having a partner.

The final point addresses three questions asked to all participants regarding engaging features or challenges of the Enchanted Escape and some final remarks.

Seventh, participants highlighted three main engaging features or challenges: the design and the box, the timer, and the AR. Bugs in the system were identified as a potential disengaging aspect, yet participants also found them memorable. Additionally, participants noted the intro to the puzzles, discovering the button sequence, and the chaotic experience of solving the maze and guessing the sequence as memorable and enjoyable. One participant emphasised the significance of clear instructions, suggesting that explicit guidance would enhance the overall experience of the Enchanted Escape system. One participant emphasised the need for clear instructions to enhance the overall experience.

8.2 Controlled User Test

The controlled user test aims to validate the Enchanted Escape experience in terms of playfulness, engagement, and social multiplayer interaction, as outlined in Chapter 1: Introduction. Conducted over three days at the office, sessions were scheduled in half-hour intervals, with participants signing up individually or with a partner. For individual sign-ups, employees were paired by us. Recruitment involved approaching employees at their workstations, with all available participants approached during the testing period. Sessions took place in a designated meeting room to ensure privacy and focus. Materials included the Enchanted Escape, pen and paper, an information letter, and consent forms.

The test commenced with an introduction, distribution of information letters, and consent forms (found in Appendix G.1): Information Letter and Consent Form. Participants then engaged with the system while notes were recorded using a form with checkboxes for rapid data collection. Participants were instructed to collaborate on puzzles, with technical assistance provided as needed. The form used during the controlled user test can be seen in Figure 8.4.

Session	Engagement			Playfulness and Enjoyment:					Sustained Engagement	Encouragement of Participation	Non-Verbal Cues
	Problem-solving strategies	Exploration of features	Focused attention	Persistence and Resilience; Level of determination, resilience, and motivation to overcome obstacles and achieve success	Verbal and non-verbal expressions of enjoyment, engagement, and social interaction.	Collaborative problem-solving and discussions between participants during gameplay.	Sharing of experiences, anecdotes, and jokes during gameplay	Encouragement and support between participants to achieve common goals during gameplay.			

FIGURE 8.4: Controlled user test form used for taking notes

8.2.1 Observation Results

The results of the controlled user test observation notes offer perspective into participants' experience as a pair in terms of engagement, playfulness and enjoyment, sustained engagement, encouragement of participation, and any non-verbal cues when using the Enchanted Escape. We summarise these observations in six parts, with detailed notes in Appendix G.4: Controlled User Test Observation Results, and an overview of the results in Figure 8.5.

Controlled User Test Results

	Observation	Survey
Engagement	12	Enjoyment despite challenges like bugs and unclear instructions; various engaging aspects including the maze and MR part
Problem-solving	12	Collaboration enhanced gaming experience; some noted that solo play would have been harder and less rewarding
Attention	12	Participants felt motivated to continue playing despite technical issues; some lost motivation due to unsolved puzzles
Resilience and Persistence	11	Positive experiences with collaboration; teamwork and mutual encouragement noted
Playfulness and Enjoyment	10	Enjoyed collaborative tasks like Morse code reading and maze navigation; balance between digital and physical elements praised
Social Interaction	12	Collaboration seen as making the game easier, more motivating, and fun; some dominance issues in gameplay noted
Non-verbal Cues	4	Overall positive feedback with suggestions for clearer instructions and improved UI accessibility

FIGURE 8.5: Overview of the Controlled User Test Results

First, the controlled user test followed the field study, with minor bugs from the field study resolved beforehand. A major bug, related to AR tracking during the maze puzzle, was not fixed until the last few controlled tests. There were 12 controlled user tests, each session involving pairs. Sessions were limited to half an hour to respect participants' schedules. While most pairs were self-selected, we arranged two sessions.

Second, engagement was noted through four points: problem-solving strategies, exploration of features, focused attention, and persistence and resilience. Firstly, all pairs demonstrated problem-solving strategies, such as dividing tasks and engaging in discussions. Secondly, almost all pairs, except for two, explored features like swiping on the box or phone and using AR, even when not needed. Thirdly, all pairs showed focused attention by thoroughly reading instructions and paying attention to both the app and physical components. Fourthly, all pairs, except for one, persisted in their efforts to complete Enchanted Escape despite difficulties, such as running out of time during the button sequence or facing bugs in the maze.

Third, playfulness and enjoyment were observed through four key points: verbal and non-verbal expressions, collaborative problem-solving and discussions, sharing of experiences and jokes, and encouragement and support between participants. Firstly, apart from two sessions, participants displayed enjoyment through laughter and positive remarks during and after puzzle-solving activities. Secondly, all sessions featured collaborative

problem-solving and discussions, with pairs strategising for efficiency and adapting plans as needed. Additionally, individual efforts towards common goals were observed in one session. Thirdly, anecdotes or jokes were shared in nearly half of the sessions, including references to Harry Potter and personal projects. Fourthly, participants provided mutual encouragement and support in half of the sessions, motivating each other to explore solutions and demonstrating determination to succeed.

Fourth, sustained engagement can be seen in all of the sessions. All participants completed the Enchanted Escape despite having the freedom to end the session at any time.

Fifth, we recorded three sessions with participants positively reinforce, encourage, or share excitement about the gameplay experience. To give an example, the participants really encouraged each other by providing them with positive comments whilst trying to solve a puzzle.

Sixth, some nonverbal cues were shown during almost half of the sessions. Four sessions included positive nonverbal cues such as laughing, and smiling, some participants started the session seated, but as they got more excited they stood up, and for some, their voices even changed to a higher pitch. During one session we noticed some frustration around the fact that the maze was buggy.

8.2.2 Survey Results

The survey results offer insights into participants' experiences, covering overall experience, engagement, collaboration, system feedback, and final remarks. With 17 responses, not every participant completed the survey. These findings are summarised in five points: the first covers general feedback, the second addresses engagement-related questions, the third pertains to collaboration, the fourth discusses system feedback, and the fifth includes final remarks. Further details are available in Appendix G.5: Controlled User Test Questions and Survey Results.

First, participants described the overall experience in diverse ways, with most finding it enjoyable despite encountering challenges like bugs or unclear instructions. Some expressed appreciation for the theme or concept. The most engaging aspect varied among participants, with the maze being the most mentioned, followed by the MR part, collaboration, and Morse code decoding.

Second, participants shared various memorable moments or highlights, with common themes including discovering puzzle solutions, collaborating, and navigating the maze. Key features or challenges that kept participants engaged were the Mixed Reality aspect, Morse code, colour combinations, and using AR to scan the box. While most participants felt motivated to continue playing and exploring the game, some mentioned losing motivation after encountering unsolved puzzles or technical issues. Motivating factors mentioned included enjoyment and curiosity.

Third, participants expressed positive experiences when playing with a partner, citing collaboration and teamwork as enjoyable aspects. Collaboration was seen to enhance the gaming experience, making it easier, more motivating, and fun. However, some participants noted that collaboration could be reduced if one person dominated the gameplay. Most participants believed that playing alone would significantly impact their experience, stating it would be harder, less rewarding, and less enjoyable. One participant felt indifferent, stating their partner only acted as an extra set of hands and eyes.

Fourth, participants highlighted standout features of the Enchanted Escape, such as MR, AR, and the integration of coloured buttons. They enjoyed collaborative tasks like Morse code reading and maze navigation. Despite challenges, they found the combination of physical and digital elements intriguing. Most participants felt the balance between digital and physical elements was good, with neither aspect dominating. However, some suggested that the balance could be improved, with opinions divided on whether the digital

part was too prominent or lacking. Lastly, participants suggested various improvements, including UI enhancements, technical fixes, gameplay adjustments, and interactive puzzle ideas. Common suggestions focused on clearer instructions, better UI accessibility, and resolving AR functionality issues. Additional individual improvements were also noted.

Fifth, participants made some final remarks on their experience by providing overall positive feedback, suggestions for improvement regarding clearer instructions and functionality, and acknowledgement of technical issues.

In conclusion, the validation process undertaken in this chapter serves to substantiate the effectiveness of the Enchanted Escape system in fostering collaborative play and delivering engaging digital-physical experiences among participants. Through a meticulous examination of field study observations and controlled user test outcomes, key insights emerged regarding participant interactions, experiences, and feedback. Despite encountering challenges, such as technical issues and varying levels of interest, participants consistently expressed enjoyment and engagement with the system.

Chapter 9

Discussion and Conclusion

This chapter will first provide an in-depth exploration of the field study and controlled user test results. It will then draw conclusions on how to create an engaging digital-physical play experience that promotes collaborative play among individuals. Additionally, it will examine the nature of the user experience with the resulting system, focusing on aspects such as playfulness, engagement, and social multiplayer interaction.

9.1 Discussion

While it is evident that removing bugs, improving puzzles, providing clearer guidance to enhance engagement, and conducting further research to refine data collection are essential steps, there are additional valuable insights to consider. We state these insights in three parts for the field study and two parts for the controlled user tests.

9.1.1 Field study

First, the Enchanted Escape system effectively promoted collaborative play among office consultants. Over four days, observations indicated that the system fostered curiosity, enjoyment, and a tendency to seek others for collaborative play.

Secondly, while we did not expect bystander interaction during the validation of Enchanted Escape, the study highlighted its significance, aligning with one of the project's objectives. Participants often engaged with the system due to encouragement or curiosity sparked by observing others. This interaction added a social dimension, with bystanders providing input, offering suggestions, and sometimes joining the gameplay. These interactions suggest the system's potential to foster broader community engagement beyond immediate users.

Mast et al. [45] identified six stages of engagement in the Participant Journey Map: Transit, Awareness, Interest, Intention to Participate, Participation/Play, and Intention to Stop, noting bystander interaction in the Interest stage. Mast et al. suggest that bystander interaction can be encouraged by design, allowing people to observe from a distance.

Additionally, Reeves et al. [60] discuss how a spectator's view can be designed by revealing or hiding manipulations (user actions) and effects (outcomes). They identify four approaches to designing public interfaces: Secretive, Expressive, Magic, and Suspenseful. Based on their research, Enchanted Escape can be classified as Suspenseful, where "spectators will not experience the effects until it is their turn. Watching others manipulate and react to the interface without seeing the content may provoke curiosity and increase anticipation, heightening the 'payoff' delivered when it is finally their turn."

Thirdly, sessions showed varied engagement levels, with durations ranging from a few seconds to twelve minutes. The physical box, AR features, and observing others struggling with the game were particularly engaging. Most participants interacted with both the physical and digital components, highlighting the balanced design of the system. Despite technical challenges and initial uncertainty about gameplay, the system generally succeeded in maintaining user interest and involvement.

We can link the variety of engagement levels to the peak-end rule introduced by [44], which states that an affective experience is remembered based on its peak moments and its end. We observed that the peak of the Enchanted Escape experience occurs during puzzle-solving and the end after completing a game or puzzle, allowing spectators to join mid-play. This transition shifts their engagement from Interest to Participation/Play as introduced by Mast et al. Interaction never ceased at the second puzzle, excluding it from the end rule.

Additionally, [13] mentions three stages of play: Invitation, Exploration, and Immersion. Although the study focuses on children, the findings are valuable as they offer a toolkit for designing playful interactions. [13] highlights the fluidity of transitioning between these stages, showing how a newcomer can seamlessly join the play environment. This observation supports our findings.

9.1.2 Controlled user test

First, participants demonstrated high levels of sustained engagement and playfulness, evidenced by their problem-solving strategies, focused attention, and persistence. Verbal and non-verbal expressions of enjoyment were common during the sessions. We can summarise these factors as immersion, which is a concept of deep engagement, as mentioned in Chapter 2: Background. Encouragement and mutual support between the duos were significant factors in maintaining engagement and enhancing the overall experience.

Second, collaboration significantly enhanced the gaming experience, making it more enjoyable and facilitating joint problem-solving (a key feature of the sessions). While collaboration was generally beneficial, some participants noted that dominant partners could sometimes reduce the collaborative aspect, and clearly assigned player roles contribute to fostering collaboration. Several sessions included instances of participants positively reinforcing each other, which added to the collaborative and enjoyable nature of the experience.

9.2 Conclusion

This thesis has examined the creation and evaluation of the Enchanted Escape system, a digital-physical play experience realised through Mixed Reality (MR) using Augmented Reality (AR). Designed to foster collaborative play among office consultants, our study provides valuable insights into user engagement, playfulness, and social interaction.

Our research demonstrated that the Enchanted Escape system, leveraging MR through AR, effectively promotes collaborative play by fostering curiosity, enjoyment, and interaction among participants. Observations over four days indicated a significant increase in collaborative tendencies and engagement levels. Additionally, unanticipated bystander interaction added a social dimension, suggesting the system's potential to engage not only the direct participants but also bystanders, thereby expanding its reach and impact.

The primary objective of this thesis was to determine how to design an engaging digital-physical play experience that promotes collaborative play. This is done through MR using AR. The results confirm that collaborative problem-solving with player roles, engaging

games and puzzles, and spectator interaction are essential components for achieving high levels of engagement and collaboration. These findings address our initial research questions and objectives, providing a robust foundation for the design of such systems.

The implications of our findings extend to the broader field of digital-physical play system design, particularly those using MR and AR. By integrating concepts such as Mast et al.'s six stages of engagement and the peak-end rule, we offer a framework for creating experiences that maintain user interest and encourage social interaction. The classification of the Enchanted Escape as a Suspenseful system, according to Reeves et al., highlights the importance of managing spectators' curiosity and anticipation to enhance engagement.

While our study yielded significant insights, it also revealed limitations. Beyond eliminating bugs and providing clearer guidance, future efforts should focus on refining puzzles, including more low-fi testing and allowing for more random solutions, such as changing the spell each time the game is played. Additionally, clearer player roles should be established to enhance both game clarity and collaboration. Further research is needed to refine data collection methods and explore the impact of various design strategies on user engagement. This includes transitions through the six stages of engagement and further exploration of the four design approaches for public interfaces.

The Enchanted Escape system exemplifies how well-designed AR-based MR digital-physical play experiences can foster collaborative play and engagement. This research contributes to the academic understanding of such systems, offering practical insights for designers and researchers aiming to enhance collaborative interactive play experiences.

In conclusion, the Enchanted Escape system showcases the potential of AR-based MR digital-physical play experiences to promote social interaction and bystander engagement. Our findings provide a strong foundation for future research and development in this field, emphasising the importance of strategic design in maintaining user interest and facilitating collaboration within an MR system. This thesis not only advances academic knowledge but also offers practical recommendations for designing engaging and collaborative MR play systems.

Chapter 10

Use of AI

In order to improve the language quality of this research paper, ChatGPT, an AI language model, was used as a tool for grammar correction and optimisation. Sections of the paper were inputted into the model, which provided valuable suggestions and feedback to enhance sentence structures, word choices, and address grammatical errors. Example prompts can be found in Appendix H: Use of AI. Next to that, AI is also used to generate images, as described in Chapter 4: From Global to Final Concept. Lastly, AI is used to help find and solve errors in code, refer to Appendix H: Use of AI for example prompts.

Bibliography

- [1] URL: <https://keeptalkinggame.com/>.
- [2] URL: <https://mecamind.eu/>.
- [3] URL: <https://unity.com/>.
- [4] URL: <https://www.arduino.cc/en/software>.
- [5] URL: <https://developer.vuforia.com/>.
- [6] URL: <https://unity.com/features/probuilder>.
- [7] URL: <https://huggingface.co/>.
- [8] Apr 2023. URL: https://en.wikipedia.org/wiki/Minecraft_Earth.
- [9] Jessica Andrews-Todd and David Rapp. Benefits, costs, and challenges of collaboration for learning and memory. *Translational Issues in Psychological Science*, 1:182–191, 06 2015. doi:10.1037/tps0000025.
- [10] Simon Attfield, Gabriella Kazai, Mounia Lalmas, and Benjamin Piwowarski. Towards a science of user engagement (position paper). 01 2011.
- [11] Ronald Azuma, Yohan Baillot, Reinhold Behringer, Steven Feiner, Simon Julier, and Blair Macintyre. Recent advances in augmented reality. *iee comput graphics appl. Computer Graphics and Applications, IEEE*, 21:34 – 47, 12 2001. doi:10.1109/38.963459.
- [12] Peijun Bao, Ana Maqueda, Carlos Del-Blanco, and Narciso García. Tiny hand gesture recognition without localization via a deep convolutional network. *IEEE Transactions on Consumer Electronics*, 63:251–257, 08 2017. doi:10.1109/TCE.2017.014971.
- [13] Tilde Bekker, Linda de Valk, and Berry Eggen. A toolkit for designing playful interactions: The four lenses of play. *Journal of Ambient Intelligence and Smart Environments*, 6(3):263–276, 2014. doi:10.3233/ais-140259.
- [14] Patrice Bouvier, Elise Lavoué, and Karim Sehaba. Defining engagement and characterizing engaged-behaviors in digital gaming. *Simulation & Gaming*, 45:491–507, 11 2014. doi:10.1177/1046878114553571.
- [15] Elizabeth Boyle, Thomas Connolly, Thomas Hainey, and James Boyle. Engagement in digital entertainment games: A systematic review. *Computers in Human Behavior*, 28:771–780, 05 2012. doi:10.1016/j.chb.2011.11.020.
- [16] Adrian David Cheok, Goh Kok Hwee, Liu Wei, Jason Teo, Teo Sze Lee, Farzam Farbiz, and Lee Shang Ping. Connecting the real world and virtual world through gaming. *Building the Information Society*, page 45–50, 2004. doi:10.1007/978\ -1\ -4020\ -8157\ -6\ _7.

- [17] Frederik Cornillie. Educationally designed game environments and feedback. *Language, Education and Technology*, page 361–374, 2017. doi:10.1007/978-3-319-02237-6_28.
- [18] David Crookall. Engaging (in) gameplay and (in) debriefing. *Simulation & Gaming*, 2014, Vol. 45(4-5):416–427, 08 2014. doi:10.1177/1046878114559879.
- [19] Deeca. Department of energy, environment and climate action, Feb 2023. URL: <http://www.dse.vic.gov.au/effective-engagement/introduction-to-engagement/what-is-community-engagement>.
- [20] Amiraj Dhawan and Vipul Honrao. Implementation of hand detection based techniques for human computer interaction. 12 2013. doi:10.5120/12632-9151.
- [21] Pierre Dillenbourg, Michael Baker, Agnes Blaye, and Claire O’Malley. The evolution of research on collaborative learning. 01 1996.
- [22] Jennifer A Fredricks, Phyllis C Blumenfeld, and Alison H Paris. School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1):59–109, 2004. doi:10.3102/00346543074001059.
- [23] URL: <https://www.oculus.com/experiences/quest/2567395559960697/>.
- [24] Rosemary Garris, Robert Ahlers, and James Driskell. Games, motivation, and learning: A research and practice model. *Simulation & Gaming*, 33:441–467, 12 2002. doi:10.1177/1046878102238607.
- [25] Marios Giakalaras. Mixed reality: A new way of experiencing videogames. 10 2020.
- [26] Philippe Giraudeau, Alexis Olry, Joan Sol Roo, Stephanie Fleck, David Bertolo, Robin Vivian, and Martin Hachet. Cards: A mixed-reality system for collaborative learning at school. *Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces*, 2019. doi:10.1145/3343055.3359721.
- [27] Anthony G. Greenwald and Clark Leavitt. Audience involvement in advertising: Four levels. *Journal of Consumer Research*, 11(1):581, 1984. doi:10.1086/208994.
- [28] Carmen Guida. URL: <https://dreamlo.js.org/>.
- [29] Dipesh Gyawali. Mixed reality: The interface of the future, 12 2022.
- [30] Alastair Henry and Cecilia Thorsen. Engagement with technology: Gaming, immersion and sub-optimal experiences. *Technology in Language Teaching & Learning*, 1:52–67, 12 2019. doi:10.29140/tl1.v1n2.202.
- [31] Wolfgang Hoenig, Christina Milanese, Lisa Scaria, Thai Phan, Mark Bolas, and Nora Ayanian. Mixed reality for robotics. pages 5382–5387, 09 2015. doi:10.1109/IROS.2015.7354138.
- [32] URL: <https://www.microsoft.com/en-us/hololens/buy>.
- [33] URL: <https://www.oculus.com/experiences/quest/4751810638214255/>.
- [34] World Leaders in Research-Based User Experience. How many test users in a usability study? URL: <https://www.nngroup.com/articles/how-many-test-users/>.
- [35] Carolina Islas Sedano, Maira Carvalho, Nicola Secco, and C. Longstreet. Collaborative and cooperative games: Facts and assumptions. pages 370–376, 05 2013. doi:10.1109/CTS.2013.6567257.

- [36] David Johnson and Robert Johnson. Research shows the benefits of adult cooperation. *Educational Leadership*, 45, 01 1987.
- [37] Martin Kaltenbrunner, Sergi Jorda, Gunter Geiger, and Marcos Alonso. The re-actable*: A collaborative musical instrument. *15th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE'06)*, 2006. doi:10.1109/wetice.2006.68.
- [38] Jan Kolkmeier, Emiel Harmsen, Sander Giesselink, Dennis Reidsma, Mariët Theune, and Dirk Heylen. With a little help from a holographic friend. *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*, 2018. doi:10.1145/3281505.3281542.
- [39] URL: <https://www.magicleap.com/magic-leap-2>.
- [40] Rafael Maio, Bernardo Marques, João Alves, Beatriz Sousa Santos, Paulo Dias, and Nuno Lau. An augmented reality serious game for learning intelligent wheelchair control: Comparing configuration and tracking methods. *Sensors*, 22(20), 2022. URL: <https://www.mdpi.com/1424-8220/22/20/7788>, doi:10.3390/s22207788.
- [41] Tony Manninen and Tuomo Korva. Designing puzzles for collaborative gaming experience - case: escape. 01 2005.
- [42] Cristina Manresa-Yee, Javier Varona, Ramon Mas, and Francisco Perales. Hand tracking and gesture recognition for human-computer interaction. *Electronic Letters on Computer Vision and Image Analysis*, ISSN 1577-5097 E:1, 01 2000. doi:10.1142/9789812834461_0022.
- [43] URL: <https://mklive.nintendo.com/>.
- [44] Danica Mast, Sanne De Vries, Joost Broekens, and Fons Verbeek. The importance of the peak-end rule for repeated visits to augmented play spaces. 04 2020.
- [45] Danica Mast, Sanne De Vries, Joost Broekens, and Fons Verbeek. The participant journey map: Understanding the design of interactive augmented play spaces. *Frontiers in Computer Science*, 3, 06 2021. doi:10.3389/fcomp.2021.674132.
- [46] URL: <https://www.meta.com/nl/en/quest/quest-pro/>.
- [47] Paul Milgram and Fumio Kishino. A taxonomy of mixed reality visual displays. *IEICE Trans. Information Systems*, vol. E77-D, no. 12:1321–1329, 12 1994.
- [48] Sep 2009. URL: <https://www.youtube.com/watch?v=cUGjXLYPaIw>.
- [49] URL: <https://www.mirrorscape.com/>.
- [50] Akash Mittal and Ragini Gupta. Mutable (music table): Turn any surface into musical instrument. *arXiv preprint arXiv:2212.14125*, 2022.
- [51] URL: <https://project-archives.etc.cmu.edu/2021/spring/amuseum/>.
- [52] URL: <https://www.nreal.ai/air/>.
- [53] Ohan Oda, Levi J. Lister, Sean White, and Steven Feiner. Developing an augmented reality racing game. *Proceedings of the 2nd International Conference on INtelligent TEchnologies for interactive enterTAINment*, 2008. doi:10.4108/icst.intetain2008.2472.

- [54] Melike Oğuz and Dennis Reidsma. Creating a collaborative mixed reality experience.
- [55] Sihwa Park. Collaborative mobile instruments in a shared ar space: a case of arlooper. 07 2020.
- [56] Anjali Patil and Shaila Subbaraman. A spatiotemporal approach for vision-based hand gesture recognition using hough transform and neural network. *Signal, Image and Video Processing*, 13, 03 2019. doi:10.1007/s11760-018-1370-1.
- [57] Guillaume Plouffe and Ana-Maria Cretu. Static and dynamic hand gesture recognition in depth data using dynamic time warping. *IEEE Transactions on Instrumentation and Measurement*, 11 2015. doi:10.1109/TIM.2015.2498560.
- [58] Sarah Reed, Sherry Hsi, Oliver Kreylos, M. Yikilmaz, Louise Kellogg, S. Schladow, Heather Segale, and Lindsay Chan. Augmented reality turns a sandbox into a geo-science lesson. *Eos*, 97, Jul 2016. doi:10.1029/2016eo056135.
- [59] Johnmarshall Reeve, Hyungshim Jang, Dan Carrell, Soohyun Jeon, and Jon Barch. Enhancing students' engagement by increasing teachers' autonomy support. *Motivation and Emotion*, 28:147–169, 06 2004. doi:10.1023/B:MOEM.0000032312.95499.6f.
- [60] Stuart Reeves, Steve Benford, Claire O'Malley, and Mike Fraser. Designing the spectator experience. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '05, page 741–750, New York, NY, USA, 2005. Association for Computing Machinery. doi:10.1145/1054972.1055074.
- [61] Charles Rich, Brett Ponsleur, Aaron Holroyd, and Candace L. Sidner. Recognizing engagement in human-robot interaction. *Proceeding of the 5th ACM/IEEE international conference on Human-robot interaction - HRI '10*, 2010. doi:10.1145/1734454.1734580.
- [62] Margarida Romero. *Competitive, Collaborative, and Cooperative Play*. 05 2017.
- [63] Jeremy Roschelle and Stephanie Teasley. The construction of shared knowledge in collaborative problem solving. *Computer Supported Collaborative Learning*, 01 1995. doi:10.1007/978-3-642-85098-1_5.
- [64] Thomas Schubert, Frank Friedmann, and Holger Regenbrecht. The experience of presence: Factor analytic insights. *Presence: Teleoperators and Virtual Environments*, 10(3):266–281, 2001. doi:10.1162/105474601300343603.
- [65] Candace Sidner, Cory Kidd, Christopher Lee, and Neal Lesh. Where to look: A study of human-robot engagement. pages 78–84, 01 2004. doi:10.1145/964442.964458.
- [66] Aug 2017. URL: <https://www.youtube.com/watch?v=CxDGgrPaQGo>.
- [67] Ellen A Skinner. *Handbook of Motivation at School*, page 157–180, 2016. doi:10.4324/9781315773384-14.
- [68] Ellen A. Skinner and Jennifer R. Pitzer. Developmental dynamics of student engagement, coping, and everyday resilience. *Handbook of Research on Student Engagement*, page 21–44, 2012. doi:10.1007/978-1-4614-2018-7_2.
- [69] Hsu Soe and Tin Naing. *Real-Time Hand Pose Recognition Using Faster Region-Based Convolutional Neural Network*, pages 104–112. 01 2019. doi:10.1007/978-981-13-0869-7_12.

- [70] URL: <https://www.kickstarter.com/projects/1539770337/spatial\protect\discretionary{\char\hyphenchar\font}{-}\multiplayer\protect\discretionary{\char\hyphenchar\font}{-}\ar\protect\discretionary{\char\hyphenchar\font}{-}\tabletop\protect\discretionary{\char\hyphenchar\font}{-}\gaming?ref=551439&token=6e07a331>.
- [71] Maximilian Speicher, Brian D. Hall, and Michael Nebeling. What is mixed reality? *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 2019. doi:10.1145/3290605.3300767.
- [72] Gal Steinfeld and Gal Alchanati. Augmented reality pinball, 2014. URL: <https://sipl.eelabs.technion.ac.il/projects/augmented-reality-pinball/>.
- [73] URL: <https://www.oculus.com/experiences/quest/4901911359882668/>.
- [74] Nathan Su. Single and multiplayer video gamers: Looking at their experiences and psychosocial well-being during the covid-19 pandemic. *International Journal of Psychological Studies*, 13:51, 11 2021. doi:10.5539/ijps.v13n4p51.
- [75] Khim Raj Subedi. Determining the sample in qualitative research. *Scholars' Journal*, page 1–13, 2021. doi:10.3126/scholars.v4i1.42457.
- [76] Lauren Thevin, Christophe Jouffrais, Nicolas Rodier, Nicolas Palard, Martin Hachet, and Anke M. Brock. Creating accessible interactive audio-tactile drawings using spatial augmented reality. *Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces*, 2019. doi:10.1145/3343055.3359711.
- [77] Phyu Thwe and May Thè. Hand gesture detection and recognition system: A critical review. *International Journal of Computer (IJC)*, 32:64–72, 04 2019.
- [78] Tommy Tran. Tommy-tran/just-dodge: Top-down unity3d game where the player avoids incoming enemies and threats. URL: <https://github.com/tommy-tran/just-dodge>.
- [79] Kellie Vella, Daniel Johnson, and Leanne Hides. Playing alone, playing with others: Differences in player experience and indicators of wellbeing. 10 2015. doi:10.1145/2793107.2793118.
- [80] Jens T. Verhey, Jack M. Haglin, Erik M. Verhey, and David E. Hartigan. Virtual, augmented, and mixed reality applications in orthopedic surgery. *The International Journal of Medical Robotics and Computer Assisted Surgery*, 16(2), Feb 2020. doi:10.1002/rcs.2067.
- [81] URL: <https://www.oculus.com/experiences/quest/4901911359882668/>.
- [82] Werner Wirth. *Involvement.*, pages 199–213. 01 2006.

Appendix A

Asking peers survey data

A.1 Complete list

All ideas as inputs from the participants can be found in the list below.

- Making X more interesting
- Designing in 3D MR
- Navigation
- Recipe when cooking
- Ordering items and finding specific items (Organising)
- Gaming
- Meeting
- Event
- Designing in 3D MR
- Meeting
- Virtual screens
- 3D render
- Simulating emergency
- Designing a house interior
- AI model training (Human shows, AI learns)
- Gaming
- Machine learning
- A game with a ball where the environment changes
- Typing with your hands in the air instead of a keyboard
- Virtual scoreboards or game statistics in physical games and sports
- 3D models with physical drawing activity

- Real-time subtitles
- Online meeting
- Games
- AI glasses (buddy)
- People learning how to fight with VR on that tells them where to go
- A VR coach with a real person
- A way to eat dinner with friends or family far away in a more realistic setting
- Enjoying a theater show with more diverse and different backgrounds, like watching a live movie in which the sets change
- The Mandalorian film set method (360 TV screen instead of a green screen)
- AR glasses
- Drawing
- Tele-interaction
- Long-distance execution (drone piloting, performing surgery)
- Art installation/experience
- AR/VR glasses/headphones
- Hologram
- Gaming
- Medical applications
- Education

A.2 Merging overlapping ideas

Merging overlapping ideas resulted in the following list.

1. Making X more interesting
2. Designing X
3. Navigation
4. Recipe when cooking
5. Organising
6. Gaming
7. Meeting (Business)
8. Virtual monitor/keyboard etc.
9. Simulation

10. AI Model training/ML
11. A game with a ball where the environment changes
12. Virtual scoreboard for sports
13. Real-time subtitles
14. AR/VR glasses
15. Teaching X
16. Meeting (Leisure)
17. Attending events
18. Film set with MR
19. Tele-interaction
20. Long-distance execution
21. Medical applications
22. Education

A.3 Subgroups

Followingly, the data is analysed further and the following subgroups are made.

1. **Teaching X**
 - (a) Education
2. **Leisure**
 - (a) Games
 - i. A game with a ball where the environment changes
 - (b) Virtual scoreboard for sports
 - (c) Attending events
 - (d) Film set with MR
3. **Meetings**
 - (a) Business
 - (b) Leisure
4. **Helping tool**
 - (a) Navigation
 - (b) Virtual monitor/keyboard etc.
 - (c) Real time subtitles
 - (d) Recipe when cooking
 - (e) Organising
5. **Technology based**

- (a) AI Model training/ML
- (b) AR/VR glasses
- (c) Tele-interaction

6. **Designing/Drawing X**
7. **Making X more interesting**
8. **Simulation**
9. **Long-distance execution**
10. **Medical applications**

Appendix B

Storyboard survey analysis

B.1 Survey questions

The complete survey can be found [here](#).

Storyboard evaluation

October 2023

This survey is held to gain insight from others to help selecting the most promising idea for development.



* Required

About you

1

This survey will take about 20 to 30 minutes, and your responses will remain anonymous. I am interested in your thoughts, impressions, and preferences regarding each idea's concept. You are at all times free to leave the survey and you are not obligated to finish it without explanation/justification. If you have any questions or concerns, you can contact either me, my supervisor or the ethics committee of the faculty EEMCS via the following:

m.oguz@student.utwente.nl
d.reidsma@utwente.nl
ethicscommittee-cis@utwente.nl

Do you consent to your data being used in my final project: Creating a collaborative Mixed Reality experience? *

Yes

No

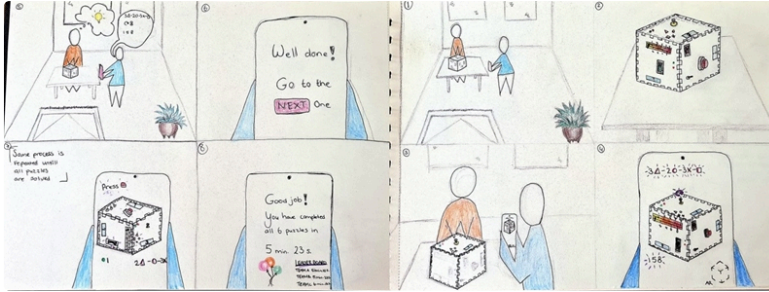
2

How old are you? *

- Under 18
- 18-24
- 25-34
- 35-44
- 45-54
- 55+

Concept 1: Escape room box

A box with on each side a puzzle or riddle that the users have to solve in order to go to the next side of the box. After the last side is solved, the box will open and a time will be set. The fastest times will be recorded into a top 3. The game is played by two people. On the box, there are AR markers that one user needs to scan with their phone. These AR markers include graphics with hints to solve the puzzle/riddle. The other person needs to execute the solution. Interaction can be done in both ways from digital to physical and visa versa. From digital to physical by using AR markers. From physical to digital using sensors/buttons sending information to the app.



3

Please share your initial thoughts and impressions about the concept. *

4

What elements do you find most engaging or captivating? Please explain. *

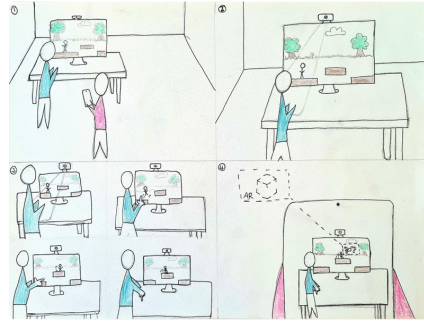
5

Does the idea introduce innovative elements or unique features that caught your attention? Please describe. *

6

Can you provide suggestions for improvements or features you would like to see added? *

Concept 2: 2D multiplayer



The game is a 2D game. There is a main screen (TV screen/monitor) from which both players can view the 2D environment. One player needs to control the game using hand gestures, e.g., moving forward, backward, jumping, or ducking. All the obstacles/extra points can be seen from an AR environment. The person controlling the avatar needs to avoid/collect those and complete the levels with the guidance of the other player.

7

Please share your initial thoughts and impressions about the concept. *

8

What elements do you find most engaging or captivating? Please explain. *

9

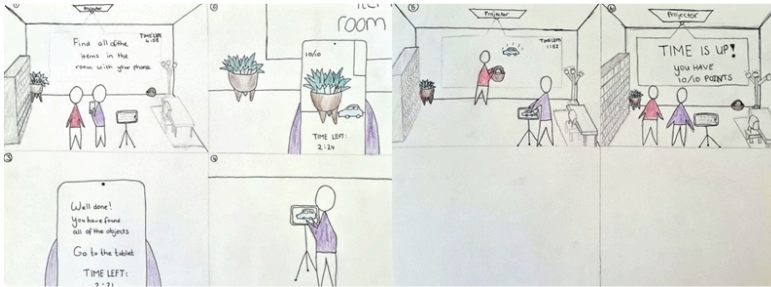
Does the idea introduce innovative elements or unique features that caught your attention? Please describe. *

10

Can you provide suggestions for improvements or features you would like to see added? *

Concept 3: 2-player drawing and catching game

This game is also played with 2 people. In the room that the players are in there are objects hidden. These objects can only be found with the help of their phone using AR. After collecting all the objects, one person needs to draw them on a tablet. These drawings are then projected onto a wall using a projector. The items will one by one fall from top to bottom. The other player needs to catch the items before they fall onto the ground. The goal is to collect and catch as many items as possible in a specific time.



11

Please share your initial thoughts and impressions about the concept. *

12

What elements do you find most engaging or captivating? Please explain. *

13

Does the idea introduce innovative elements or unique features that caught your attention? Please describe. *

14

Can you provide suggestions for improvements or features you would like to see added? *

Overall thoughts

These questions are about your overall thoughts on all of the concepts presented above.

15

Which of the three ideas stood out the most? Why did it catch your attention? *

16

Among the three ideas, is there one that did NOT resonate with you as much? What aspects of this idea do you think need improvement? *

17

Do you have any creative ideas or concepts that could enhance the overall experience for any of the concepts? *

18

Thinking about real-world implementation, which concept do you believe would be the most viable? Are there any practical challenges or benefits you foresee? *

19

If you had to recommend one of these concepts for development, which one would it be, and what influenced your choice? *

20

Do you have any other ideas, suggestions or comments that you would like to share? *

This content is neither created nor endorsed by Microsoft. The data you submit will be sent to the form owner.



B.2 Raw data

Initial raw data from the survey can be seen below. The green colour stands for the first presented concept, the escape room box. The blue stands for the second presented concept which is the 2D multiplayer game. The red colour stands for the third presented concept, 2-player drawing and catching game.

ID	This survey will take	How old are you?	Please share your initial thoughts and impressions about the concept.	What elements do you find most engaging or captivating? Please explain.	Does the idea introduce innovative elements or unique features that caught your attention? Please elaborate.	Can you provide suggestions for improvements or features you would like to see added?
1	Yes	18-24	Keep talking and nobody explodes (similar game) Solving the puzzles is more interactive than giving tips	The puzzle solving aspect Collaborative problem solving	It reminds me of keep talking and nobody explodes, the physicality would then make it innovative.	Add dimensions with sound, smell and/or smoke Maybe add puzzles on the app to keep both engaged
2	Yes	18-24	I really like the back and forth of using AR and the physical interface. I think it has potential to be something cool. In this design I'm worried what will happen after the game is solved a few times. How will it stay interesting or update itself? Also it wasn't clear how exactly the collaboration will happen.	The idea of having one player on AR and another on the physical interface, and them collaborating to solve.	I guess I answered in the previous responses.	I think the interplay between physical and AR can be pushed further. Right now I understood it works with some hints, but both players could have an equal part in solving the riddle. I also think there's room to get very creative with the riddle solving - for example include bigger movements and intricate synchronization between the two players. Also to think about how to keep the game interesting after multiple runs.
3	Yes	18-24	Looks fun!	The fact there is also a physical object next to digital parts of the game	Although I don't think I've seen this before, it doesn't seem very innovative. It uses innovative technology	The AR aspect could help with the fact that escape rooms are not really replayable. You could make it that it does not only give hints but changes aspects between games or difficulty levels
4	Yes	18-24	Interesting but it has already been done 😊	Like the different sides, but it is really dependent on what type of games. Also like the simplicity	Not really.	I'm in general missing what it should do, with what intention.
5	Yes	18-24	Cool concept, love it! Be careful to make sure that it does require two people and that not one person can take control and solve everything on their own.	As a freelance expert in the field of escape rooms and puzzle boxes, I really like the physical puzzle box.	There is nothing that I haven't seen before	One aspect you could look at is making it modular so people can switch out modules to make it a different box so they can play it again
6	Yes	25-34	Leuk en uitdagend!	Zeker, combinatie van technologie maar toch ook de offline interactie zorgt voor dat het boeiend en actief blijft.	De combinatie van technologie en communicatie. En de hoge mate van de vraag naar denken en samenwerken.	Misschien een versie dat de deelnemers elkaar niet kunnen zien, maar alleen horen. Zo leren ze goed een boodschap verwoorden en maakt het nog uitdagender.
7	Yes	18-24	Fun game with lots of possibilities	Cooperation using different mediums. Hard to know without seeing it physically and knowing all of the puzzle interactions (is it buttons, sliders, numbers, ... What purpose do they have for the puzzle?)	Using both digital and physical elements that are meant to go together, without it being AR or something	More of a source for inspiration: There is a game called 'Keep Talking And Nobody Explodes'. This concept reminds me of it, as both players get different information to solve a puzzle. Using many different types of interactions is always fun!
8	Yes	18-24	I think this is an interesting idea as I like puzzle boxes. It doesn't really strike me as an 'escape room' per se, but that is just semantics. I especially like that it can integrate into something bigger, like one part of an escape room experience.	I think the most captivating part is the physical and digital interaction. I really like the idea of implementing AR and using your phone as a part of the riddle. It makes it feel more personal and also more like I am using the tools I would have at my disposal (in this case a phone) to solve the riddles. I can imagine this would make people feel smarter and more resourceful while solving the riddles.	I think once again the usage of AR is a really nice idea. I also like that every side of the box has a different riddle and you must solve all of them to open it. That's a really cool way to tie the physical shape of the object to the interactions you have with it. It also makes total sense and is intuitive.	I think one thing to think about is how you plan to enforce the current flow of actions. You say that one side of the box must be solved before moving on to the next, but how do you make sure that happens? You could make it so you need a part of the previous riddle to solve the next, or maybe once you solve one - the next one is revealed. It may even be that you don't really care about the order of the riddles and would like to give participants the freedom of choice to go about it their own way. Regardless, I think it's worth having a clear vision for this. Another point to consider is how much do you want collaboration to be part of this. You mention you want two participants to solve it together, but from what I gathered it seems like this collaboration is mostly quite surface level and the installation is not built with cooperation in mind. I can see how one participant could solve this by themselves just as easily as two could (or maybe even easier depending on the participants). So, if you want this to be a really 'together' activity, it's worth leaning into the collaboration aspects a little more by maybe making the riddle designs more coop oriented.
9	Yes	25-34	Interesting! It will create some engagement between two players.	AR markers and solving the problem.	I think box concept is quite compact, and I like the combination with AR.	I think the idea of AR combination and physical touch. Maybe some sensory effect from box when u scan AR would be nice to be added (like vibration or led light so that player knows AR captured correctly)
10	Yes	25-34	The game would be intellectual challenging for those playing it, yet it would be doable for a specific target audience - depending on the complicatedness of the games. Furthermore, it's nice that the game has physical and digital aspects which makes it interactive.	Physical vs. Digital elements in the game	Yes, AR in combination with phone and physical elements. Even looks like something you would see in films. The game is written from a broad perspective.	In the details I would add different levels to choose from
11	Yes	18-24	Fun! It would need to be very fool-proof, as I assume people will not treat the box well and try to brute-force things. I believe there are already similar concepts out there (I have a 'puzzle pyramid' at home for example), but without the technology part, so this concept would still be novel Something I'm wondering is to which degree the AR aspects would add a lot (also if you compare it to using a QR code for example), but that might be because I find it hard to imagine what it would like to have AR added. Additionally, it feels like the non-AR person should not look on the phone, but I am wondering if that is an aspect that adds fun rather than annoyance. There is also not a lot that withholds the users from looking at the same screen. An inspiration maybe could be Keep Talking And Nobody Explodes, which I think is a really fun game	The puzzle aspect, as I love escape rooms and puzzles (AIVD kerspuzzel for example)	The fact that there's also technology involved (see earlier comment). Escape rooms often also do not have this, or only very simple (crappy), but it would also make the concept more fragile	Accounting for fragility. Something to also think about is the setting in which you can use the box (best), as I can imagine that there's a difference in designing options when designing for someone's home / in a public place (maybe a cafe or something) / outside, etc.
12	Yes	25-34	It's nice to have an interactive escape room game, but I am wondering whether the puzzles and riddles will then be different everytime? I don't get yet how the AR markers would work. Is the idea that one person performs physical to digital actions and the other digital to physical?	the sensors and buttons add more modality to the escape room game then when you would have a table top or card game as an escape room, since it includes more actions and movement and allowing the user to physically touch and change things. This could add to the immersion of the game.	I think the innovative thing will be the physical interactions with the object. Furthermore, I am wondering what the AR markers could add as unique features, I think there will be potential. It would be nice to see the AR markers used for more than tips, but perhaps there are more digital to physical interactions than I know of. At least I would include those interactions certainly as well and make a nice balance in the two different interaction types.	It would be nice if the two players have to work together (maybe a bit like, "keep talking and nobody explodes") include interactions they have to perform simultaneously, or that one has information that the other hasn't. Maybe add some creative constraints or different game modes.
13	Yes	25-34	Nice idea, it looks very interactive. Of course it needs different levels of challenging games for different users.	The both ways interaction.	The both ways interaction, the fact that it is a box and not an escape room. It could be used inside an escape room too.	The box could give a code at the end instead of a time if used in a larger context, or open to give a key.

Please share your initial thoughts and impressions about the concept.2	What elements do you find most engaging or captivating? Please explain.2	Does the idea introduce innovative elements or unique features that caught your attention? Please	Can you provide suggestions for improvements or features you would like to see added?2	Please share your initial thoughts and impressions about the concept.3
Would be cool if the guiding person cannot see the screen but only were the objectives are	Movement translates to game movement	Not really	Maybe the two players can combine movements in certain levels	Hide and seek concept is interesting! It feels like you are trying to combine multiple games into one. The drawing is a bit strange I.m.o.
The overall concept is fun but I think the idea needs refinement (more intricate gameplay). I was confused how the 2nd player interacts. And why only hand gestures?	I like how the collaboration is thought up. The mix of AR and gesture control again seems like it can generate a lot of fun.	Mix of AR and gesture control is innovative and has a lot of potential.	The concept has a lot of potential, but I think it needs much more refining and ideating to become something really cool. The gameplay might be upgraded, but given the main objective, I think the collaboration between players should receive the most focus. How the players interact with one another and what kind of unique combinations can they create? Basically, what can the game do (that is unique to this concept) that encourages the two players to really collaborate, besides just splitting up the controls?	I immediately had a lot of questions about how exactly the process will work (who hides the objects if both players have to search?). In this one I don't see the collaboration aspect very clearly.
Not very clearly described what the second player is doing and how they are using the ar, but seems fun	From what i understand, only one player knows certain things that the other player has to avoid. This seems to me it will make for funny/infuriating (in a good way) gameplay	Not really	Not from the top of my head	Seems too difficult/too many parts for me to find it enjoyable. Although others might of course like that
Fun, a bit like beat saber but then without the glasses	The interactivity	Yeah that you can move, but to be honest it is a bit similar to a wii, but now with 3d effects	Not really	Ehh, a bit boring
Interesting. But maybe it would be easier to just add another TV screen for the second player that the first player cant see. Integration of AR on a moving screen may be unnecessary complicated	Teamwork is essential for completion	This type of teamwork for this type of game is new to me	See answer at #7 No apparent need for AR	Sounds fun!
Deze is wat actiever en meer speelt dan de eerste	Het is een spel die tegelijkertijd gecreëerd wordt door iemand als gespeeld door de ander	Gamen waar er ter plekken iemand anders de omgeving bepaald	Nee	Hier wordt van de 3 het meeste motorische vaardigheden verwacht
Bit confusing. Seems that only one person can play using this concept?	Fun physical activity where you can move around	Interesting combination of bringing real movement to a digital environment	Maybe making the moving automatic would make the game more natural to play. Also having the other player do something in the game would make it more engaging. Maybe he can spawn platforms or explode bombs to defend the player?	More interaction between the two players.
I am a massive fan of 2D games and 2D platforming games so this appeals to me from that aspect. I do have several concerns about the way this would work in practice, however, as it seems like it could easily become difficult to control or cumbersome to interact with. I will elaborate further in the next questions.	I think this could be very cute and attractive for pretty much anyone. If it is similar to Mario like the sketches suggest, most people of all ages know how Mario looks and functions so there is an immediate sense of familiarity. On the other hand there seems to be an interesting twist to it as well, which makes it original and novel.	I think motion controls are always an interesting element, although I don't think this way of control in and of itself is particularly innovative anymore. However, I think that combining this with the idea of different perspectives (one of the player controlling the avatar and one of the environment) is really unique and AR seems like a perfect fit to execute such a mechanic. I also especially like the collaboration in this one - it is very much something that has to be done by 2 people and each of them has a very clear role and contribution to the overall experience.	While I think the idea is really cool, I do think there are several points of concern for me. Firstly, motion controls (especially Kinect-style ones) are notoriously unreliable even for simple gaming experiences that just require you to flail your arms around like a lumatic. I can imagine these issues being even more prominent in a platforming-style game where precision and dexterity are most of the time of essence. What's more, by having physical controls like this you may alienate people with disabilities. Another point of worry for me is the AR aspect. I think you might run into the problem that the player playing the game must sit in front of the TV in order to control it, thus, being in the way of the other player's view of said TV. This might also become quite frustrating, so you need to put a decent amount of thought into how you place things in physical space. Furthermore, I am not sure if the AR player might have too passive of a role. All they do is see the environment in full and communicate with the other player actually in control. This might be fun for less experienced game players to enjoy the fun without too much skill being required of them (imagine a gamer child and a not-so-gamer parent), but I think it might be nice to add some more things for the AR	I like how this idea utilizes the physical space a lot. It feels most like an escape room out of the ones I have seen so far. I like the searching elements incorporated as well.
I think it is a good collaboration concept, however, you might need really good collaboration. Not sure whether action of player and player who control AR can be synchronised well.	AR control.	AR control.	I think there should be some wearable on player who do move so that AR player can detect whether the Synchronisation is made well.	I think the difficulty of level can be decided based on how player is confident on drawing.
A nice game with movements/motions, maybe also good to stay active	The combination of 2d elements with AR	Yes, AR	No	Another interactive game, with a variety of activities such as searching drawing and catching. It speaks to different senses also.
I think this type of game would lead to a lot of annoyance on both sides. Especially considering that using hand gestures is a technology that is not too advanced at the moment, I think that it would result in a lot of screaming back and forth haha. I am also wondering how fun it would be for the person who cannot see the obstacles and rewards - what would be the attention point for them? Why would they keep their attention, aside from their partner giving them orders?	The idea of two people not seeing the same thing but working towards one goal is interesting	I cannot think of any games that work with AR in this way, so that would make it novel	See answer on question 7, I am worried that there will be a lot of frustration and I am wondering how fun it would be for the person that cannot see the obstacles/rewards. I think it would be a lot less rewarding to complete/avoid/etc. something if you cannot see at any time	The different types of activities feel very disconnected. Why are the objects hidden, why do they need to be drawn, and why are they falling down? And why can only 1 person draw/catch? I am also wondering about the location. If you do it in your living room, there is not a lot of room for objects to be hidden, let alone that there will be a projector. If it's in a special location, there is not a lot of replay value, while the game feels very short
It seems fun to have to use bodily movement as controller input, however it is not really clear how it differs from most kinect games. It is nice to have some teamwork, with the other player that sees the hidden layer and helps to guide the other through the game. However, the job of the second player seems tremendously less fun.	the hidden layer that only one of the players can see.	The hidden layer that enables teamwork.	It could be nice if the other player that sees the AR environment could control something in the game as well, maybe that player can change the level, so if there are puzzles, they could change certain objects in the environment to help the first player to collect or avoid certain things. You could look at the different game modes of "Rayman Legends" in which sometimes you play as Rayman in the platformer and other times you are Glowbox or a frog that manipulates Rayman's surroundings so that Rayman can proceed through the level, however you should have the timing right at certain points.	I am wondering whether this game could be played in any room or whether there is this specific room in which certain items are tagged. I like how the physical world is immersed with the digital world. I am wondering how fun the activity would be to do, I think the timer helps adding unto the fun, but maybe this is just something that needs to be playtested to see how fun it will be or to make things more fun. participants can surprise you with their playfulness.
It looks a bit complex for the 2 players to coordinate.	The hand gestures part because it is very interactive.	A bit similar to the wii, the element of having 2 players is new but is also a bit complex.	I think it would be better if both players uses the same mean to play, both AR or both a controller.	It looks funny, maybe a bit boring for the second player to wait for the first one finding the objects and drawing them. The second player seems to play less, for a shorter time.

What elements do you find most engaging or captivating? Please explain.	Does the idea introduce innovative elements or unique features that caught your attention? Please explain.	Can you provide suggestions for improvements or features you would like to see added?	Which of the three ideas stood out the most? Why did it catch your attention?	Among the three ideas, is there one that did NOT resonate with you as much? What aspects of this?
Hide and seek, you can do that in any kind of room	The fall/catch relates a bit to fruit ninja.	One person hides, one person seeks?	The third	The second one, seems a bit static/stationary
The search seems most thrilling if there is time pressure.	The AR search, it seems like it might be possible now with AI tools.	First, I think the collaboration can be thought out more in this idea. Both players just search and its individual, but what if the search requires some kind of working together? This could also tie into my next point that the search does not need to be limited to objects. What if I need to find a shape or pattern and I have the option of also creating it (i.e. by placing objects together). Perhaps this can require the help of the other player (or more players), where they have to take some abstract poses. This can also add a lot of versatility.	I'm stuck between the 2nd and 3rd one, but I might choose the 3rd one cause I see it having a lot of creative and interactive potential. Im worried that in the 2nd one, carrying a phone or tablet might get tiring and it also seems harder to execute in a really fun way.	The first simply because I don't see how to keep it interesting after the puzzles are solved.
I like the looking for things, like an Easter egg hunt, and the drawing the items. Just not together imo	I think having the objects light up in ar is unique. From my understanding, the objects are random objects from your house. This is nice since then it makes the game harder and makes it so that you dont have to keep track of special items	Not from the top of my head	The second, it is the one id like to play most	The third, its just too complicated for me/too many parts
The catching might be really fun	The catching might be fun if the other person has to give directions in where to catch	Not sure if the collecting is much fun, might skip that part	The second one for it provides the most interaction with the ar	The first, because I know it already has been done multiple times.
The multiple steps of engagement could keep it interesting	Nice combination of existing technologies	It seems like one player does a lot of collecting and drawing while the other only waits until they have to catch something	I really liked the first one, but that's because I'm a little biased. It also has been around for several years now. I think the second one has the most potential due to the level of interaction and teamwork required to succeed	Like I said before, the first idea isn't really new. And the third idea may make one person stand around a lot until the other finally finds and draws something
Reactiesnelheid test	Ja, deze game ken ik online wel maar offline nog niet eerder gezien, leuk!	Nee, is goed	3, omdat je dan echt actief fysiek bezig bent	Nee, allemaal leuk op hun eigen manier
Always fun bringing your drawings to life!	Multiple games coming together	It feels like two different games that are a bit separate from each other. I like both of them, but they don't make sense to combine in my mind. Why would I need to draw an object if I already collected it? Why do I collect object and then draw them again?	The first one, because it feels like it has the most tangible interaction and possibilities to explore	I like all of them quite a lot, but if I had to choose it would probably be the second one. It needs more interactions between players.
I think the searching elements are most interesting to me. I think if you have control over how the room is set up you can easily come up with some interesting perspective / optical illusion puzzles to take the concept even further. Don't know if it's any use to you but you might want to check out Superliminal or some of the Batman Arkham games Riddler challenges for inspiration for cool perspective puzzles.	I think it's quite cool that one player draws objects on a tablet and those then get projected on a screen. It makes the whole thing feel more interactive and personalized. I also don't think I have seen this idea of projector and physical interaction much before, so that's quite cool and innovative as well.	I think the biggest thing that sort of lacks for me is a cohesion of the narrative here. You look for objects, then you draw them on a tablet, then you catch them falling from the sky and the goal is to do this as quickly and as accurately as you can. These are all really cool ideas in isolation, but they don't feel like they follow logically from one another. Why does the player need to draw the objects? Why do they fall from the sky suddenly? Why must one catch them to win? It feels like there is not really a narrative drive to the experience and the experience in general is less self-explanatory than the other two. The box puzzle is very intuitive simply from a spacial point of view, the game idea has the benefit of everyone knowing what a 2D platforming game is, but this one feels a little abstract, which may turn some participants off. I think given the right set of objects and the right 'packaging' of the experience, you can definitely make it work, but it needs a bit more cohesion for my taste. Furthermore, it seems like it would be difficult to have players physically interact with the projector. I don't know how you could achieve this from a technical standpoint (at least of the top of my head). One last point is that it might take a long time for one	I think the best idea of the bunch is the first one. I do think that idea two is most attention-grabbing though. Depends on what you are going for.	I think idea three is least resonant for me. While idea one is basically already there in terms of a good functional and logical experience and idea two is really interesting, albeit with some rough edges to sand off, idea three feels a little too abstract and too all over the place for my liking. I already went into more detail about what could be improved to make it more appealing to me.
I think finding object is interesting	I think AR combination with finding object.	Not sure how drawing will add the value. Maybe something puzzling or other way would be better?	I think AR escape box. I like collaboration setting.	AR 2D runner setting? I think synchronisation of players might be difficulty.
The variety of elements being used	Yes, using AR	You would need a big room with high ceilings	Idea #3	2, a little dull compared to the other 2 since one is using just the phone
I think that the activities separately would be fun, but not together. Looking for objects 'in the wild' using your phone for example could be nice, perhaps kind of pokemon-go style (sending people outside is always good haha). Drawing objects which will be displayed could be fun in 30-seconds kind of settings, where you take turns. The catching part still feels quite un-interesting to me	A little bit, see previous answers (Q11 and Q12)	Also see previous answers haha (especially Q12)	The first one, because I am interested in puzzles and it seemed most captivating to me	The last one felt like there were 3 games just glued together without reason. Having them separate and thinking them out more would be better
I like that you could catch digital stuff with a physical object. I think that really helps in the immersion.	I think it is unique how the physical and digital worlds get combined and how physical objects get "loaded" into the digital. This provides a lot of opportunities.	I think that you could do so much more with combining a physical object which can interact with digital projections that goes beyond catching things. Maybe the physical object could manipulate the digital objects in other ways as well. And other games could be played, a sort of hide and seek game where the digital objects pop-up from behind objects in a digital environment or you could play pong with the two people and the falling objects. I think a lot of the classic games we used to play could be altered into really fun immersive upgraded versions.	I think the last one (falling objects game), because there are so many opportunities there. Although the second one with the hidden layer stood out a lot as well, since the feature of the hidden layer also allows for so many nice new interactions between the two different players to be explored.	The escape room box resonated the least. I think because it is a bit similar to a normal escape room game. However, if different modalities (visuals, touch, sounds) would be emphasized even more it would be a wonderful idea. I would at least love to play that. (In conclusion: I think all three ideas have great potential)
Finding objects with AR in the room.	It is a mixture of pictonary and fruit ninja, nice the AR element. Not everyone can have a projector.	Not everyone has or can have a projector, this game may require too many items to be played.	The first one, it can be played on its own and in a larger environment. It doesn't require too much equipment. Easy for the players to coordinate and play together.	The second one, I think it would take too long for the 2 players to coordinate movements and actions.

Do you have any creative ideas or concepts that could enhance the overall experience for any of the A battle mode?	Thinking about real-world implementation, which concept do you believe would be the most viable? The third, drawback would be that people might try to find really challenging hiding spots.	If you had to recommend one of these concepts for development, which one would it be, and what The third, innovativeness	Do you have any other ideas, suggestions or comments that you would like to share? Nope
I already put for each one separately. An extra for the 3rd one is that it could also accommodate more players.	The 3rd concept because it can be done without complicated recognition software. It can be made very complex, but in a very basic way it can already be fun.	The 3rd, because it's the most physical and engaging. But I'm also influenced by the vision I had for it.	I'd say just refine the two favourite ideas and test them out.
Well for the first one, i put it in there	I think all are viable	The first or second, might be easiest	No
Not sure, you could pisdily think of combining some aspects from the three ideas into one, for example the avoiding of elements with catching	All three are quite viable.	The second one cause km most interested into playing it myself	Nope, good luck!
Is AR really necessary? Otherwise for the second idea VR might be an option for the second player in such a way that this player can only see the avatar and the objects, but not the platforms and such	Depends on where each idea would be implemented. Puzzle boxes require a lot of construction and testing	The second one based on novelty and feasibility	Good luck!
Je kan deze spellen ook doen met grotere aantallen dan 2. Voor teambuilding	3, omdat die het leukste is	3, is gewoon leuk	Nee
Maybe looking at other existing games that use interactions between platforms. For example, the Jackbox party packs let people play together on a TV screen using their phone. These games are mostly competitive though. Maybe competitive games could also be fun? I didn't get enough context to know why these ideas are being made.	Second one seems the hardest to make good in my eyes. You need to have a camera, enough space and need to fine-tune it to recognise movement properly. The other two concepts are about the same for me.	Same as question 15, first cube idea, because it feels like it has the most tangible interaction and possibilities to explore	I don't have enough context, as I don't know what the purpose is for the research or design.
I think I shared most of them in the previous answers, but to recap: - For idea one I think given the right puzzle design that facilitates collaboration a bit more, it can be a great small-scope part of a puzzle escape room. - For idea two I think you need a slightly more reliable control scheme and some more interaction for the AR player to make it fun. - For idea three I think it might be nice to give it more narrative cohesion by perhaps even making the mini-game of catching objects different and more connected to the drawing aspects (maybe a Pictionary style game?)	I think idea one is the smallest in scope so it is the most viable to implement. Idea two could suffer from unreliable Kinect-related issues and idea three has really interesting concepts, but I genuinely don't even know how the projector interaction could be achieved. Plus, you need a big space for it, which makes it less portable and more difficult to test.	I'd say idea one for all the reasons I have listed so far.	I think AR is a really cool thing and the biggest benefit it gives in my opinion is allowing users to see something different on a screen as opposed to with their eyes. So, regardless of which of the ideas you go for I think you should lean into this aspect of AR as much as possible. Make it so seeing something that is not physically there is a big part of what you need to do to solve puzzles. Use perspective to your advantage to create cool optical illusions or maybe have one player guide the other through the information they have available on their phone screen. These are the aspects that I like most about AR and if that is a central element, it might be a good idea to use them to their full potential. These are also the aspects I like the most about idea two, despite it being not my favorite of the bunch. Overall, I think all of these have great potential and I hope I have not sounded too harsh in my feedback. I simply want to see the best project come out of this and I hope my feedback can help you achieve that. Best of luck with your thesis!
Keep an eye on players' synchronisation.	I think Escape room box. Not too big setting, but appealing.	I think how it is easy to implement within the time period.	I think AR escape room box could add interesting value on new type of game. Plus, you can easily make multiple duplicates. Therefore, i would go for AR escape room box.
No, i am not that creative unfortunately	3, yes - maybe in Healthcare, for people who are in medical rehabilitation, so they can use/practice/exercise the specific senses they want to regain again in order to better their lives.	3, the practical use and multifunctionality of the game to be operated or executed in more than one field	No, good job! And good luck
I think that it is okay to have people work together. It felt like some of the concepts pushed for a "you do this, and you do this" style, while teamwork could be interesting	All have practical challenges, be it that things need to be sturdy, motion tracking needs to work smoothly and room for something like a projector/enough space to hide stuff is necessary. I think that the first option would be viable, but the technology would need to be simple and the users instructed not to move the box too harsh. The others would also be available as long as the technology works well and there is enough oom	the first one, mainly based on my interest in puzzles and because I think that the dynamic between the two people would be best	Interesting research! Wondering what you will come up with
haha, I think I already told a lot of ideas as answers to all the other questions c; (so see my other answers)	I think they would all be viable, however, I think the third one would be most easy to implement given that the interaction between physical object and digital environment works). For the second game, namely, different levels and layers need to be created and that seems like an awful lot of work for someone working alone on a research project. For the escape room, different riddles and puzzles need to be thought out, which seems also like a lot of effort. However, if you're up for the work and really like that sort of thing, I believe all three are great ideas.	the third one (finding and falling objects) I think it's the most simple concept, but it is a clever one, and it has great potential to implement a lot of games and interactions in this. It provides a lot of creativity and heart to be put in there.	I like your concepts a lot, it was inspirational to read about them, you are doing a great job with your research!
Find all the possible cases where these concepts may be used, not look at them as a finite single game. Combine it with equipment people may already have at home.	The first one, easy to implement. You just need to buy the box.	The first one, it looks funny and challenging. I like escape rooms.	No

B.3 Structured data

After organising the data by grouping the questions, a clearer structure is achieved. Which can be seen below. The same colour code is used here as well.

1) Please share your initial thoughts and impressions about the concept.			2) What elements do you find most engaging or captivating? Please explain.			3) Does the idea introduce inn
Escape room box	2D Multiplayer	2-player drawing and catching game	Escape room box	2D Multiplayer	2-player drawing and catching game	Escape room box
Keep talking and nobody explodes (similar game) Solving the puzzles is more interactive than giving tips	Would be cool if the guiding person cannot see the screen but only were the objectives are visible	Hide and seek concept is interesting. It feels like you are trying to combine multiple games into one. The drawing is a bit strange. L.m.o.	The puzzle solving aspect Collaborative problem solving	Movement translates to game movement	Hide and seek, you can do that in any kind of room	It reminds me of keep talking and nobody explodes, the physically would then make it innovative.
I really like the back and forth of using AR and the physical interface. I think it has potential to be something cool. In this design I'm worried what will happen after the game is solved a few times. How will it stay interesting or update itself? Also it wasn't clear how exactly the collaboration will happen.	The overall concept is fun but I think the idea needs refinement (more intricate gameplay). I was confused how the 2nd player interacts. And why only hand gestures?	I immediately had a lot of questions about how exactly the process will work (who hides the objects if both players have to search?). In this one I don't see the collaboration aspect very clearly.	The idea of having one player on AR and another on the physical interface, and them collaborating to solve.	I like how the collaboration is thought up. The mix of AR and gesture control again seems like it can generate a lot of fun.	The search seems most thrilling if there is time pressure.	I guess I answered in the previous responses.
Looks fun!	Not very clearly described what the second player is doing and how they are using the ar, but seems fun	Seems too difficult/too many parts for me to find it enjoyable. Although others might of course like that	The fact there is also a physical object next to digital parts of the game	From what I understand, only one player knows certain things that the other player has to avoid. This seems to me it will make for funny/inturating (in a good way) gameplay	I like the looking for things, like an Easter egg hunt, and the drawing the items. Just not together imo	Although I don't think I've seen this before, it doesn't seem very innovative. It uses innovative technology
Interesting but it has already been done !!	Fun, a bit like boat saber but then without the glasses	Ehh, a bit boring	Like the different sides, but it is really dependent on what type of games. Also like the simplicity	The interactivity	The catching might be really fun	Not really.
Cool concept, love it! Be careful to make sure that it does require two people and that not one person can take control and solve everything on their own.	Interesting. But maybe it would be easier to just add another TV screen for the second player that the first player cant see. Integration of AR on a moving screen may be unnecessary complicated	Sounds fun!	As a freelance expert in the field of escape rooms and puzzleboxes, I really like the physical puzzle box.	Teamwork is essential for completion	The multiple steps of engagement could keep it interesting	There is nothing that I haven't seen before
Leuk en uitdagend!	Deze is wat actiever en meer speels dan de eerste	Hier wordt van de 3 het meeste motorische vaardigheden verwacht	Zeker, combinatie van technologie maar toch ook de offline interactie zorgt voor dat het boeiend en actief blijft.	Het is een spel die tegelijkertijd gecreëerd wordt door iemand als bespeelt door de ander	Reactiesnelheid test	De combinatie van technologie en communicatie. En de hoge mate van de vraag naar denken en samenwerken.
Fun game with lots of possibilities	Bit confusing. Seems that only one person can play using this concept?	More interaction between the two players.	Cooperation using different mediums. Hard to know without seeing it physically and knowing all of the puzzle interactions (is it buttons, sliders, numbers, ... What purpose do they have for the puzzle?)	Fun physical activity where you can move around	Always fun bringing your drawings to life!	Using both digital and physical elements that are meant to go together, without it being AR or something
I think this is an interesting idea as I like puzzle boxes. It doesn't really strike me as an 'escape room' per se, but that is just semantics. I especially like that it can integrate into something bigger, like one part of an escape room experience.	I am a massive fan of 2D games and 2D platforming games so this appeals to me from that aspect. I do have several concerns about the way this would work in practice, however, as it seems like it could easily become difficult to control or cumbersome to interact with. I will elaborate further in the next questions.	I like how this idea utilizes the physical space a lot. It feels most like an escape room out of the ones I have seen so far. I like the searching elements incorporated as well.	I think the most captivating part is the physical and digital interaction. I really like the idea of implementing AR and using your phone as a part of the riddle. It makes it feel more personal and also more like I am using the tools I would have at my disposal (in this case a phone) to solve the riddles. I can imagine this would make people feel smarter and more resourceful while solving the riddles.	I think this could be very cute and attractive for pretty much anyone. If it is similar to Mario like the sketches suggest, most people of all ages know how Mario looks and functions so there is an immediate sense of familiarity. On the other hand there seems to be an interesting twist to it as well, which makes it original and novel.	I think the searching elements are most interesting to me. I think if you have control over how the room is set up you can easily come up with some interesting perspective / optical illusion puzzles to take the concept even further. Don't know if it's any use to you but you might want to check out Superliminal or some of the Batman Arkham games Riddler challenges for inspiration for cool perspective puzzles.	I think once again the usage of AR is a really nice idea. I also like that every side of the box has a different riddle and you must solve all of them to open it. That's a really cool way to be the physical shape of the object to the interactions you have with it. It also makes total sense and is intuitive.
Interesting! It will create some engagement between two players.	I think it is a good collaboration concept, however, you might need really good collaboration. Not sure whether action of player and player who control AR can be synchronized well.	I think the difficulty of level can be decided based on how player is confident on drawing.	AR markers and solving the problem.	AR control.	I think finding object is interesting	I think box concept is quite compact, and I like the combination with AR.
The game would be intellectual challenging for those playing it, yet it would be doable for a specific target audience - depending on the complexity of the games. Furthermore, it's nice that the game has physical and digital aspects which makes it interactive.	A nice game with movements/motions, maybe also good to stay active	Another interactive game, with a variety of activities such as searching drawing and catching. It speaks to different senses also.	Physical vs. Digital elements in the game	The combination of 2d elements with AR	The variety of elements being used	Yes, AR in combination with phone and physical elements. Even looks like something you would see in films. The game is written from a broad perspective.
Fun! It would need to be very fool proof, as I assume people will not treat the box well and try to brute-force things. I believe there are already similar concepts out there (I have a 'puzzle pyramid' at home for example), but without the technology part, so this concept would still be novel. Something I'm wondering is to which degree the AR aspects would add a lot (also if you compare it to using a QR code for example), but that might be because I find it hard to imagine what it would like to have AR added.	I think this type of game would lead to a lot of annoyance on both sides. Especially considering that using hand gestures is a technology that is not too advanced at the moment, I think that it would result in a lot of screaming back and forth haha. I am also wondering how fun it would be for the person who cannot see the obstacles and rewards - what would be the attention point for them? Why would they keep their attention, aside from their partner giving them orders?	The different types of activities feel very disconnected. Why are the objects hidden, why do they need to be drawn, and why are they falling down? And why can only 1 person draw/catch? I am also wondering about the location. If you do it in your living room, there is not a lot of room for objects to be hidden, let alone that there will be a projector. If it's in a special location, there is not a lot of replay value, while the game feels very short	The puzzle aspect, as I love escape rooms and puzzles (AVD kerspuzel for example)	The idea of two people not seeing the same thing but working towards one goal is interesting	I think that the activities separately would be fun, but not together. Looking for objects 'in the wild' using your phone for example could be nice, perhaps kind of pokémon-go style (sending people outside is always good haha), drawing objects which will be displayed could be fun in 30-seconds kind of settings, where you take turns. The catching part still feels quite un-interesting to me	The fact that there's also technology involved (see earlier comment). Escape rooms often also do not have this, or only very simple (crappy), but it would also make the concept more fragile
It's nice to have an interactive escape room game, but I am wondering whether the puzzles and riddles will then be different everytime? I don't get yet how the AR markers would work. I don't get yet how the game is supposed to be played with two. Is the idea that one person performs physical to digital actions and the other digital to physical?	It seems fun to have to use bodily movement as controller input, however it is not really clear how it differs from most Kinect games. It is nice to have some teamwork, with the other player that sees the hidden layer and helps to guide the other through the game. However, the job of the second player seems tremendously less fun.	I am wondering whether this game could be played in any room or whether there is this specific room in which certain items are tagged. I like how the physical world is immersed with the digital world. I am wondering how fun the activity would be to do, I think the timer helps adding onto the fun, but maybe this is just something that needs to be playtested to see how fun it will be or to make things more fun. Participants can surprise you with their playfulness.	The sensors and buttons add more modality to the escape room game then when you would have a table top or card game as an escape room, since it includes more actions and movements and allowing the user to physically touch and change things. This could add to the immersion of the game.	The hidden layer that only one of the players can see.	I like that you could catch digital stuff with a physical object. I think that really helps in the immersion.	I think the innovative thing will be the physical interactions with the object. Furthermore, I am wondering what the AR markers could add as unique features. I think there will be potential. It would be nice to see the AR markers used for more than tips, but perhaps there are more digital to physical interactions than I know of. At least I would include those interactions certainly as well and make a nice balance in the two different interaction types.
Nice idea, it looks very interactive. Of course it needs different levels of challenging games for different users.	It looks a bit complex for the 2 players to coordinate.	It looks funny, maybe a bit boring for the second player to wait for the first one finding the objects and drawing them. The second player seems to play less, for a shorter time.	The both ways interaction.	The hand gestures part because it is very interactive.	Finding objects with AR in the room.	The both ways interaction, the fact that it is a box and not an escape room. It could be used inside an escape room too.

Native elements or unique features that caught your attention? Please describe.		4) Can you provide suggestions for improvements or features you would like to see added?		
Not really	2D Multiplayer 2-player drawing and catching game The fall/catch relates a bit to fruit ninja.	Escape room box Add dimensions with sound, smell and/or smoke Maybe add puzzles on the app to keep both engaged	2D Multiplayer Maybe the two players can combine movements in certain levels	2-player drawing and catching game One person hides, one person seeks?
Mix of AR and gesture control is innovative and has a lot of potential.	The AR search, it seems like it might be possible now with AI tools.	I think the interplay between physical and AR can be pushed further. Right now I understood it works with some hints, but both players could have an equal part in solving the riddle. I also think there's room to get very creative with the riddle solving - for example include bigger movements and intricate synchronization between the two players. Also to think about how to keep the game interesting after multiple runs.	The concept has a lot of potential, but I think it needs much more refining and ideating to become something really cool. The gameplay might be upgraded, but given the main objective, I think the collaboration between players should receive the most focus. How the players interact with one another and what kind of unique combinations can they create? Basically, what can the game do (that is unique to this concept) that encourages the two players to really collaborate, besides just splitting up the controls?	First, I think the collaboration can be thought out more in this idea. Both players just search and its individual, but what if the search requires some kind of working together? This could also tie into my next point that the search does not need to be limited to objects. What if I need to find a shape or pattern and I have the option of also creating it (i.e. by placing objects together). Perhaps this can require the help of the other player (or more players), where they have to take some abstract poses. This can also add a lot of versatility.
Not really	I think having the objects light up in ar is unique. From my understanding, the objects are random objects from your house. This is nice since then it makes the game harder and makes it so that you dont have to keep track of special items	The ar aspect could help with the fact that escape rooms are not really replayable. You could make it that it does not only give hints but changes aspects between games or difficulty levels	Not from the top of my head	Not from the top of my head
Yeah that you can move, but to be honest it is a bit similar to a wil, but now with 3d effects	The catching might be fun if the other person has to give directions in where to catch	I'm in general missing what it should do, with what intention.	Not really	Not sure if the collecting is much fun, might skip that part
This type of teamwork for this type of game is new to me	Nice combination of existing technologies	One aspect you could look at is making it modular so people can switch out modules to make it a different box so they can play it again	See answer at #7 No apparent need for AR	It seems like one player does a lot of collecting and drawing while the other only waits until they have to catch something
Gamen waar er ter plekke iemand anders de omgeving bepaald	Ja, deze game ken ik online wel maar offline nog niet eerder gezien, leuk!	Mischien een versie dat de deelnemers elkaar niet kunnen zien, maar alleen horen. Zo leren ze goed een boodschap verwoorden en maakt het nog uitdagender.	Neer	Neer, is goed
Interesting combination of bringing real movement to a digital environment	Multiple games coming together	More of a source for inspiration: There is a game called "Keep Talking And Nobody Explodes". This concept reminds me of it, as both players get different information to solve a puzzle. Using many different types of interactions is always fun!	Maybe making the moving automatic would make the game more natural to play. Also having the other player do something in the game would make it more engaging. Maybe he can spawn platforms or explode bombs to defend the player?	It feels like two different games that are a bit separate from each other. I like both of them, but they don't make sense to combine in my mind. Why would I need to draw an object if I already collected it? Why do I collect object and then draw them again?
I think motion controls are always an interesting element, although I don't think this way of control in and of itself is particularly innovative anymore. However, I think that combining this with the idea of different perspectives (one of the player controlling the avatar and one of the environment) is really unique and AR seems like a perfect fit to execute such a mechanic. I also especially like the collaboration in this one - it is very much something that has to be done by 2 people and each of them has a very clear role and contribution to the overall experience.	I think it's quite cool that one player draws objects on a tablet and those then get projected on a screen. It makes the whole thing feel more interactive and personalized. I also don't think I have seen this idea of projector and physical interaction much before, so that's quite cool and innovative as well.	I think one thing to think about is how you plan to enforce the current flow of actions. You say that one side of the box must be solved before moving on to the next, but how do you make sure that happens? You could make it so you need a part of the previous riddle to solve the next, or maybe once you solve one - the next one is revealed. It may even be that you don't really care about the order of the riddles and would like to give participants the freedom of choice to go about it their own way. Regardless, I think it's worth having a clear vision for this.	While I think the idea is really cool, I do think there are several points of concern for me. Firstly, motion controls (especially Kinect-style ones) are notoriously unreliable even for simple gaming experiences that just require you to flail your arms around like a lunatic. I can imagine these issues being even more prominent in a platforming-style game where precision and dexterity are most of the time of essence. What's more, by having physical controls like this you may alienate people with disabilities. Another point of worry for me is the AR aspect.	I think the biggest thing that sort of lacks for me is a cohesion of the narrative here. You look for objects, then you draw them on a tablet, then you catch them falling from the sky and the goal is to do this as quickly and as accurately as you can. These are all really cool ideas in isolation, but they don't feel like they follow logically from one another. Why does the player need to draw the objects? Why do they fall from the sky suddenly? Why must one catch them to win? It feels like there is not really a narrative drive to the experience and the experience in general is less self-explanatory than the other two. The Not sure how drawing will add the value. Maybe something puzzling or other way would be better?
AR control.	I think AR combination with finding object.	I think the idea of AR combination and physical touch. Maybe some sensory effect from box when u scan AR would be nice to be added (like vibration or led light so that player knows AR captured correctly)	I think there should be some wearable on player who do move so that AR player can detect whether the Synchronization is made well.	
Yes, AR	Yes, using AR	In the details I would add different levels to choose from	No	You would need a big room with high ceilings
I cannot think of any games that work with AR in this way, so that would make it novel!	A little bit, see previous answers (Q11 and Q12)	Accounting for fragility. Something to also think about is the setting in which you can use the box (best, as I can imagine that there's a difference in designing options when designing for someone's home / in a public place (maybe a cafe or something) / outside, etc.	See answer on question 7, I am worried that there will be a lot of frustration and I am wondering how fun it would be for the person that cannot see the obstacles/rewards. I think it would be a lot less rewarding to complete/avoid/etc. something if you cannot see at any time	Also see previous answers haha (especially Q12)
The hidden layer that enables team work.	I think it is unique how the physical and digital worlds get combined and how physical objects get "loaded" into the digital. This provides a lot of opportunities.	It would be nice if the two players have to work together (maybe a bit like, "keep talking and nobody explodes") include interactions they have to perform simultaneously, or that one has information that the other hasn't. Maybe add some creative constraints or different game modes.	It could be nice if the other player that sees the AR environment could control something in the game as well, maybe that player can change the level, so if there are puzzles, they could change certain objects in the environment to help the first player to collect or avoid certain things. You could look at the different game modes of "Rayman Legends" in which sometimes you play as Rayman in the platformer and other times you are Glowbox or a frog that manipulates Rayman's surroundings so that Rayman can proceed through the level, however you should have the timing right at certain points.	I think that you could do so much more with combining a physical object which can interact with digital projections that goes beyond catching things. Maybe the physical object could manipulate the digital objects in other ways as well. And other games could be played, a sort of hide and seek game where the digital objects pop-up from behind objects in a digital environment or you could play pong with the two people and the falling objects. I think a lot of the classic games we used to play could be altered into really fun immersive upgraded versions.
A bit similar to the wil, the element of having 2 players is new but is also a bit complex.	It is a mixture of pictorial and fruit ninja, nice the AR element. Not everyone can have a projector.	The box could give a code at the end instead of time if used in a larger context, or open to give a key.	I think it would be better if both players uses the same mean to play, both AR or both a controller.	Not everyone has or can have a projector, this game may require too many items to be played.

B.4 Evaluation storyboard survey

The data analysis is done question by question. With each question, it is looked at all of the three concepts. Small notes are taken from each answer. The answers that were mentioned before are merged into one note. This makes the data more concise and clear. These notes can be found below.

Evaluation storyboard survey

Q1) Please share your initial thoughts and impressions about the concept.

Escape room box:

- Reminds people of the game Keep talking and nobody explodes
- Solving puzzle is more interactive than giving tips
- People like the MR aspect of the game (digital to physical and vice versa interaction)
- Worry about playability after several plays
- Make sure to assure a good collaboration
- Fun
- Interesting
- Cool
- Challenging
- Lots of possibilities
- Possibility to integrate in another idea like an actual escape room
- Needs to be fool proof (people will brute force things)
- Puzzles and riddles should be hard enough to keep it interesting but not too hard
- Different levels for different users

2D Multiplayer:

- Would be cool if the guiding person could not see the main screen
- Fun
- Needs refinement
- Confusion in interaction from both players/Confusion in general
- Resembles beat saver without glasses
- Interesting
- AR aspect might be unnecessary complicated/Too complex
- More active than the previous idea
- Concerns about practicality
- A lot of annoyance on both ends
- Nice to have some teamwork
- The task of the 2nd player seems less fun

2-player drawing and catching game:

- Hide and seek concept is interesting
- Multiple games in 1/Too many games in 1/Disconnected feeling
- Confusion in how it works
- Confusion in collaboration part
- Too difficult
- Boring (for catching person)
- Fun
- A lot of motor skills involved
- A lot of interaction involved between the two players
- Utilises the space a lot in a good way
- Feels like an escape room
- Difficulty of level can be decided on how confident the player is with drawing
- Interactive game
- Variety of activities
- Multiple senses

- Not a lot of playability after playing it more than once
- Confusion in what type of room it can be played
- Good immersion physical and digital world
- Not sure how fun it will be
- Unfair distribution of playtime

Q2) What elements do you find most engaging or captivating? Please explain.

Escape room box:

- Puzzle solving aspect
- Collaborative problem solving
- AR and physical aspect together
- Multiple sides of the cubes
- Simplicity
- Physical part
- Cooperating using different mediums
- Using phone gives a personal feeling
- Sensors and buttons

2D multiplayer

- Movement translates to game movement
- Combination of AR and gesture control
- Asymmetric multiplayer aspect
- The interactivity
- Teamwork
- Familiarity to games such as Mario
- Interesting twist to known games
- AR control
- 2D elements with AR
- Hand gestures

2-player drawing and catching game

- Hide and seek/Searching with AR
- The search in combination with time pressure
- Drawing items
- Catching digital elements with physical item
- Multiple steps of engagement
- Reaction speed test
- Bringing your drawings to life
- Variety of elements

Q3) Does the idea introduce innovative elements or unique features that caught your attention? Please describe.

Escape room box:

- Physical aspect of game compared to “Keep talking, nobody explodes”
- The technology used in the game
- No (4 times)
- The amount of thinking and collaborating
- Using digital and physical elements that ment to go together
- Each side of box having riddles
- Physical elements

2D multiplayer

- No (2 times)
- Mix of AR and gesture control
- That you can move with 3D effects
- Asymmetric multiplayer
- Gaming while at the spot someone determines the setting
- Combination of bringing real movement to digital movement
- The combination of 2 perspectives (game world + obstacles)
- Clear collaboration needed
- AR in this way

2-player drawing and catching game

- No (3 times)
- AR searching
- Catching
- The combination of existing technology
- Physical elements
- Multiple games coming together
- Drawings being projected
- Projection and physical interaction
- Digital - Physical interaction

Q4) Can you provide suggestions for improvements or features you would like to see added?

Escape room box:

- Add different senses such as sound, smell, and/or smoke
- Puzzles on the phone as well
- Interaction between physical and AR can be pushed further
- Include bigger movements
- Keep it interesting after multiple runs.
- Use the AR to change aspects between games or difficulty levels
- Make the box modular to be able to change the box (to make it playable multiple times)
- A version where the players can only hear each other rather than see
- Have a clear vision of the current flow of actions. How to enforce players to go from one side to other. Maybe don't enforce it, let people be free in which side to solve when.
- Make sure the collaboration is really needed
- Add different levels

- Account for fragility
- If used in a larger context, instead of time use a code or a key as end product

2D multiplayer:

- Maybe 2 players can combine movements
- The collaboration between the two should receive the most focus. What can the game do to encourage collaboration rather than splitting up the controls
- No need for AR
- Making the movements automatic
- Make the player with the phone more involved by defending the other player or spawn platforms
- Hand gestures are not reliable enough for a setting like this
- Not inclusive for people with disabilities
- The AR view might be blocked by the person controlling the game by sitting in front of the monitor
- The AR player is too passive now, adding other features to AR to keep it more exciting
- The game might be frustrating for the person who cannot see everything
- AR person controlling more, like changing certain objects in the environment to help the other person
- Symmetric multiplayer instead of asymmetric multiplayer

2-player drawing and catching game

- One person hides one person seeks
- The search could be more collaborative
- The search can be broadened by searching for shapes or patterns that the players can form themselves as well.
- Skip the collecting part
- A lot of waiting involved
- The combination of the two games makes no sense
- No cohesion to the games, no narrative
- Technically seen it might be too difficult
- Would need a big room with high ceilings
- More could be done with the catching part than just catching, like playing pong with the objects with the players passing the objects.
- Not everyone can have a projector, this game may require too many items to be played

General questions

Which of the three ideas stood out the most? Why did it catch your attention?

- 1 (6 times)
- Most tangible interaction
- Personal bias
- Collaborating setting
- Most captivating
- Interested in puzzles
- Can be played on its own and in a larger environment
- Not much equipment
- Easy to coordinate for players
- 2 (3 times)
- Highest change of playing the most
- Provides more interaction with AR
- Level of interaction and team work required
- 3 (5 times)
- A lot of creative and interactive potential
- Due to active physical activity
- Many opportunities

Some answered two options, both were included

Among the three ideas, is there one that did NOT resonate with you as much? What aspects of this idea do you think need improvement?

- 1 (4 times)
- Not sure how to keep it interesting after playing it once
- Because it has been done multiple times
- 2 (5 times)
- Static/stationary
- Needs more interaction between players
- Synchronisation between players might be difficult
- 3 (4 times)
- Too complicated/Too many parts
- Lot of waiting time
- Not coherent

Do you have any creative ideas or concepts that could enhance the overall experience for any of the concepts?

- A battle mode
- More players for 3rd concept
- Combining aspects of the three concepts
- If AR is not necessary, VR for 2nd idea. 2nd player can only see avatar and objects, not platform
- All of the games with more players for teambuilding
- Look at existing games that use interaction between platforms such as Jackbox party packs
- Competitive games

- For idea 1: right puzzle design for allowing collaboration
- For idea 2: More reliable control scheme
- For idea 2: More interaction for the AR player
- For idea 3: More narrative cohesion, maybe Pictionary style game
- Keep an eye on players' synchronisation
- Some ideas were more like you do this you do this rather than teamwork, allow more teamwork
- Find all the possible cases where the concepts may be used

Not enough context about why I designed these games provided lead to a bit of confusion in some parts of the games (e.g. why projector, why AR not VR etc)

**Thinking about real-world implementation, which concept do you believe would be the most viable?
Are there any practical challenges or benefits you foresee?**

- 1 (6 times)
- Smallest in scope
- Appealing
- Technology needs to be simple
- Instructions needed on being gentle with the box
- Coming up with riddles and puzzles seems like a lot of effort
- Easy to implement
- 2 (3 times)
- A lot of layers and levels needs to be created
- Tracking needs work smoothly
- Need enough space
- 3 (6 times)
- People might try to find challenging hiding spots
- Can be executed with simple technology
- In a healthcare setting for rehabilitation
- Tracking needs work smoothly
- Need enough space

Again, multiple people answered multiple options

If you had to recommend one of these concepts for development, which one would it be, and what influenced your choice?

- 1 (6 times)
- Might be the easiest to implement
- Most tangible interaction
- Most possibilities to explore
- Most attention grabbing
- Due to the puzzles
- Dynamic between the players
- Funny
- Challenging
- 2 (3 times)
- Might be the easiest to implement
- Most interested to play it themselves
- Novelty of the idea
- 3 (5 times)
- Innovativeness
- Most physical and engaging

- Fun
- Practical use
- Multi-functionality of the game to be operated or executed in more than one field (healthcare)
- Most simple concept
- Clever
- Great potential to implement a lot of games and interactions

Do you have any other ideas, suggestions or comments that you would like to share?

- Refine the two favourite ideas and test them out
- Not enough context in terms of purpose of designing
- AR is the biggest benefit. Regardless of which idea, lean into AR as much as possible.
- Use perspective to create optical illusions
- AR escape room box could add interesting value on new type of game

Appendix C

Co-design session

C.1 Session plan

The detailed session plan of the co-design can be found [here](#).

Session plan co-design

Before the session

In preparation for the co-design session a few things need to be done.

- Prepare some technical interactions to show the participants how a physical to virtual and virtual to physical interaction can be done. Make sure the technology works on that day as well. In a worst case scenario, show them a video.
- Prepare the needed tools to write down ideas such as;
 - Post its
 - Pens/Sharpies
 - Paper (A3)
 - Whiteboard markers
- Prepare some ideas to help the participants in their thinking process when needed, such as
 - Themes for the escape room box
 - Role play, let participants pretend to play the game
 - Analogous inspiration
 - Prepare a few examples from the state of the art.
- Bring some snacks/drinks to provide a nice atmosphere and allow small breaks when needed

Goal of the session

The goal of the session is to achieve the following:

- Gain a lot of ideas for escape room puzzles (starting divergent thinking)
- Gain ideas for interactive mechanics and technical aspects
- Gain ideas to ensure collaborative play, especially in asymmetric gameplay.

During the session

Time	Activity
11:00 – 11:10	<p>Introduction: Explain briefly:</p> <ul style="list-style-type: none">• What the concept is The final concept will be a box with puzzles on each side made with physical elements, including solving problems collaboratively. To incorporate more physical activity, the escape room box will require the use of a phone and AR. The AR aspect of the game will not only provide tips on how to solve the puzzles, but it will also be part of the puzzle. Meaning that AR will be used to solve a (part of) the puzzle. An example of such a puzzle could be that one person needs to hold the phone on which a figure can be seen through AR, and the other person needs to show the camera that figure within the exact boundaries of the AR figure. Apart from that, the phone will also be used to recognise hand gestures which will be needed to solve puzzles as

	<p>well. This type of interaction with the physical world and digital world will, next to incorporating more physical activity, also ensure that collaboration is indeed needed to be able to solve the puzzle. The addition of this heightened interaction between the physical world and digital world will also aid in having clear player roles, and therefore a clearer asymmetric gaming experience. The overall flow of the game is that three puzzles need to be solved in order to get one digit for a three-digit code. The three-digit code will then be filled in by the users to move to the next part of the game. The game ends when all parts are finished. A record time will be shown to add competitiveness to the game with other players.</p> <ul style="list-style-type: none"> • What the design session will include <ul style="list-style-type: none"> ○ Warming up ○ Designing for the puzzle aspect of the concept in different ways ○ A brief example of what type of interaction could be possible
11:10 – 11:15	<p>Warming up:</p> <ul style="list-style-type: none"> • https://mecamind.eu/cards/view.php?c=MS0015 (Creative, not too awkward, no physical touch)
11:15 – 11:20	<p>Showing a bit of technology, emphasising that the shown technology is just to give an idea of what type of interaction is intended for the concept</p>
11:20 – 11:25	<p>Individual thinking (Let them write as many ideas as possible for the escape room box concept in terms of puzzles)</p>
11:25 – 11:35	<p>Sharing the ideas and creating a mind map</p>
11:35 – 11:45	<p>Creating interaction ideas from technical aspect</p> <ul style="list-style-type: none"> • Introduce themes to help the process when needed
11:45 – 11:55	<p>Creating ideas to assure collaborative play</p> <ul style="list-style-type: none"> • What can we do to make the players work together? <ul style="list-style-type: none"> ○ Let participants roleplay the game to gain more ideas
11:55 – 12:00	<p>Ending session, summarizing a bit of the ideas and thanking participants for their participation</p>

C.2 Information letter and consent form

The information letter and consent form for the co-design session can be found [here](#).

Information letter and consent form co-design

Dear Participant,

Thank you for participating in the co-design session focusing on the creation of a collaborative Mixed Reality (MR) experience for our research project. Before we begin, I would like to provide you with some essential information. The purpose of this co-design session is to gather your valuable insights and develop collaboratively creative ideas for the development of an engaging MR experience.

This will be done starting with a warm up session. During this warming up session, you will be paired with another participant and a small game will be played. The game does not involve any physical touching with the other person. It is rather played by saying words and moving accordingly, back and forth. This is to help the creative thinking process. Next, a few sets of technology will be shown to get an idea of what is possible. After that, the brainstorming starts. The complete session will take about an hour. The session will be audio recorded to collect data that might be missed otherwise. The audio files will be transcribed into text, and the data from the text will be used for the remaining of the research.

Your input and contributions will be instrumental in shaping (parts of) this research project. The session will take about an hour. A follow up session might be needed depending on the results of the first session, if you agree with it. You may withdraw from the research at any time without explanation/ justification. Any information you share during the session will be treated with the utmost confidentiality. Your inputs will remain anonymous, and I will not collect any personal information beyond basic demographic details like age, study, or occupation.

If you have any queries or need further clarification, please feel free to contact me, my supervisors, or the EEMC ethics committee at:

m.oguz@student.utwente.nl

d.reidsma@utwente.nl

ethicscommittee-cis@utwente.nl

I look forward to your valuable input during the co-design session. Thank you for your time and participation. Before participating to the co-design session, I would like to ask you to fill in the consent form down below.

Best regards,

Melike Oğuz
Researcher

Consent Form for Co-design: Creating a collaborative mixed reality experience

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes

Yes No

Taking part in the study

I have read and understood the study information dated 23/11/2023, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves a warming up to help creative thinking, active thinking and sharing ideas, either verbally or on paper. And that the session might be audio-recorded to record ideas that might be missed during the session. The recordings will be destroyed after analysing the data that might come from it. The data will be analysed by transcribed as text.

Use of the information in the study

I understand that information I provide will be used for further development of the Master thesis of the researcher; Creating a collaborative mixed reality experience.

I agree that my information can be quoted in research outputs

I agree to be audio/video recorded. Yes/no

Future use and reuse of the information by others

I give permission for the ideas that I provide via transcribed audio recordings to be archived in the Appendix of the research paper so it can be used for future research and learning. No audio files will be kept, only transcription of (parts of) the audio files. The information retrieved from the audio files will remain anonymous as no names or other identifiable data will be recorded in any form.

Signatures

Name of participant

Signature

Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name

Signature

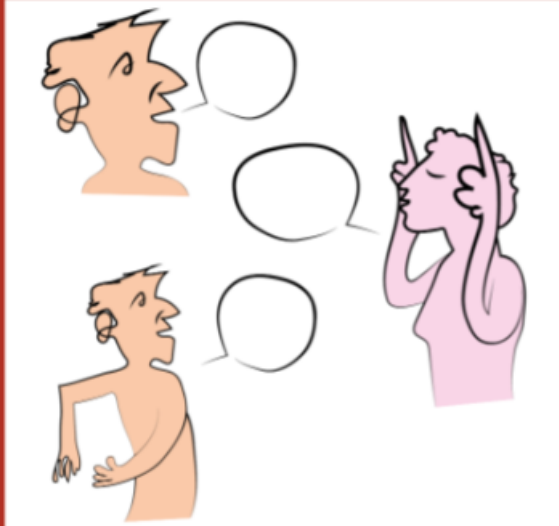
Date

C.3 Mood setting card for warming up

The specific card used for the warming up can be found below.

Mood setting card for warming up

Move to Words



Duration

-  Set-up time
-  Activity ± 10 min

Pair



Body Awareness



Exertion



Creativity



Playfulness



Mood Setting 

Move to Words

Outcomes

- + To create movements inspired by words..

Props in use

- + None.

Step by step

1. Divide the participants into pairs.
2. The first participant says a word.
3. The other participant responds with a movement inspired by the word and says another word.
4. The first participant now performs a movement with that word as an inspiration.

Note

- + It is essential to keep moving until your partner provides a new word for inspiration. High pace is sought; keep ping-ponging back and forth.

Variations

- + Use modifiers cards that promote creativity training of various movement types and directions.

Why

- + To warm up participants and promote their focus on bodily activity and creativity.

Mood Setting 

C.4 Mind map

A picture of the mind map from the co-design session can be found below.

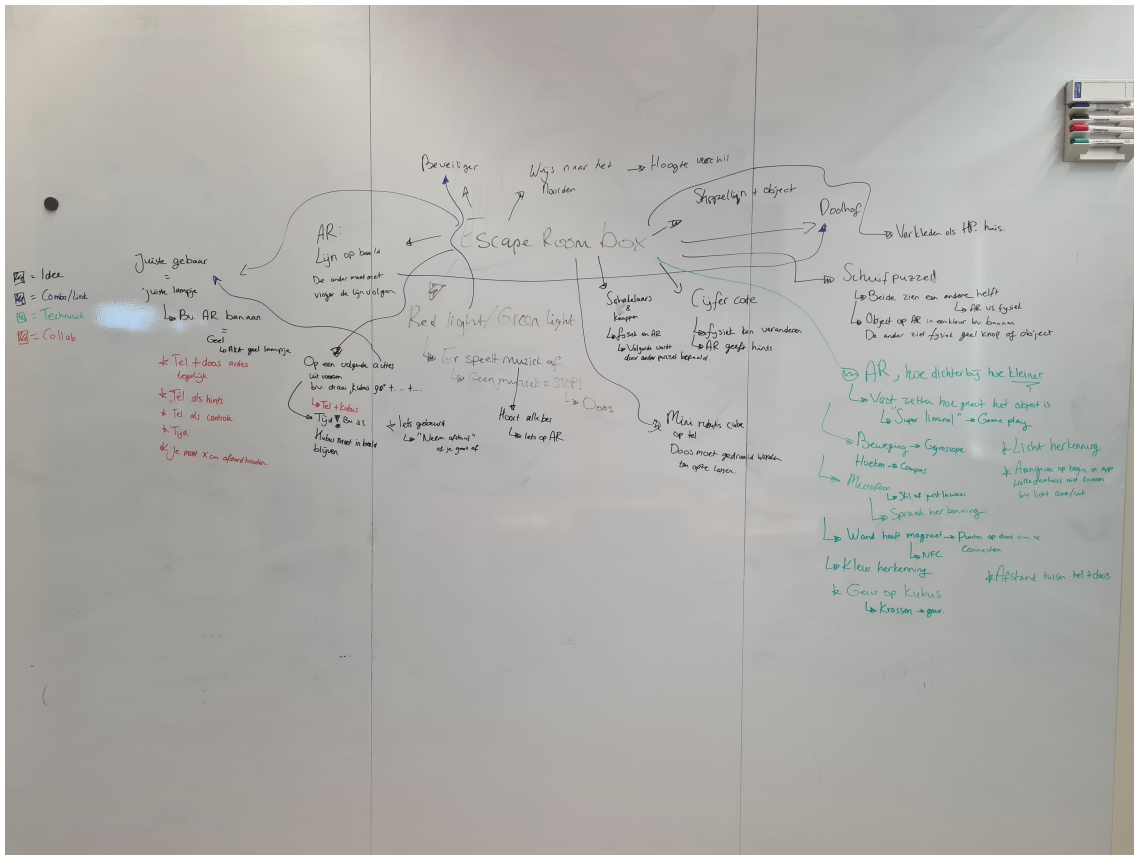


FIGURE C.1: Mind map co-design session

C.5 Data overview

An overview of all the ideas from the co-design session including notes from the audio file can be found here.

Co-Design

27 November 2023 11:39

Audio notes:

Mind map general ideas:

- 1) Security guard
- 2) Point to the North
- 3) Play with height differences
- 4) Matching shape/object with dashed line on phone
- 5) Maze
- 6) Dressing up as a member of one of the Harry Potter houses/Dressing up in a theme
- 7) Sliding puzzle
 - a. Both see only one half of the puzzle (AR/ physical)
 - b. Object in AR in a certain color e.g. banana. The other person sees a physical button in the color of the object (yellow in case of a banana)
- 8) Digit code
 - a. Can physically change
 - b. AR gives hints
- 9) Buttons and switches
 - a. Physical and AR
 - i. The order is determined by another puzzle
- 10) Mini rubiks cube (2x2) on the phone
 - a. The escape room box needs to be turned to solve the rubiks cube
- 11) Red light/Green light
 - a. A music is played, when the music stops, the box needs to stop as well.
 - b. Alternatively, as both players would hear the music, something is seen on AR to indicate the box needs to be still.
- 12) A set of actions needs to be done adding one action to the sequence every round. E.g. turn the box 90 degrees + ... + ...
 - a. Adding time to this idea for example 3 s.
 - b. Additional rule might be to keep the box in the frame of the camera at all times
- 13) Something happens during the game --> "Take a step back or your turn ends"
- 14) On AR there is a line like a buzz wire game. One person uses their finger (or an other object like a wand) to follow the line. The person with the phone needs to give direction to the person who needs to follow the line on how to follow the line.
- 15) Correct gesture leads to correct LED to turn on. For example on the AR you see a banana, which is yellow, meaning the yellow LED needs to turn on. So you see an object on AR and you have to match the correct gesture to the object to turn on the correct LED.

Mind map combos:

- 1) Red light/green light idea with a security guard
- 2) In the sequence game (listed as idea 12) one of the sequences could be idea 15
- 3) Following the line with your finger/wand can be combined with the maze idea

Technical aspects:

- 1) In AR, play with perspective e.g. , the closer you get the smaller the object becomes (instead of the other way around)
- 2) To be able to freeze the size of the object when playing with the perspective
- 3) Using movements with the box, using a gyroscope
- 4) Measuring angles
- 5) Compass
- 6) Heights
- 7) Using a microphone
 - a. To measure dB
 - b. For speech recognition
- 8) Having a magnet on a wand and points on the box to make a connection
 - a. Same idea using NFC instead of a magnet
- 9) Color recognition
- 10) Using smell on the box (scratching to get a scent)
- 11) Measuring distance between phone and box
- 12) Light sensor
- 13) A feature in the app to let people select what they cannot do in the room, e.g. turn off lights (like in the office)

Assuring collab:

- 1) Making sure that the players need to perform actions on the phone and the box at the same time
- 2) Using the phone for hints while the other needs to perform a certain action
- 3) Using the phone to check whether the action is being completed correctly or not
- 4) Using time constrains to make it difficult to perform an action on your own
- 5) Requiring a certain distance between the box and the phone

- Red light/green light, try to hold the box as still as possible. No shaking hands etc.
- Digit code is on the box. On the AR you receive hints. The hints are more like, e.g. the digit on the left should be smaller than the digit on the right
- The order of buttons and switches from idea 9 can be determined by idea 12
- Idea 12: The actions need to be done on both the phone and the box

Appendix D

Puzzle

D.1 Information letter and consent form Puzzle 1

The information letter and consent form for the user test of Puzzle 1 can be found [here](#).

Dear Participant,

Thank you for agreeing to participate in our user test for the escape room puzzle and AR app. Your insights are invaluable in helping us improve the overall experience. Please take a moment to read through the information below:

This user test aims to evaluate the difficulty level of the escape room puzzle, the effectiveness of the AR app in providing hints, and likelihood of playing with the puzzle. Your feedback will help us enhance the puzzle and app for a more enjoyable experience.

During the test, you will interact with the physical puzzle and use the AR app to receive hints. Your time will be recorded to assess the duration of the puzzle-solving process. Detailed notes will be taken on your actions and feedback. To mimic a bluetooth connecting between the physical aspect of the puzzle and the AR app, the researcher will provide you with the needed parts of the hints.

After the test, I will ask you to fill in a survey to get a better understanding of the likelihood of you playing this puzzle.

Your participation will remain completely anonymous. Any data collected will be used for research purposes only, and your identity will not be disclosed in any reports or publications.

Your participation in this test is entirely voluntary. You are free to leave the session at any time without the need for explanation. Your decision to participate or withdraw will not affect your relationship with us.

Before participating, please read and sign the attached consent form. The form includes contact information for the researcher, supervisor, and ethics committee in case you have any questions or concerns.

Thank you for your willingness to contribute to our research. We appreciate your time and effort.

Sincerely,

Melike Oğuz
m.oguz@student.utwente.nl

Consent Form Escape room puzzle 1

Escape Room Puzzle and AR App User Test

I, _____, acknowledge that I have read and understood the information provided in the information letter regarding the user test for the escape room puzzle, AR app, and survey. I voluntarily agree to participate in this test.

I understand that:

My time will be recorded during the test user test.
Detailed notes will be taken on my actions and feedback.
My participation will remain anonymous.
I am free to leave the session at any time without having to provide an explanation.
Participant's Signature: _____

Date: _____

Contact Information:

Researcher: Melike Oğuz
Email: m.oguz@student.utwente.nl

Supervisor: Dennis Reidsma
Email: d.reidsma@utwente.nl

Ethics Committee
Email: ethicscommittee-cis@utwente.nl

D.2 Survey questions with answers Puzzle 1

The detailed survey questions including the answers from the participants can be found here.

Survey data

ID	Describe your overall experience with the escape room puzzle. What aspects did you find most enjoyable?	Describe your overall experience with the escape room puzzle. What aspects did you find most challenging?	How would you rate the difficulty level of the puzzle? Please provide specific examples of elements that you found either too easy or too difficult.	Share your thoughts on the AR app's role in the puzzle solving process. Did it enhance your experience, and if so, in what way?	Describe how you utilized the AR app for hints during the puzzle. What prompted you to seek hints, and were they helpful in overcoming challenges?	What suggestions do you have for improving the escape room puzzle or the AR app? Are there specific changes or additions you would recommend?	Reflect on the perceived value of the AR app in the context of the escape room puzzle. In your opinion, did it add a meaningful layer to the experience?	One way to enhance the engagement of the puzzle is to add a collaborative aspect. Using only 1 device for AR, what can be added to or modified within the puzzle to make it collaborative. Keep in mind that collaboration should be in the same room and cannot be over e.g. the internet.	Is there anything else you would like to share about your experience with the escape room puzzle and AR app that hasn't been covered in the previous questions?
1	device (the) interaction	None	easy	yes, to find colors.	To get the colors.	More questions and buttons.	If it is enhanced, it may be valuable tool in a real game.	more interactive screen and comprehensive app	None
2	Trying to find the puzzle. What is the relation between the AR and the hints provided?	What to do? Goal did not become clear.	As I was looking for another game element and did not want to "waste" lives it became pretty difficult. The actual smpson says game I think should be interesting although I'm not sure if 8 steps and 4 lives is the correct ratio. As part of the game is figuring out what to do perhaps a few more steps might be needed. Something to figure out with these hints.	It comes across as a bit too much of a gimmick as it is only used to figure out which colour each picture is. Perhaps making the colour change every question, adding movement or having different shapes or orientations could enhance this aspect.	Currently the hints where required to get anywhere. Because there was no way of knowing (the first time) which button to press it felt like the only way to progress. Perhaps some feature like the first time you get the to the nth press have some hint in AR, but after that you'd have to remember	See long rants in the other questions.	Right now it does not add much. See remark in other question.	Again see other remarks	Nope, I've feel like this is plenty of info to work with :P
3	The puzzle itself and resetting the progress back from start when you get something wrong	- Keeping track of how many lives I had left. - What I did previously - The colours of the previous hint was still showing on the screen which made it seem a little busier than I expected	The difficulty was higher than expected because of the abstract nature of the puzzle, there was no question or story to try and follow so it was more random button presses or ask for hints constantly I would say a 6/10 if I used all hints it would have been too easy and if I don't use any hints it is impossible with the amount of lives you get	It is interesting to have clues hidden in an app, I can see it becoming super fun if it was multiple people racing to solve something and when you guess a step you get more hints in the next step than the other people	The open abstract nature of the puzzle pushed me to ask for more hints, the given hints trivialize the puzzle	For the puzzle: The puzzle needs a story to try and solve without needing hints and only ask for hints if stuck, otherwise you depend on the hints. For the AR App: It is a very cool concept, maybe the coloured shapes could be the same size every time you look at it or compared to one another because hints sometimes they grow different sizes which made me doubt what the given hint it without double checking and reading on the screen.	I think it has a very interesting potential, with more complexity naturally it is harder to make but has nice applications for an escape room puzzle in a home setting	Like I mentioned before I think a competitive aspect of the puzzle might be more fun than collaborative, trying to solve it quicker with more than one device solving the same puzzle and given different clues depending on their progress. I can't see how two people solving this exact type of puzzle can work aside from the fact they can remind each other of the sequence so far.	It is a fun interesting idea that could bring the concept of escape rooms into your hand with minimum setup, more complicated puzzles and different levels can easily be added in updates and have a competitive aspect to it.
4	I think the part about having to look for the right clue after the hint	Understanding the hint	It's not too easy but also not too hard. It's just a matter of understanding what to do. However, what might be a little difficult but also enjoyable for some is the challenge to remember the order	Yes I did, I enjoyed the interaction of the AR and the pictures	I asked hints as I already had a few strikes and could've used all the help I could get in order to get further	One thing I saw was that the AR showed a color before even scanning the picture	I think I did, I am eager to see what it would look like when it's completely finished	Not so sure, maybe the use of a VR goggles?	no
5	The mix between analogic and digital	the rules	very easy the hints were too obvious	was ok, perhaps the hint could be in the app	was the only guidance	make more abstract the hints, make them more complex, and create different phrases of the same picture	no comments	make more difficult the descriptions of the pictures, to discuss with the team which picture the hint could refer to	nope
6	The board with the buttons	Figuring out the sequence without asking any hints	I was guessing the sequence now. Maybe a bit more information could be provided on how to figure it out	It was fun to use the phone for hints	It showed the colour if you figured out the hint	Hints that are more puzzling and try to break my brain more	Yes I did. I always find it fun to have more techy stuff	Using more players and use them as hints	Nope
7	The AR visualization in combination with the embedded device	Remembering the order of the buttons (in case of a mistake) was challenging	Fairly easy. The hints were straightforward, so I could easily find the right options using the AR device. I would say that the puzzle was simple.	The AR made it engaging and fun to play with.	Finding the right button was a guess, so using unlimited hints made me utilize that option with every next step to prevent making mistakes.	Less hints to start with, but also combine every step with a question, so that the player have a starting point. Now, you had 4 lives with every step having 25% chance of being good, so it felt very risky and risky to randomly pick an option.	The AR app made it fun, although there were 4 cubes shown. As for a new version, I would try to present other types of information	Have one use the AR device and have him/her describe what they see, so that the other player should make a decision based on the information presented.	No
8	I liked how the pictures are colors	I took the easy path with the hints, but maybe it would be nice if I had less hints, so that I must remember the sequence, and must guess a few.	I think I would have liked to figure out the whole thing myself. How things are connected, how I can get hints and so on. And my answer above is also relevant here.	Yes! I liked that the colors are connected to the photos. It could be also nice if I have to find that out myself, so the photos are on random places and I need to find them, and use the app. And the more photos the better, a few more would be nice.	Yes, hints were helpful	See above, yes. Maybe also other than color, there could be shapes shown, and we have to figure out something about that too.	Yes, it made it more exciting, how things (colors) are hidden behind reality.	Maybe giving a task that can be solved as a group, e.g. smaller tasks that make up the solution, and they can divide up those. Or if it was connected to facial recognition, then something would only show to some persons. Or voice input is needed to get the next hint, and that voice is someone else's or the groups.	It was cool :)
9	To remember the right sequence of colours	To remember the right sequence of colours	Its quite easy because you get a limited amount of hints. So the only challenge is remembering the sequence of colours	It's a nice idea, but because the questions were so simple, it just gave away the answers	For every number I got hint, because otherwise the change is too low of getting the right color	Harder questions. Maybe also more than only seeing the color in AR. Maybe a quest in the AR popup.	A bit low because the AR only gave the colors, so the answers. Not the hints	Combine the hints from different phones	It was a bit simple, so maybe a bit more challenge

D.3 Detailed notes user test Puzzle 1

Detailed notes taken during the user test can be found here. User test notes

P1:

Time: 3:33

Succeeded

Uses hints for each step

Did not know all the characters, therefor used 2 lives

I had to explain the game a bit more

Mentioned that the survey is too long

P2:

Time: 9:00

NOT succeeded

Tried to figure out how the hints work

Plays around with the AR to see if anything changes

Uses hint for every step

Tries to figure out/get more information from the quotes

"How to solve without a hint?"

"I feel like I am missing something"

"I feel lost"

"The cubes in AR all rotate except for 1, is that a hint to solve the puzzle?"

"I don't know how far I am"

Keeps coming back to trying to solve it without using hints

P3:

Time: 2:30

NOT succeeded

"What is the goal?"

"How do I see how many lives I have?"

"It's a nice game"

P4:

Time: 2:30

NOT succeeded

Tries to solve without hints

Uses the hints after -2 lives

Made no comments during the test

P5:

Time 5:00

Succeeded

Tried to figure out the hints

I needed to explain quite often what needed to be done and how things work

Used hints for each step

P6:

Time: 3:30

NOT succeeded

"Ooohh. . . " After seeing the AR

I still need to explain how things work while playing

Died bc of technical issues. Would succeed otherwise

"Fun"

P7:

Time: 1:47

NOT succeeded

Tried to solve without hints

Quickly understood the task, but could not solve without using hints.

P8:

Time: 2:00

Succeeded

"Well.. If I have infinite amount of hints..."

-> Solved everything using a hint

"Fun"

P9:

Time: 2:51

Succeeded

Finds the red color of LEDs confusing for a correct answer (more people had this reaction)

Used hints for each step, but is still careful with pressing the buttons

Remembers which quote (hint) corresponds with which color, so when a quote is recognised there was no need to look at the AR anymore.

No comments while playing

P10:

Time: 1:28

Succeeded

Uses hint for each step

Understands how it works, but I explained excessively in the beginning.

General remarks:

- When people have infinite amount of hints, they are likely to use it for each step
- Not everyone knows the Harry Potter characters, which gave the impression that the puzzle was harder for them. As they did not understand the references in the hints.
- A good explanation of the goal and how to get there is very important for people to be able to play it with how the puzzle works at this moment
- People are looking at other clues to solve the puzzle without using hints, e.g. do the pictures tell you something, do the AR objects tell you something, is there a logical reasoning to solve it instead of just pure luck?
- People tend to want to see which step they are, how many lives they have
- The red LEDs can be confusing for some, as it is mentioned a few times by participants.
- The delaytime of the feedback is currently 2 seconds, this should be a bit shorter as you have to wait for the delaytime to be 0 to press the next button. Sometimes people are faster than that with clicking which makes the system register not fast enough, without them knowing

D.4 Information letter and consent form Puzzle 2

The information letter and consent form for the user test of Puzzle 2 can be found here.

Information Letter for User Test 2

Dear Participant,

Thank you for agreeing to participate in our user test for the escape room puzzle. Your insights are invaluable in helping us improve the overall experience. Please take a moment to read through the information below:

This user test aims to evaluate the difficulty level of the escape room puzzle, the effectiveness of collaboration, and likelihood of playing with the puzzle. Your feedback will help us enhance the puzzle and app for a more enjoyable experience.

During the test, you will interact with the physical puzzle and use an app to solve the puzzle. Your time will be recorded to assess the duration of the puzzle-solving process. Detailed notes will be taken on your actions and feedback. Depending on the group you are selected in (A or B), you will be solving the puzzle alone (A) or together with a friend/colleague or the researcher (B).

After the test, I will ask you to fill in a survey to get a better understanding of the effectiveness of collaboration, and the likelihood of you playing this puzzle.

Your participation will remain completely anonymous. Any data collected will be used for research purposes only, and your identity will not be disclosed in any reports or publications.

Your participation in this test is entirely voluntary. You are free to leave the session at any time without the need for explanation. Your decision to participate or withdraw will not affect your relationship with us.

Before participating, please read and sign the attached consent form. The form includes contact information for the researcher, supervisor, and ethics committee in case you have any questions or concerns.

Thank you for your willingness to contribute to our research. We appreciate your time and effort.

Sincerely,

Melike Oğuz
m.oguz@student.utwente.nl

Consent Form for Creating a collaborative Mixed Reality Experience
YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes

Yes No

Taking part in the study

I have read and understood the study information dated 08/02/24, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves solving a puzzle either alone (group A) or with someone (group B). I understand that my time will be recorded, notes will be taken during the user test, and a survey will be held after the user test.

Use of the information in the study

I understand that information I provide will be used for the researchers Master graduation thesis; Creating a collaborative mixed reality experience.

I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.

Future use and reuse of the information by others

I give permission for the user test notes and survey data that I provide to be written in the research paper anonymously so it can be used for future research and learning.

Name of participant

Signature

Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]

Signature

Date

Study contact details for further information:

Melike Oğuz, melike-oguz@hotmail.com

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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D.6 Detailed notes user test Puzzle 2

Detailed notes taken during the user test can be found here. Observations User test puzzle 2

Group A: Average time 10 min 32 sec

P1

Time: 10:45

- Knew directly its morse code
- Needed clarification about voice recognition as input mechanism
- Waits to see the morse sequence
- Tried to solve it, but was wrong
- Moves on to writing ./- then solves it using the hint button
- Presses the two buttons on the table first
- Ended up pressing the 3 buttons by laying the phone between the other two buttons

P3

Time: 5:47

- Understood directly its morse
- Resets the sequence by going back and forth in the app
- Starts noting down ./-
- Tried 2 buttons first
-

P5

Time: 8:30

- Tries the buttons
- Sees LED after going back and forth
- Does not know its morse code
- But then sees the hint button and knows its morse
- Tries without writing down first, but then switches to writing ./-
- Started wrong and then started over to see whats wrong
- 2nd try went better
- Wasn't sure when to stop
- Solved, but technical issues with voice recording

P7

Time: 13:54

- Instantly knew its morse

- Saw the hint button fast
- Tried to write the morse down immediately
- Waits for the beginning of the sequence
- Tries to decode the ./- instantly instead of first writing it down and then decoding it
- Takes his time to solve it
- After some time goes back and forth to start the sequence but does this for each letter
- Writes down in words long/short instead of ./- which takes longer
- Tries the capsens buttons first

P10

Time: 13:00

- Directly skips morse scene
- Tries some thing in the last scene
- Goes back to morse seen and sees LED
- Reads intro from first scene again
- Sees morse hint
- Figures it should be morse code, but struggles with what the LED meant
- User Test Puzzle 2 notes
-
- Figures it should be morse code, but struggles with what the LED meant
- Starts trying after some time
- Tries to figure out how to reset the sequence
- Presses capsens buttons and says "Reset" to reset
- After some time, goes back and forth to reset
- Starts writing ./- , but gets distracted fast by other things so needs to start over quite often

Group B: Average time 8 min 16 sec

P2 + Researcher

Time: 9:36

- Looks through the app
- Tries the buttons
- Task dvision, P2 writes down ./- and the researcher (partner) telss short/long
- Solves puzzle using hint button
- 1 person pressed the two buttons on the table 1 on the UI

P4 + Researcher

Time: 6:30

- Direct task division
- Technical difficulties with recording voice
- Waited to see the beginning of the sequence
- Tried to press the two capsens buttons

P6 + Researcher

Time: 9:00

- 2nd scene with morse on it) is skipped fast
- Did not see the LED at first
- Task division after seeing the LED
- Went well after that

P8 + P9

Time: 8:00

- Mentions its a good team bonding moment
- Directly goes to next page (skips morse)
- Sees LED after going back to morse page
- Notices its morse
- Finds hint button after some time
- First there is no task division and one person seems to take the lead
- Then loses track so they dicide to divide the task. One writes down one tells ./-
- Divide deciphering morse code as well, one deciphers one half the other the other half
- First try to press the capsense only, then the 3 buttons at the same time. 1 person did 1 button
- and the other 2.

D.7 Recruitment of participants

The table used to recruit participants for user test 3 can be found here.

Time	Group A	Group B	
		Person A	Person B
09:30 - 09:50			
09:50 - 10:10			
10:10 - 10:30			
10:45 - 11:05			
11:05 - 11:25			
11:25 - 11:45			
11:45 - 12:05			
12:05 - 12:25			

Amount of participants

Group A:

Group B:

D.8 Information letter and consent form Puzzle 3

The information letter and consent form for the user test of Puzzle 3 can be found here.

Information Letter for User Test

Dear Participant,

Thank you for agreeing to participate in our user test for the escape room puzzle/challenge. Your insights are invaluable in helping us improve the overall experience. Please take a moment to read through the information below:

This user test aims to evaluate the difficulty level of the escape room puzzle/challenge, the effectiveness of collaboration, and likelihood of playing with the puzzle. Your feedback will help us enhance the puzzle and app for a more enjoyable experience.

During the test, you will interact with an AR application and a physical image of a maze. Your time will be recorded to assess the duration of the puzzle-solving process. Detailed notes will be taken on your actions and feedback. Depending on the group you are selected in (A or B), you will complete the challenge alone (A) or together with a colleague or the researcher (B).

After the test, I will ask you to fill in a survey to get a better understanding of the effectiveness of collaboration, and the likelihood of you playing this puzzle.

Your participation will remain completely anonymous. Any data collected will be used for research purposes only, and your identity will not be disclosed in any reports or publications.

Your participation in this test is entirely voluntary. You are free to leave the session at any time without the need for explanation. Your decision to participate or withdraw will not affect your relationship with us.

Before participating, please read and sign the attached consent form. The form includes contact information for the researcher, supervisor, and ethics committee in case you have any questions or concerns.

Thank you for your willingness to contribute to our research. We appreciate your time and effort.

Sincerely,

Melike Oğuz
m.oguz@student.utwente.nl

Consent Form for Creating a collaborative Mixed Reality Experience
YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes

Yes No

Taking part in the study

I have read and understood the study information dated 01/03/24, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves solving a puzzle either alone (group A) or with someone (group B). I understand that my time will be recorded, notes will be taken during the user test, and a survey will be held after the user test.

Use of the information in the study

I understand that information I provide will be used for the researchers Master graduation thesis; Creating a collaborative mixed reality experience.

I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.

Future use and reuse of the information by others

I give permission for the user test notes and survey data that I provide to be written in the research paper anonymously so it can be used for future research and learning.

Name of participant

Signature

Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Melike Oğuz

Researcher name

Signature

01-03-24

Date

Study contact details for further information:

Melike Oğuz, melike-oguz@hotmail.com

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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D.9 Survey questions with answers Puzzle 3

The detailed survey questions including the answers from the participants for Puzzle 3 can be found here.

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40	Q41	Q42	Q43	Q44	Q45	Q46	Q47	Q48	Q49	Q50	Q51	Q52	Q53	Q54	Q55	Q56	Q57	Q58	Q59	Q60	Q61	Q62	Q63	Q64	Q65	Q66	Q67	Q68	Q69	Q70	Q71	Q72	Q73	Q74	Q75	Q76	Q77	Q78	Q79	Q80	Q81	Q82	Q83	Q84	Q85	Q86	Q87	Q88	Q89	Q90	Q91	Q92	Q93	Q94	Q95	Q96	Q97	Q98	Q99	Q100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

D.10 Detailed notes user test Puzzle 3

Detailed notes taken during the user test can be found here.

P1:

Time: 1 min 30 sec

Collectable: 0
Comments: "So close "Yes!"

P2:
Time: 2 min 57 sec
Collectable: 1
Comments: "Oohw" "Too far" "Not much time"

- Chuckles
- Tried to swipe to move
- Used one hand to move one to look
- Struggles a bit with moving

P3:
Time: 2 min 55 seconds
Collectable: 4
Comments:

- Tries to swipe to move
- Instruction about having to move the physical image not clear enough
- Struggles with controlling, because of multi tasking.
- The participant wants to see the AR and the physical maze at the same time not just through the phone

P4 & P5:
Time: 2 min 57 seconds
Collectable: 1
Comments:

- Discusses what to do and how to play
- One holds camera one the maze. The one with the camera(phone) gives instructions to the other participant on how to move the maze. The other participant does not see the AR.
- Laughing
- Changes way of holding the physical maze to see if it is more efficient. Now both can see what is going on in AR
- "Go!" "Go!" "Yeah!"

P6 & P7:
Time: 2:51
Collectable: 4
Comments:

- One holds maze, both look
- Give comments like ooh... yeah.. Left, right
- Slight struggle with moving around

- "When you move along with camera it works better"
- Both communicate together

P8 & P9:

Time: 1:38

Collectable: 1

Comments:

- Swipes to move
- "No, you need to move the camera"
- "Oh wait"
- Tries with 1 holding phone, one the maze
- Switches to 1 person holding phone and maze the other gives comments

P10:

Time: 2:18

Collectable: 3

Comments:

- Tries with holding the phone in one hand and the maze in the other
- Had to restart the app due to technical issues
- Goes for the collectables
- "Oh it does not like this" (About the AR)
- Asks if it game over when the time is up
- After confirming -> "Then I will just go to the finish"
- After seeing they still had a bit of time -> I could have went for an other collectable

P11:

Time: Game Over

Collectable: 2

Comments:

- One hand phone one hand phone
- Struggles a bit with controlling
- "Ooh noo... "
- Chuckles
- Game Over but more because of technical issues

Appendix E

Final Implementation Software

This appendix shows all the screens from the application starting from the Bluetooth connection screen up till and including the last leaderboard screen.

The Bluetooth screen is not part of the Enchanted Escape, and therefore not shown to the user.

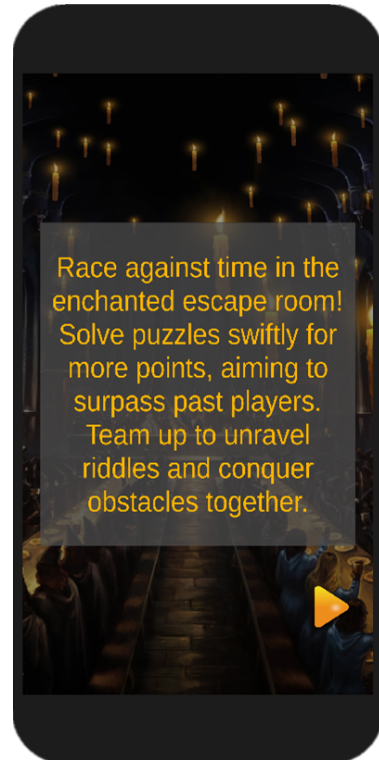


FIGURE E.1: Screen to connect to Bluetooth

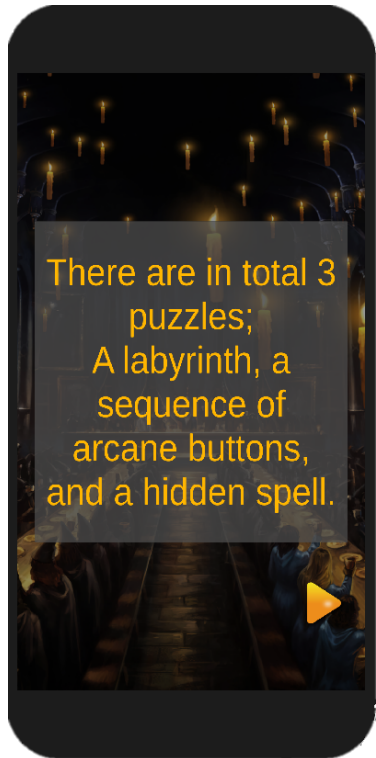
The Home screen is the first screen the user encounters, after clicking "Start", the system starts timing.



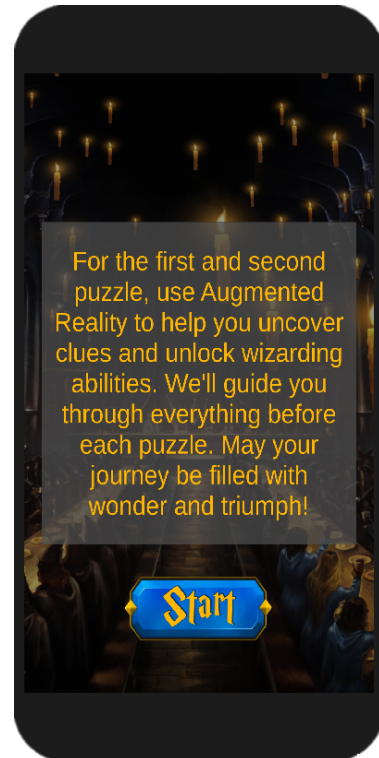
(A) Home screen with first explanation



(B) Home screen with second explanation

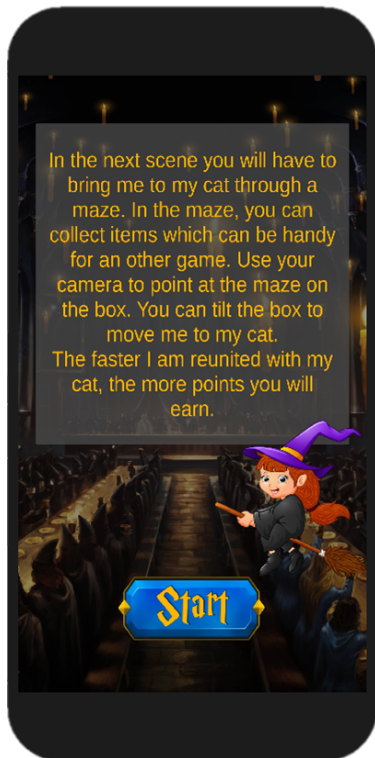


(C) Home screen with third explanation



(D) Home screen with fourth explanation

FIGURE E.2: Home screen

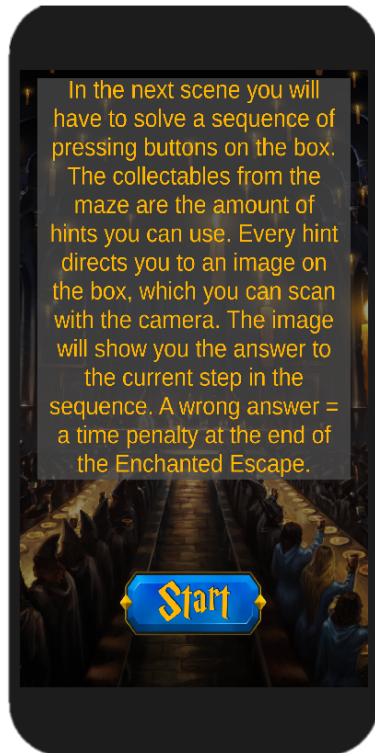


(A) Explanation of the Maze

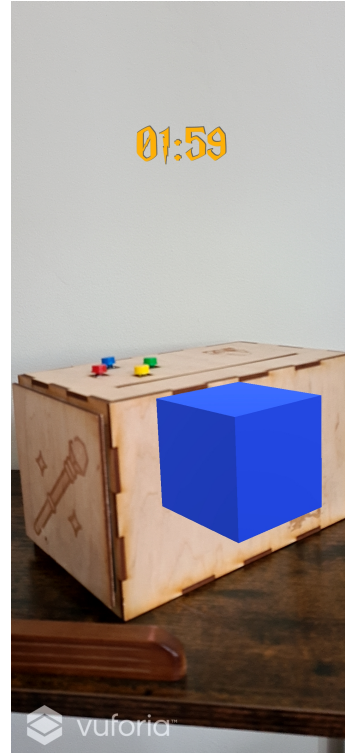


(B) Maze shown through AR

FIGURE E.3: Final software implementation of the Maze

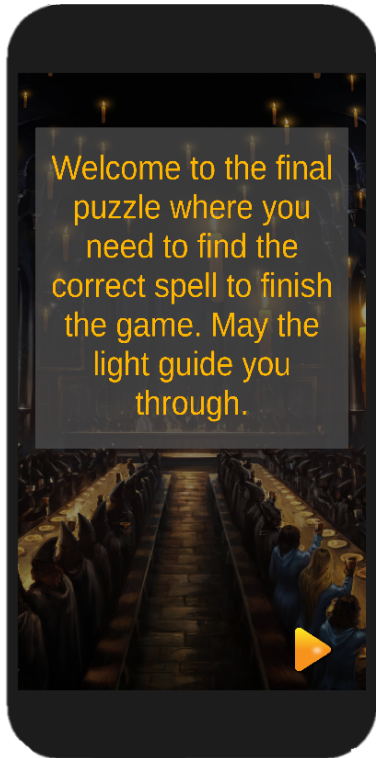


(A) Explanation of the Button Sequence



(B) Hint shown through AR

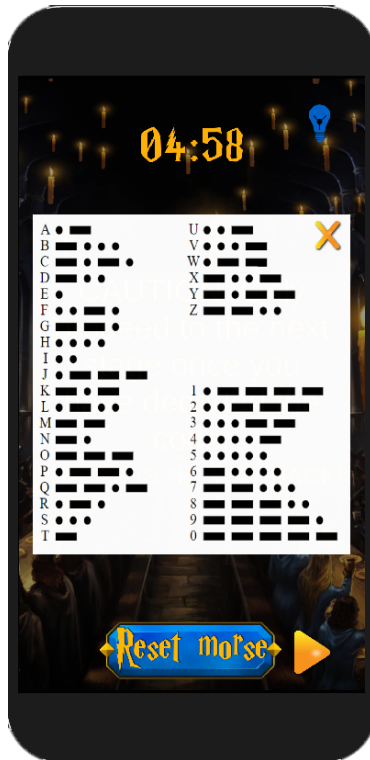
FIGURE E.4: Software implementation of the Button Sequence



(A) Explanation of the Casting Spell



(B) Initial screen of the Morse code scene



(C) The screen after clicking the light bulb

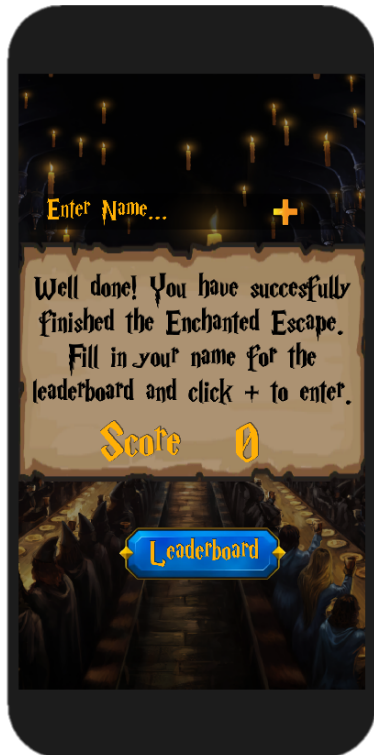
FIGURE E.5: Casting Spell part 1



(A) Initial screen for voice recording the spell



(B) Screen when the system did not recognise spell



(C) Screen when the spell is recognised



(D) Screen showing the leader board

FIGURE E.6: Casting Spell part 2

Appendix F

Laser-cut Design

Figure F.1 the design used to laser-cut the box for the Enchanted Escape.

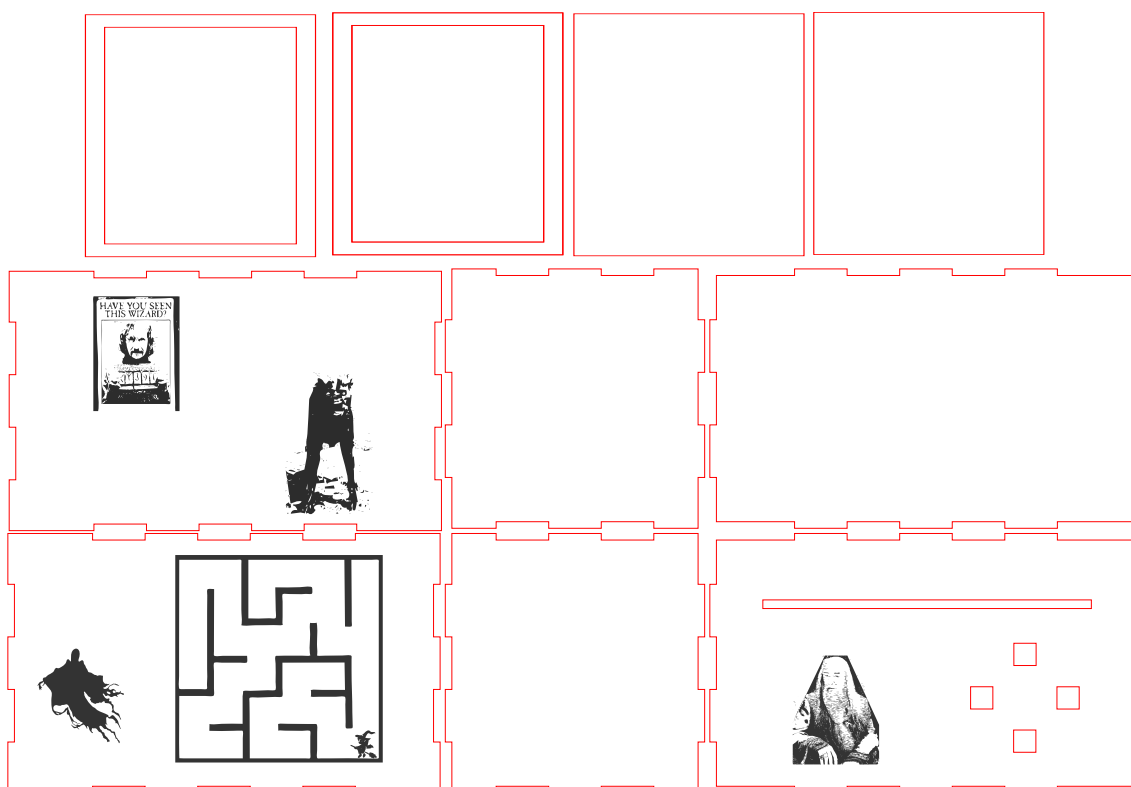


FIGURE F.1: Laser cut design

Appendix G

Validation

G.1 Information Letter and Consent Form

The information letter and consent form used for the Validation can be found here.

Consent Form for Creating a collaborative Mixed Reality Experience
YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes **Yes** **No**

Taking part in the study

I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves solving a puzzle either someone. I understand that notes will be taken during the user test, and a survey will be held after the user test.

Use of the information in the study

I understand that information I provide will be used for the researchers Master graduation thesis; Creating a collaborative mixed reality experience.

I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.

Future use and reuse of the information by others

I give permission for the user test notes and survey data that I provide to be written in the research paper anonymously so it can be used for future research and learning.

Name of participant _____ _____

Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____ Melike Oğuz _____

Researcher name _____ _____

Signature Date

Study contact details for further information:
Melike Oğuz, melike-oguz@hotmail.com

Contact Information for Questions about Your Rights as a Research Participant
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

UNIVERSITY OF TWENTE.

Information Letter for User Test

Dear Participant,

Thank you for agreeing to participate in our end evaluation Enchanted Escape. Your insights are invaluable in helping us improve the overall experience. Please take a moment to read through the information below:

This user test aims to evaluate the experience users have with the end product in terms of playfulness, engagement, and social multiplayer interaction. Your feedback will help us enhance the puzzle and app for a more enjoyable experience.

During the test, you will interact with an AR application and a physical box, together with a colleague. Detailed notes will be taken on your actions and feedback.

After the test, I will ask you to fill in a survey to get a better understanding of your experience with the Enchanted Escape.

Your participation will remain completely anonymous. Any data collected will be used for research purposes only, and your identity will not be disclosed in any reports or publications.

Your participation in this test is entirely voluntary. You are free to leave the session at any time without the need for explanation. Your decision to participate or withdraw will not affect your relationship with us.

Before participating, please read and sign the attached consent form. The form includes contact information for the researcher, supervisor, and ethics committee in case you have any questions or concerns.

Thank you for your willingness to contribute to our research. We appreciate your time and effort.

Sincerely,

Melike Oğuz
m.oguz@student.utwente.nl

G.3 Field Study Survey Questions and Results

The survey questions and Results for the field study can be found here.

ID	Did you give consent to use the collected notes and this survey data in my research thesis?	Describe your overall experience with the escape room.	What aspects did you find most engaging?	What aspects of the game encouraged or discouraged spontaneous participation?	Can you describe any specific moments that prompted you to interact with the game?
1	Yes	Good	The physical box	Phone discouraged because I wasn't sure if it was ok to pick up. But the box and paper were inviting.	Coffee break
2	Yes	I saw it standing at the end of the table	It looked interesting, did not interact with it	It looked interesting, but not interesting enough to walk to it and interact.	No
3	Yes	I only played with few buttons, but the design looked very nice.	The design.	It was in our lunch corner, and the design looked nice and attracting.	The looks of the game.
4	Yes	I saw the game on the table during lunch, and was curious what it was. I briefly checked it out, and did not engage any further.	Did not fully engage with it, but the fact that it was placed on the table with a note inviting me to try it out, drew my attention.	The look of the game, it looks home made and well built. The note in front of it.	I was waiting for my lunch to be heated in the microwave, so I had a few minutes where I was just looking around. That's when I noticed it.
5	Yes	Cool! but also bit unclear	button sequence	the box looks cool and inviting	the timer
6	Yes	it was an interesting experience playing around with it, but also seeing others struggle without exactly knowing what they are doing.	the most engaging part is the AR that makes it a great interactive game.	I was very interested about the AR implementation.	seeing others struggling with the game without seeing what they were doing, made me want to try it out for myself.
7	Yes	It is quite interestingly done. The case itself attracted me, but I will admit that it was not well explained how the game should be played.	I've only played the game once so it's hard to say.	In a way we could not take the next step in the game. It was not possible to advance to the next round by skipping this step.	Interestingly designed housing.
8	Yes	It was fun but not easy to play	The fact that the box was actually physical	The game had a lot of bugs which did not allow to actually play.	When the item moved in the maze
Did you play alone or did you collaborate?					
1	A. Alone	It was buggy, so wasn't able to finish it. But it did look fun	Hard to hold the phone and use my hands to move the box at the same time	Yes, I would of either of the two	
2	A. Alone	Did not interact	N/A	N/A	
3	A. Alone	I only clicked on a few buttons, so I did not really play the game to reach a goal.	I only clicked on a few buttons, so I did not really play the game to reach a goal.	I only clicked on a few buttons, so I did not really play the game to reach a goal.	
4	A. Alone	-	-	-	
5	A. Alone	didn't know whether just trying sequences was the way to go or just cheating. Also: didn't get how to find the spell in the last game	didn't take a bit of time to read instructions carefully. Also was hungry so wanted to be done quickly so I could have lunch	yes I might have taken more time to understand the game	
6	B. Collaborative				
7	B. Collaborative				
8	B. Collaborative				
Can you describe your experience of playing with a partner to reach the goal of the game?					
1		How did collaborating with others enhance or reduce your experience with the game?	Did you find the collaboration with your partner enjoyable or beneficial? Why or why not?		
2					
3					
4					
5					
6	It was a fun experience with a lot of laughter and communication.	collaborating makes games more fun in general, especially interactive games like this.	It was for sure enjoyable and beneficial at certain point, others not so much. Giving direct instructions to rotate the box in a certain way is very difficult, but helping to remember the order of pushing buttons is useful.		
7	It was very entertaining	Collaboration enhanced the gaming experience as we were able to work together to find solutions and get there faster.	Enhanced the experience, allowed to share the solutions together	Yes, helped with the solutions	
8	Fun!	Enhanced the experience, allowed to share the solutions together	Yes, helped with the solutions		
Were there any particular features or challenges within the game that you found most engaging?					
1	The art and the box	Mostly buggy, but the introduction was nice	No		
2	N/A	N/A	No		
3	I only clicked on a few buttons, so I did not really play the game to reach a goal.	I only clicked on a few buttons, so I did not really play the game to reach a goal.	I only clicked on a few buttons, so I did not really play the game to reach a goal.	I only clicked on a few buttons, so I did not really play the game to reach a goal. But the design looked attracting.	
4	-	-	-	-	
5	the timer	I liked finding the sequence		I think it would be good to be VERY explicit & clear about DO NOT CLICK THE WINDOW BEFORE YOU INCUBATE OUR THE SPELL.	
6	the AR keeps me engaged, even just seeing games pop on the screen is fascinating to me.	the pure chaos of trying to solve the maze and the guessing game for the order of pushing buttons was great.	nothing more to add		
7	Not really	Not really	rather not.		
8	Could not actually play the game due to the bug	No	No		

G.4 Controlled User Test Observation Results

The observation results for the controlled user test can be found here.

Session	Engagement				Playfulness and Enjoyment:				Sustained Engagement	Encouragement of Participation	Non-Verbal Cues
	Problem-solving strategies	Exploration of features	Focused attention	Persistence and Resilience; Level of determination, resilience, and motivation to overcome obstacles and achieve success	Verbal and non-verbal expressions of enjoyment, engagement, and social interaction.	Collaborative problem-solving and discussions between participants during gameplay.	Sharing of experiences, anecdotes, and jokes during gameplay	Encouragement and support between participants to achieve common goals during gameplay.			
F= Finished S=Solved N=not finished											
1*	✓ Divide tasks	✗ Trying to swipe	✓	✗ Still tried to solve after time is up (button)		✗ Let's go for candies... then wait for time		✗ Let's just try - & Really tried to win	✓		✓ Smiling ✓ Yes!
2*	✗ Dividing tasks ✗ Discussing	✗ Button OK looking without hints.	✓ Bending thought.	✓ Try to solve maze in other ways, working together	✓ Laughing.			✗ Maybe the red light is good... figures out	✓		✓ Laughing
3*	✗ Discussing & cooperating well.	✗ Touching to move the switch.	✓	✗ Going for candies while considering time.	✗ Laughing & Awesome!			✗ Let's figure out the maze	✓	✓ Giving positive comments to each other.	✗ Getting excited because maze is easier to solve than maze
4*	✗ Dividing tasks.	✗ Try to move with touchscreen.	✓		✓				✓		✗ Getting excited because
5	✗ Initially, one trying, one looking at looking tasks.	✓ Looking around box SAR	✓					✓ Help, played together on their own.	✓		
6	F+S		✓	✓	✓			✓	✓		
✗ Maze is still buggy because of lightning. ✗ Check reset mouse ✗ Check Hint button.											
Session	Engagement				Playfulness and Enjoyment:				Sustained Engagement	Encouragement of Participation	Non-Verbal Cues
	Problem-solving strategies	Exploration of features	Focused attention	Persistence and Resilience; Level of determination, resilience, and motivation to overcome obstacles and achieve success	Verbal and non-verbal expressions of enjoyment, engagement, and social interaction.	Collaborative problem-solving and discussions between participants during gameplay.	Sharing of experiences, anecdotes, and jokes during gameplay	Encouragement and support between participants to achieve common goals during gameplay.			
7*	✓	✓	✓	✓	✓ After solving the puzzle				✓		
8	✓	✓	✓	✓	✓		✓ Made Smith similar to maze but was shiny	✓	✓		
9	✓	✓	✓	✓	✓		✓ HP reference	✓	✓		
10	✓ Discussing strategies	✓	✓	✓	✓		✓		✓		✗ Frustrated for Maze
11	✓		✓	✓	✓		✓	✓	✓		✗
12	✓	✓	✓		✓		✓				
✗ Hint somehow still does not work?											

FIGURE G.2: Controlled User Test Notes

G.5 Controlled User Test Survey Questions and Results

The survey questions and results of the controlled user test can be found here.

Do you play games on the virtual reality and the survey data in your master thesis?	Describe your overall experience with virtual reality games.	What aspect of the game did you enjoy most?	Can you describe the virtual reality experience in your own words?	Were there any particular features or challenges that you enjoyed or found difficult?	Did you feel motivated to continue playing and exploring the game? Why or why not?	Can you describe your experience of playing with a team to reach the goal of the game?
1 Yes	Fun games, no level of difficulty. Very clear use of augmented reality.	Rotating the box to play the game	We needed to work together to use the phone and box at the same time	Finding the color code was fun	Yes, curious about the use of technology	Nice to play with 2 partners, discussion helped a lot as we needed to explore the box and phone together
2 Yes	Interesting, fun, but unclear	The music	Physically having to turn the box around for the mouse to work	Spinning the box with the camera	Yes, with the attention on the box to find out what the color should be for the code, but not after not knowing the mouse code, and we were not going to find a code.	It was fun to discuss the best course of action.
3 Yes	Very fun game, needed a little guidance apart from the app to finish it.	The augmented reality aspect was very cool to finish it.	The moment we found out how we could turn the box to movement through the mouse was fun. Had to use the game with the buttons we had a similar moment.	Agreed reality	Yes, it required us to think about and find out what was being asked from us, which made it challenging.	It was fun, really enjoyed cooperation
4 Yes	The camera game was fun, and the different sound waves were original. However, the instructions sometimes were a bit vague.	The connection with the box and the app	The voice recording of the quest	The connection with the box and the app	Sometimes the instructions and the reaction of the box to the app were a bit vague and slow, making it difficult to play the game. That was a bit difficult in having movement to further explore the game.	I think playing the game together makes it really fun, it also more on creating to keep playing.
5 Yes	It was quite fun.	The 3D display	When without hints we realized the connection between the camera and the buttons	The moving puzzle	Yes, as soon as you realized that you really interact with the box it becomes really engaging.	Fun
6 Yes	I liked the theme. Technically it was not working so well.	I liked the AR theme	I liked the Harry Potter style text and story	I liked the AR	We needed help to finish the first and last game. That was a bit demotivating	I liked doing it together, when one finds the camera, the other is moving the box
7 Yes	I enjoyed playing, but what I noticed most was that I was never really clear on what to do. The hints were: 1. Where you need to interact on what buttons to press in the interface 2. When the second game was not clear to us the box did not give us feedback on how it's going.	The parts when you needed two people to play	Discovering that the code is repeating with the three dots was the best part of solving the puzzle	The game was not fun when there were two things to do, one for the box and one for the camera	We knew that there were only three parts to go, so always knew what they were for.	Some parts were very collaborative, but other games were not. Make sure that each game always has two parts. You can even use the properties of the box to do it in the game. Have the information displayed on separate sides of the box at the same time.
8 Yes	Yes, but it's a bit confusing at times for the first due to the mouse not working as expected due to the light, then due to missing this and then completing the first part	The combination of the physical box and the app	The 3D movement control of the mouse was a bit weird	Interaction between the 2 environments	Yes, and no. No because it was a fun thing to do because you cannot complete the first part of the second part is almost impossible.	Fun! You have to communicate and think together
9 Yes	Good, it was quite fun experience	Having the box and combining that with the application	Solving the riddles in very quickly	The switching between app and then the box	Yes, as there were still things on the box I didn't know what they were for, it was a bit confusing.	It was fun and gave the box to finish it quickly as it was a puzzle.
10 Yes	I had a good time. Some parts were really fun but it was fun.	The logic aspect. It was fun connecting physical to the interface with the camera and trying to connect with my partner in the interface. Even though I wasn't always sure what I was doing something.	The moment we were first moved. And the moment we finally moved into a puzzle box. The fact that we got the code from the app was really interesting.	Well there was a puzzle and I always had something to do. Even though I wasn't always sure what I was doing something.	Yes. Something always was moving at least a bit. We did not have to resort where nothing worked.	Yes, good to be able to cooperate. It was fun that we at least learned how to cooperate.
11 Yes	It was very fun.	The team work and trying to figure out	The mouse code figuring out was the most team work moment	The puzzle was hard to control but very nice to try it	Yes, it was really fun	The best part of it was the team work aspect
12 Yes	Nice user game experience.	The mouse it works a bit more fluidly	Teamwork with the mouse code	The lights and story	Yes, only not being able to solve the mouse to a bit frustrating. And I didn't understand the logic of the 2nd game.	I like to see games.
13 Yes	Great. Fun theme and interesting assignments.	The overall combination between the box and the phone	The fun was not with the camera buttons and translating mouse into app	The feeling of time pressure and willingness to win	Yes, because the time was running and you want to score the most points	Fun. Thinking about and working together to reach the goal.
14 Yes	It was ok, the game seems well thought out.	Reversing the pattern of the colors and decoding the message	It was fun to remember the pattern as a team	The color code kept me the most engaged and the mouse code	Yes, the challenges seemed all fun as you would also be fun probably	It was fun to team to work together with a game as a thing
15 Yes	Fun but bit buggy	Music	-	Music and color code	Yes	More fun than alone
16 Yes	Overall it should be quite interesting. The idea was creative, but the first round unfortunately our equipment worked.	Overall it was engaging as you had to figure out how to finish	A highlight was figuring out what the mouse code was and how to use it	The fact that it was virtual, the instructions and steps were clear and easy to follow. But the time pressure was a bit frustrating and had to use the box in order to figure it out.	The combination of phone and the camera, therefore motivated to continue	It was a team effort
17 Yes	As someone that likes puzzle boxes and escape rooms, I was. The mouse code puzzle	With the random sequence puzzle, we eventually just decided to randomly guess the sequence, which was apparently the only way to complete it.	The mouse code puzzle kept me engaged to find the right letters.	Yes, as I was curious what came next.	I liked to work together to find the solution.	

FIGURE G.3: Controlled User Test Notes

Appendix H

Use of AI

A few of the prompts used for optimisation and to enhance the grammar of the report can be found here.

Use of AI for grammar

Is this well formulated?: The user notes show that almost all participants finished the game in time, except for one. The person who could not finish though, had some technical issues regarding a leggy game.

- ④ The formulation could be improved for clarity and conciseness. Here's a revised version:

"The user notes indicate that nearly all participants completed the game within the allotted time, except for one individual who experienced technical issues related to laggy gameplay."

Other word for allotted?

- ④ Another word for "allotted" could be "designated." So, the revised version would be:

"The user notes indicate that nearly all participants completed the game within the designated time, except for one individual who experienced technical issues related to laggy gameplay."

Is this clear: When asked about what the impact is of playing alone on reaching the goal of the game, the participants mainly mentioned that it either has no effect, that playing alone is more efficient and relaxed. However, some mentioned that it would have been better if one person could hold the phone so that they could control the maze with two hands. An other participant mentioned that they had to figure out on their own how things work.

- ④ Yes, your statement is clear. It effectively conveys the responses of the participants regarding the impact of playing alone on reaching the goal of the game. However, there are some minor improvements that can enhance clarity and flow. Here's a revised version:

"When asked about the impact of playing alone on reaching the goal of the game, participants mainly mentioned that it either has no effect or that playing alone is more efficient and relaxed. However, some suggested that it would have been better if one person could hold the phone to control the maze with two hands. Another participant mentioned that they had to figure things out on their own."

These adjustments maintain clarity while enhancing the readability of the statement.

Could it be more concise?

- ④ Certainly, here's a more concise version of your statement:

"Participants stated that playing alone had either no impact or made the experience more efficient and relaxed. Some suggested it would be preferable to have one person hold the phone for better control, while others mentioned having to figure things out independently."

This version maintains clarity while reducing the length of the statement.

A few of the prompts used to find and solve issues in the code can be found here.

Use of AI for programming

The gamelogic script does not seem to work in my vuforia image tracking scene, why?



If the `GameLogic`` script is not working in your Vuforia image tracking scene, there could be several reasons for this. Here are some potential issues to check and troubleshoot:

1. **GameObject Setup:** Ensure that all necessary GameObjects (such as the player, collectables, finish trigger, and UI elements) are correctly set up and positioned within your Vuforia image tracking scene.
2. **Collider Setup:** Double-check that the colliders on your collectable objects and finish trigger are configured correctly and set to be triggers if necessary.
3. **Tags and Names:** Verify that GameObject names and tags used in the script (`"collectable"`, `"Finish"`, etc.) match the actual names and tags of GameObjects in your scene.
4. **Audio Setup:** Ensure that the `AudioSource`` component and audio clips (such as Collectable and Finish) are correctly assigned in the Unity Editor.
5. **TMP Text Component:** Make sure that the TMP Text component (for displaying the finish message and collectables count) is correctly assigned in the Unity Editor.
6. **Timer Script Reference:** Check if the reference to the `Timer`` script (`timerScript``) is correctly assigned. If the `Timer`` script is not present or active in the scene, this reference could cause issues.
7. **Event Trigger Setup:** If your Vuforia image tracking scene relies on UI interaction events, ensure that the event triggers (such as `OnTriggerEnter``) are correctly configured and are being called as expected.
8. **Testing Environment:** Test the `GameLogic`` script in a non-Vuforia scene to ensure that it works as expected without Vuforia. This can help isolate whether the issue is specific to Vuforia integration or if it's related to the script itself.
9. **Debugging:** Use `Debug.Log`` statements throughout your script to track the flow of execution and identify any errors or unexpected behavior.
10. **Vuforia Configuration:** If you suspect that Vuforia integration is causing issues, review the Vuforia configuration settings and ensure that the necessary components (such as the ARCamera and ImageTarget) are properly configured and functioning correctly.

By investigating these areas and debugging the script, you should be able to identify and resolve any issues preventing the `GameLogic`` script from working as expected in your Vuforia image tracking scene.

It never goes in the stopTimer if statement, why?

```
using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using TMPro;
using UnityEngine.SceneManagement;

namespace HuggingFace.API.Examples
{
    public class TimeManager : MonoBehaviour
    {
        public Button startTimer;
        public Button stopTimer;
        public TMP_Text endTimeText;
        public float timeRemaining;
    }
}
```

It seems like the issue might be related to the timing of the condition check in the `stopTimer()` method. Let's break down your code to identify the problem:

```
csharp Copy code
public void stopTimer() //Stop timer when spell is recognised
{
    bool escapeFinish = VoiceRecognition.finishEscape;

    if (VoiceRecognition.finishEscape == true)
    {
        timerOn = false;
        Debug.Log("Timer is off");
        // Calculate points based on timeRemaining
        int points = CalculatePoints(timeRemaining);
        // Convert the timeRemaining to a formatted string
        string formattedTime = FormatTime(timeRemaining);

        // Create a message indicating the time taken, points earned, and collectables col
        string message = "You finished the Enchanted Escape in " + formattedTime + " and e
        endTimeText.text = message;
    }
}
```

In this method, you're checking the `finishEscape` variable from the `VoiceRecognition` class to determine whether to execute the code block inside the `if` statement. However, it seems like `finishEscape` is static and may not be updated properly when the conditions change.

Here are a few steps to debug this:

1. Ensure that `finishEscape` is being set to `true` somewhere in your code when the condition is met. Without setting it to `true`, the `if` condition in `stopTimer()` won't be satisfied.
2. Verify the timing of when `stopTimer()` is called. Ensure that it's called after `finishEscape` is set to `true`.
3. Add additional debug logs to trace the flow of your program. For example, you can add a debug log just before the `if` condition to see the value of `finishEscape`.

```
csharp Copy code
Debug.Log("Finish Escape: " + VoiceRecognition.finishEscape);
```

By doing this, you can verify whether `finishEscape` is `true` when you expect it to be. If not, you'll need to revisit where `finishEscape` is being set and ensure it's set correctly.

If `finishEscape` is being set correctly and the condition still isn't triggering as expected, double-check the logic inside the `if` block to ensure there are no issues there.