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SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Making Memories Stick: Designing MR Activities to Reinforce Learning

Tesi di Laurea Magistrale in
Computer Science Engineering - Ingegneria Informatica

Matteo Saglimbeni, 102589

Abstract: Mixed Reality (MR) is showing significant potential in the educational domain; however, existing applications remain largely limited to the reproduction of specific entities—such as objects that are difficult or hazardous to handle in real-life contexts—and to fixed content that cannot be easily adapted. This thesis proposes a novel approach to MR, not merely as a representational tool, but as a means to design customizable, activity-based learning experiences.

This thesis adopts a novel perspective in which MR is not used merely to represent elements of the real world, but rather to create activity-based learning experiences that can be customized according to the users' desired content. Specifically, it aims to support the memorization and consolidation of knowledge acquired during a pedagogically significant event in students' educational experience: the school field trip.

The developed application enables educators to create customized and reusable MR activities—such as 2D and 3D puzzles and quizzes—using content (images, videos, 3D models) collected by students during a school trip, with the aim of supporting memory retention through a gamified approach. The system is user-friendly, and the experience is fully customizable in terms of content, directly by the teachers.

The application's effectiveness was evaluated through two user studies with a total of 37 students. The results from a public demo and a focus group were positive, indicating that participants found the experience highly engaging, comfortable, easy to use, and educationally valuable. The findings demonstrate that a thoughtfully designed MR application can serve as an effective and playful tool for reinforcing memories and learning outcomes from cultural activities, overcoming common limitations of current educational MR applications providing a scalable and highly customizable application in the future.

Advisor:
Prof. Nicoletta Di Blas

Co-advisors:
Matteo Valoriani

Academic year:
2024-2025

Key-words: Mixed Reality, Education, School trip, Puzzle, Recollection, Gamification

1. Introduction

Mixed Reality (MR) is a rapidly expanding technology that is gaining increasing relevance in the field of education. Its ability to create immersive and interactive environments offers new opportunities to engage learners and support educational processes in ways that go beyond the limitations of traditional teaching methods.

Several educational applications based on Mixed Reality (MR) have been developed and are well-documented in the literature. These approaches have the merit of enhancing learner engagement and providing access to otherwise inaccessible content. However, they also suffer from certain limitations. For instance, they are often designed for a specific topic and cannot be easily customized, resulting in experiences that are engaging but lack clear learning outcomes. Additionally, they tend to focus primarily on the reproduction of real-world elements that, for various reasons, may be difficult or impossible to handle in a traditional classroom setting—such as mechanisms, tools, or archaeological artefacts.
Moreover, few studies have explored the use of MR activities to aid in recalling educational activities such as the school trip experiences, which serve as cultural activities that can enhance students' learning.

This thesis adopts a novel perspective in which MR is not used merely to represent elements of the real world [2–5], but rather to create activity-based learning experiences that can be customized according to the users' desired content. Specifically, it aims to support the memorization and consolidation of knowledge acquired during a pedagogically significant event in students' educational experience: the school field trip. In addition to fostering social interaction, such trips typically offer a full immersion in cultural contexts—such as a different city, its streets, buildings, and museums.

Our idea is to create a set of reusable activities that are instantiated at runtime, and the content of the experiences is selected a priori and uploaded by the creator of the experience, which we assume is a teacher. With this approach, students and teachers gather content (including images, videos, and 3D models) during a school trip, which the educator then uses to create personalised "challenges" (like puzzles or quizzes...) for a post-trip experience. This means that each school trip will have many activities with the content regarding that trip (the photos taken, the videos recorded, and the 3D models scanned). This setup makes the application scalable with more and more activities in the future, and the content would always be interchangeable.

The project is centred around clear educational objectives, offering a high degree of content customisation to empower teachers in tailoring learning experiences to their students' needs. Designed to be user-friendly, the application ensures intuitive access for both educators and learners. By prioritising accessibility and adaptability, it effectively overcomes many of the key limitations commonly found in existing mixed reality educational applications.

This thesis explores the existing literature in the field of MR applications in chapter 2, outlines the application's requirements and a possible use case scenario in chapter 3, details the technical implementation in chapter 4, presents the results of two user evaluations conducted with a total of 37 students in two different scenarios in chapter 5 and discusses the results and future directions in chapter 6.

This work is carried out in collaboration with FifthIngenium (which made available its proprietary platform "TINALP"), the first company in Italy to develop extended reality solutions, and the PRIN "Through the City" project. We thank “Archivio Storico Casa del Sole” in Milano for the multimedia content we use in the project for evaluation and demonstration purposes.

2. State of the art

This chapter lays the foundational framework for the thesis. It begins by proposing a definition of mixed reality, followed by a discussion of its use in educational contexts and noting some limitations. It then explores MR applications designed for school trips and finally concludes by summarising the found results.

2.1. Mixed reality in education

2.1.1 Definition

Mixed reality (MR) is a term used to describe the merging of a real-world environment and a computer-generated one. Physical and virtual objects may co-exist in mixed-reality environments and interact in real time [15]. Mixed reality is an immersive technology that falls in between virtual and augmented reality. It's not just a fusion of AR and VR but also integrates 3D modelling, 360-degree video capture, and other advanced tools that combine the physical world with digital elements in real time. Unlike virtual reality, which creates a fully virtual world, or augmented reality, which creates a partial digital world, mixed reality (MR) seamlessly merges both realms by integrating virtual objects into the physical environments of the users [1]. To make mixed reality possible, a combination of technologies works behind the scenes. Devices must be able to sense and map their environment (chapter 4.1), understand where physical objects are, and recognize how users are moving, speaking, and gesturing. The system then must render digital content in real time, adjusting dynamically to the user's perspective and surroundings.

2.1.2 Educational MR applications and their limitations

Mixed Reality (MR) is gaining attention in education but remains limited in use, mainly applied in higher education and vocational training for STEM and medical fields. In K-12, it is used more sporadically, often to boost engagement in subjects like science and history. While MR supports immersive and spatial learning, its wider adoption faces barriers such as high costs, low scalability, and usability issues. Most MR tools are also narrowly focused and not easily adaptable across different curricula. There follow some examples:

For early education and collaboration, the MR.Brick platform uses augmented physical blocks and headsets to support co-located and remote play-based learning. Children can work together in real-time to solve puzzles, with MR facilitating social interaction and cooperative learning [16]. This application has proven especially effective in teaching basic problem-solving and communication skills to young learners. Another interesting feature to cite is the roles' division between children; assigning different roles in the game creates a more constructive environment regardless of which role they play.
In the evaluation process MR.Brick encountered some usability issues. For example, some children found the interaction with the tangible toolkit in MR.Brick complicated compared to using a mouse, and spent more time searching for the correct tangible card than playing the game, possibly due to the quantity and size of the cards. Difficulty with 3D operation, including using a mouse to determine correct positions in a 3D environment, was also a challenge for the majority of children, attributed to their limited spatial awareness skills.

In technical and vocational training, ChameleonControl allows instructors to remotely teach hands-on skills using MR overlays [6]. The system synchronises an instructor's gestures and voice with a remote student's headset, creating a shared physical-digital workspace for activities like physiotherapy demonstrations or mechanical assembly. This solution enables high-fidelity skill transfer without requiring physical proximity.
In examining the limitations, it becomes clear that this approach using mixed reality (MR) falls short compared to physical ones—particularly when embodied interaction plays a crucial role. In such cases, the novelty of the technology tends to overshadow its actual educational value. As the paper highlights: "However, this approach does not scale well for classrooms, where dozens of students learn by observing an instructor's hands-on demonstration. In such a case, each student needs to wear a MR headset, which incurs a large financial cost as well as a cumbersome preparation and calibration process that significantly hinders practical use in actual classrooms. Moreover, even if the headset becomes cheap, small, and easily accessible, the virtual demonstration is still far from the actual physical demonstration, especially when the embodied interactions matter. For example, we learn from our formative study that the lack of physical demonstrations and human touch results in a poor learning experience in certain domains like physiotherapy training." Moreover, a usability issue to take into consideration is the psychological and physical discomfort or the "uncanny valley" effect caused by mismatches between the surrogate's physical body and the projected virtual face of the instructor.

In creative design education, IllusionX blends generative AI with MR to support students in tasks such as spatial modelling and interactive storytelling [17]. Students use natural gestures to manipulate virtual objects in 3D space while receiving real-time design suggestions from the system's AI component. This setup encourages self-directed learning and creative exploration in architecture and game design education.
IllusionX introduces critical ethical considerations. A major concern is the risk of hallucination, where the language model generates plausible but factually incorrect content, which can mislead learners if not properly mitigated. The developers address this by embedding external, validated knowledge to ground the responses more reliably, which is a convoluted approach since it creates extra work in scaling the application and might not cover all possible scenarios.

In pharmacy education, for example, the University of Pittsburgh developed an MR module using Microsoft HoloLens 2 that allows students to explore 3D cardiac anatomy [13]. This application enables learners to walk around a holographic human heart, view internal structures in real time, and interact with visual annotations, dramatically improving anatomical comprehension and spatial reasoning. This immersive approach allowed

students to interact with detailed cardiac anatomy, including arteries and conduction systems, and to visualise the effects of medications on the heart. This simulation enables students to engage with virtual patients in infectious disease scenarios, interact with electronic medical records, and respond to real-time changes in patient conditions.
While effective for teaching targeted tasks, the technology's evolving nature limits personalization, resulting in a repetitive experience with little room for growth or variation.

Gómez-Cambronero in 2019 developed a mixed-reality escape room video game demonstrating how real-world exploration combined with virtual puzzles can complement traditional teaching methods and promote learner engagement in indoor educational settings [7]."Escape The Place" is a mobile-based mixed-reality escape room developed with the Unity engine to complement traditional learning activities by situating players within a real university building and guiding them through a narrative of "being trapped" via their smartphones as learners physically move to key locations such as the entrance, kitchen, and basement. Bluetooth beacons detect their position and unlock context-sensitive scenes where virtual puzzles (e.g., interpreting a floor map or solving a device-locking code) are integrated with physical exploration.
The video game, while educational in scope, was developed as a specific use case to support GIS Day and promote geospatial technologies, making it complex to adapt to other scenarios.

2.2. School trip MR Applications

Let us now explore recent advancements in MR technology that enhance students' learning beyond the immediate experience of a school trip. Despite the potential of MR as a tool for post-trip reflection and integration, few studies have explored its use in this context. The results presented here mostly focus on MR applications designed to enhance learning during the trip itself:

MacCallum's study [10], grounded in participatory action research with teachers in New Zealand in 2022, emphasises the pedagogical value of blending digital and physical experiences, highlighting that MR not only supports logistical and cognitive preparation but also fosters reflection and cross-curricular learning while empowering both teachers and students to co-create immersive learning experiences.
Practically, the project developed three integrated MR applications around a landfill field trip:

- Before the trip, students explored a virtual field trip (VFT) created using 360° photos and embedded audio, helping them familiarise themselves with the site layout and key concepts.
- During the trip, an augmented reality (AR) scavenger hunt was implemented using mobile devices and GPS-triggered tasks, encouraging active, gamified learning at various locations.
- After the trip, students created their own VFTs using 360° imagery and interactive content, applying their knowledge and gaining skills in digital storytelling, programming, and sustainability education.

Something worth one of the teachers saying is, "The [VFT] provided an opportunity to engage more with the landfill field trip. The tour deepened this experience, as you could actually show them what they would see, not just talk about it... a really neat little activity that the students could hook into, and it provided them with initial information about our local landfill area and provided an opportunity to go deeper into the ideas before the actual tour."

One relevant initiative, a bit older (2013), is the EcoMOBILE project by Kamarainen [9], which combined mobile devices, augmented reality, and probeware to support inquiry-based learning during field trips, followed by classroom activities that extended and reflected on those experiences. Although EcoMOBILE primarily focused on the during-trip phase, it highlighted the value of connecting physical experience with later conceptual development. The EcoMOBILE app is designed to enhance environmental science field trips by providing students with real-time, location-based digital content through mobile devices. The app employs augmented reality (AR) and GPS to activate inquiry tasks, multimedia explanations, and educational prompts associated with particular physical locations as students navigate a natural setting, like a pond or forest ecosystem. When a student arrives at a specific tree or water sample location, for instance, the app might show an augmented reality animation that explains the ecological role of that feature or ask them to gather data using portable sensors like pH or temperature probes. These encounters are captured on video and then played back in class, where students utilize the gathered information and electronic notes to evaluate results, consider their fieldwork, and relate their observations to more general scientific ideas.

Hwang's application in 2016 [8] is an AR-based educational game designed to enhance elementary school students' learning during ecology field trips by combining AR technology with competitive gameplay. Set in a butterfly garden, the game uses QR codes to trigger location-specific missions, such as identifying butterfly species or host plants, and integrates mini-games like AR shooting challenges to teach about predators. Struc-

tured as a board game, students roll a digital dice to navigate the garden, earning points for correct answers, with leaderboards fostering competition. If a student answers incorrectly, the system provides guided support, such as supplementary materials or comparison tasks, before revealing the solution.
By blending real-world observations with interactive digital content, the app aims to improve learning outcomes such as knowledge retention and boost student engagement and motivation.

Summary and considerations

This literature review shows that several critical considerations emerge for the design and implementation of educational mixed reality. While introducing novelty and interesting concepts, some of them show up with limitations. For example, applications like the mixed-reality escape room "Escape The Place" demonstrate how compelling location-based experiences can be created, yet its development as a specific use case for a single event makes it complex to adapt to other scenarios, exemplifying a low degree of customization. In vocational tools like ChameleonControl, the impressive MR overlay for remote instruction struggles to replace the essential value of embodied, physical interaction, making the experience more about the technology than the learning. Furthermore, usability frequently emerges as a critical barrier, where unintuitive design choices counteract the intended benefits. The MR.Brick platform illustrates this perfectly, as its tangible interface proved more confusing than helpful for some children, leading to frustration rather than engagement. This challenge extends to user discomfort, from motion sickness during prolonged sessions in anatomy modules to the psychological unease of the "uncanny valley" effect in remote teaching systems. Ultimately, this focus on the immediate, in-the-moment experience is especially evident in applications designed for school trips. Prominent projects like EcoMOBILE and Hwang's AR game excel at enhancing on-site learning through real-time data or gamification, yet they also highlight a gap: the potential for MR to support the crucial post-trip phase of reflection and memory consolidation remains largely untapped.

3. Application design

This chapter shifts the focus to the application design, outlining how the system was conceptualised and structured to address specific needs. It begins by presenting the application's goals and requirements, which are built around the issues identified in the literature. Next, it delves into the functional requirements, outlining the primary system actors, their interactions within the environment or with the online platform, and the corresponding system responses to those inputs and behaviours. Finally, a use case scenario is provided to illustrate a potential real-world application of the system in an educational context.

3.1. Application goals and requirements

Our work aims to fill a gap in the field of mixed-reality applications for school field trips. Many existing educational applications discussed in the literature face notable limitations, particularly their lack of flexibility and adaptability across different contexts. These solutions are often overly specific and difficult to customize, limiting their educational impact. To overcome this, our approach allows users to select a priori the most suitable content for each experience. This not only enhances adaptability but also ensures that the educational value is preserved from the outset, as the selected content—such as a painting or a statue—possesses inherent educational significance.

This **customizability** is a core tenet of our design; the application is not limited to predefined content but can host continuously updated materials, depending on what users choose to upload. Educators can thus create truly bespoke experiences by incorporating their own images, models, and texts that are directly relevant to their specific curriculum or the unique focus of a recent field trip. This dynamic capability ensures the platform remains a long-lasting and adaptable tool for countless educational scenarios.
To achieve these promises, we designed a set of modular activities that teachers can place and customize within the mixed-reality experience. These activities guide students in revisiting and consolidating the key moments of their field trip. The puzzle activity serves as a tool for reconstructing memories and challenging the user. And the quiz activity is used as an assessment tool by the educator. The result is a versatile tool that serves multiple purposes: teachers can test students' understanding of the topics covered in class and explored during the trip, use the app to present additional details that may not have been addressed in place, and enrich the overall learning process. For students, the experience becomes a playful and collaborative alternative to traditional lessons, one that encourages learning through exploration, reconstruction, and teamwork.

Furthermore, **usability** is often overlooked, despite being crucial for ensuring a smooth and engaging experience for all users. In our application, we focused on designing a minimal set of intuitive interactions supported by a user-friendly interface. For example, grabbing a puzzle piece is achieved through ray-based interaction: when the user points the controller's ray at a puzzle piece, the ray changes color, providing visual feedback. A simple button press then allows the user to pick it up, creating a seamless and accessible interaction flow. Moreover, selecting an answer of a quiz is like using a remote; clicking a button is all the user is asked to do.

Another issue highlighted in the literature is the discomfort users may experience when wearing a headset for extended periods. As demonstrated in our evaluation (Chapter 5), our simulations were intentionally kept under 20 minutes to maximize such **comfort** and adjoin the experience with the correct background music playlist can drastically improve the immersion. Based on this, we recommend that educators avoid creating lengthy mixed reality experiences. If longer sessions are necessary, we suggest incorporating regular breaks, ideally every 30 minutes, to ensure user comfort and maintain engagement.

3.2. Use case scenario – Dive into the Renaissance: a journey from Firenze to the augmented classroom

Narrative: Class 3A of a secondary school is studying the Renaissance period with their art teacher. To bring history to life and strengthen long-term memory through hands-on and immersive learning, the teacher plans a multi-phase educational experience, integrating real-world exploration with mixed reality.

Step-by-Step Use Case Flow:

3.2.1 Preparation in Class

The art teacher introduces the Renaissance period, focusing on major artists such as Leonardo da Vinci, Michelangelo, Raffaello, Caravaggio, and Botticelli.
To deepen understanding, she organises a cultural field trip to Museo degli Uffizi in Firenze where students can "touch with hands" the artworks and atmosphere of that era.

3.2.2 On-Site at Museo degli Uffizi

Upon arrival, the class is divided into 5 groups, each assigned to one Renaissance master:

- Group 1: Leonardo da Vinci
- Group 2: Michelangelo
- Group 3: Raffaello
- Group 4: Caravaggio
- Group 5: Botticelli

Each group visits their assigned section of the museum, where the teacher provides live explanations about the artist's key works. Students are reminded that this will be part of their assessment, so active listening is required. While exploring, students take photos of paintings they find most meaningful. Students and the teacher scan 3D models of sculptures or objects using their phones to capture important Renaissance elements.

3.2.3 Post-Trip Collection

After the trip, the teacher asks students to upload their materials (images and 3D scans) to a shared folder or platform.
The goal is to gather raw assets (pictures and 3D models) to build MR learning activities.

3.2.4 Creating the MR Experiences

The teacher logs into the Tinalp portal and creates 5 MR learning experiences, one for each artist/group (she registers to the platform if not already done).
For each experience, she uploads:

- Puzzle2D activities using the collected images (e.g., Caravaggio's paintings).
- Puzzle3D activities using the scanned models (e.g., Leonardo's constructions or Michelangelo's sculptures).
- Quizzes (image-based and text-based) to test student knowledge and reinforce concepts. And eventually video-based if there are any meaningful.

3.2.5 In-Class MR Group Activities:

Back in class, students are regrouped as per their original trip teams. Each group takes turns guiding one member using the MR headset while others watch the AR view on a phone or screen. The active user interacts with the MR environment, solving:

- Puzzle2D and Puzzle3D: Rebuilding artworks. In these activities, students are tasked with collecting all the scattered puzzle pieces to rebuild the original artwork or object. The process is intuitive and accessible but also mentally complex because placing each piece requires attention to detail and challenges their visual memory and pattern recognition.
- Quiz: Answering questions based on the artist's life and works. Remembering the teacher's explanation before and during the trip to assess the comprehension of the topics.

The teacher monitors progress using her laptop (with Oculus cast), providing help and noting which students show particular effort or leadership. Each group rotates through all 5 artist experiences.

3.2.6 Completion and discussion

At the end, the teacher takes a moment to discuss with the class the whole experience, gathering questions and comments. She can also reward the most engaged, successful groups or the best photos with "+" marks or commendations, reinforcing participation and competition and, above all, sticking memories of the trip.

3.2.7 Bonus Activity

As a fun twist, the teacher also creates an extra MR puzzle using funny photos of the students or hilarious moments from the trip, making the students reconstruct those images and turning good times into memory-sticking experiences.

3.3. Functional requirements

- **G1**: A teacher aims to design an educational experience that integrates Mixed Reality activities using content from a previous school trip.
  - **R1.1**: The Tinalp portal allows the teacher to register into the system (just username and password)
  - **R1.2**: The Tinalp portal allows the teacher to log into the system with credentials input at registration time
  - **R1.3**: The Tinalp portal allows the teacher to upload all the content of the school trip (the photo taken, the video recorded, the 3D models scanned or simply some texts)
  - **R1.4**: The Tinalp portal assigns a unique media ID to each multimedia content
  - **R1.5**: The Tinalp portal allows the teacher to use the multimedia content to create as many activities as necessary of type: Puzzle2D (image-based reconstruction), Puzzle3D (3D object assembly), and Quiz (image, video or text-based questions) as detailed in Section 4.3
  - **R1.6**: The Tinalp portal allows the teacher to change the content each time they want to
- **G2**: The student starts the application and scans the room to detect all possible surfaces in the classroom (walls, floor, tables, ...).
  - **R2.1**: The application allows the student to move around the play area to perform a room scan and recognition. This process automatically detects most of the objects in the room, assigning a label to each of them (table, storage, chair...)
  - **R2.2**: The application allows the student to scan objects not identified automatically by the system and manually add them
  - **R2.3**: The application allows the student to scale and relabel scanned objects if the automatic detection is inaccurate.
- **G3**: The student finds a puzzle piece (2D or 3D) on the ground, picks it up in his hand, and tries to complete the puzzle activity.
  - **R3.1**: The application allows the student to use one of the controllers with a digital ray to point to one of the puzzle pieces and by pressing one of the button on the controller, the piece appears as grabbed
  - **R3.2**: The application allows the student, while grabbing the digital object, to rotate and translate it in each direction
  - **R3.3**: The application allows the student, while grabbing the digital object, to place it in a puzzle socket (2D or 3D) in the position they prefer
  - **R3.4**: The application provides visual or auditory feedback when a puzzle piece is correctly placed.
- **G4**: The student finds a quiz activity, reasons on the question (it can be an image, a video, or a text), and chooses the correct answer.

- **R4.1**: The application allows the student to select the right answer between multiple choices by the pressing a button
- **R4.2**: The application informs the student whether the selected quiz answer is correct or incorrect.

4. Implementation

This chapter focuses on the technical details of the application. It begins by outlining two fundamental components: the devices we decided to target for our experience and the scene recognition and understanding they can perform. Finally, we proceed to detail the various activities developed to reinforce student learning, such as interactive puzzles and questions, allowing students to relive and reflect on their school trip experiences.

4.1. Devices: Oculus Meta Quest 3 and 3S

The `Meta Quest 3` and `Meta Quest 3S` are the most recent standalone mixed reality (MR) headsets developed by Meta, each designed to cater to distinct user needs within the immersive technology landscape. Both devices are powered by the Qualcomm Snapdragon XR2 Gen 2 chipset and run on Meta's Horizon OS, yet they differ notably in terms of visual fidelity, optical systems, and target use cases. Together, the Meta Quest 3 and Quest 3S represent a scalable approach to mixed reality hardware. The Quest 3 offers high-fidelity, precision-driven performance suitable for professional and industrial use, while the Quest 3S delivers core MR features in a more cost-effective form, making immersive technology accessible to a broader user base.

Launched in October 2023, the `Meta Quest 3` is engineered for high-performance mixed reality experiences. Its full-color stereoscopic passthrough, enabled by dual RGB cameras, facilitates highly accurate spatial mapping and real-time integration of digital elements into the physical world. Battery life averages around 2.9 hours, and spatial audio performance has been significantly enhanced compared to its predecessor, the Quest 2. The device is shown in Figure 1a.

In contrast, the `Meta Quest 3S`, introduced in 2024, serves as a more accessible alternative aimed at general consumers and educational institutions. While it shares the same XR2 Gen 2 chipset and 8 GB of RAM, it features a lower display resolution of 1832×1920 pixels per eye and utilises Fresnel lenses, which are more cost-effective but bulkier and less optically advanced. With a slightly reduced battery life of around 2.5 hours, the 3S prioritises affordability and simplicity while retaining essential MR functionality such as hand tracking, high refresh rates (up to 120 Hz), and room-scale environmental awareness. The device is shown in Figure 1b. (The technical data are taken at [11])

Both devices are equipped with a `Guardian system`. A core component that ensures the user moves without fear of colliding with real-world objects. The Meta Quest 3 introduced a significant evolution of the Guardian system, often referred to as "Smart Guardian." This upgraded system offers a more automated and seamless setup process. Key features of the Quest 3's Guardian system include:

- **Assisted Space Setup**: When you first put on the Quest 3 in a new environment, it can automatically scan your room. By simply looking around, the headset maps the walls, furniture, and other obstacles, suggesting a safe play area without the need for manual tracing with the controllers. This makes getting into a VR experience quicker and more user-friendly
- **Stationary and Roomscale Modes**: The Guardian system continues to offer two primary modes. Stationary Mode creates a small, circular boundary around you for seated or standing experiences. Roomscale Mode allows for a much larger, customized area that you can freely walk around in. The Quest 3 can intelligently recommend which mode to use based on the available space.
- **Glanceable Boundary**: A convenient feature that allows you to quickly see your virtual boundary by simply looking down. This provides a subtle and non-intrusive way to orient yourself within your play space.
- **Customizable Sensitivity**: Users can fine-tune the sensitivity of the Guardian, adjusting how close they need to get to the boundary before it becomes visible. This allows for a more personalized experience, catering to different room sizes and user comfort levels.
- **Multiple Room Memory**: The Quest 3 can remember the Guardian setups for multiple rooms, so you don't have to rescan your environment every time you switch locations.

A more detailed technical explanation of these features is provided in the following section.

(a) Meta Quest 3 device.

(b) Meta Quest 3S device.

Figure 1

Scene recognition and understanding

Scene recognition and understanding are fundamental components of our application. At the launch of the application, in a new environment, users are prompted to perform a scene scan. During this process, the user is guided to move around the room to capture comprehensive visual data. The Quest system uses this input to automatically detect and map structural surfaces, identify static objects, and establish the floor level. Upon completion, the user is given the option to manually refine the scan results to ensure spatial accuracy and alignment. This process is already handled by integrating the MRUK APIs into the project, which additionally associates a label name to all scanned items [12]. The labels are catalogued as:

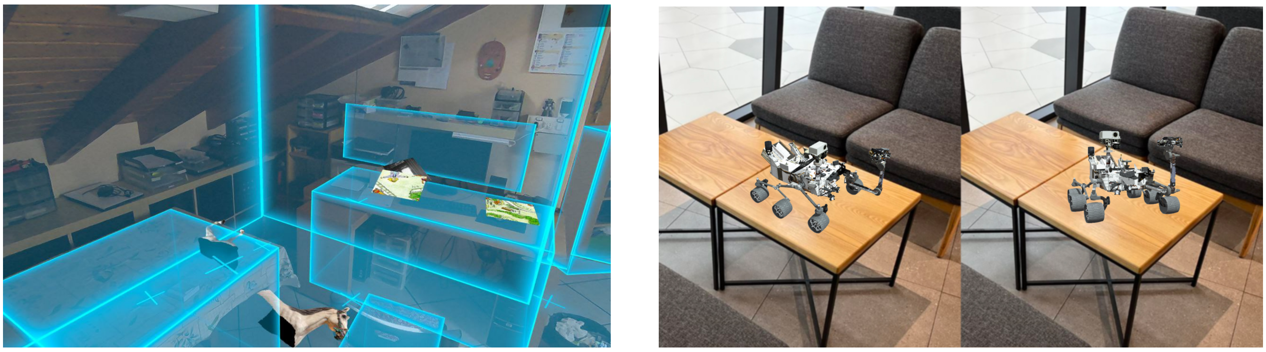
- FLOOR
- CEILING
- WALL_FACE
- TABLE
- COUCH
- DOOR_FRAME
- WALL_FACE
- WINDOW_FRAME
- OTHER
- STORAGE
- BED
- SCREEN
- LAMP
- PLANT
- WALL_ART
- GLOBAL_MESH
- INVISIBLE_WALL_FACE

Completing the scene recognition step enables the application to accurately place or spawn objects onto physical surfaces or programmatically generated ones. The next phase involves object placement within the scanned environment. In alignment with Meta's best practices, the spawning process follows a structured three-step approach:

1. Ensure that the scene has fully loaded and all spatial data (surfaces, labels, and mesh information) is available.
2. Find an unoccupied spot in the room that can fit enough space for the object that needs to be spawned.
3. Verify that the selected spot has an appropriate surface label. If not, repeat the search from step 2.

For multiple objects (e.g., an array of items to spawn), steps 2 and 3 are repeated for each item to ensure all objects are placed in valid and distinct locations within the room.

If an object is detected to be positioned on or near the room boundary, due to gravity and physics simulation, these objects can fall outside the room. To address this issue, we programmatically repositioned to a safe, predefined central area within the room. This ensures spatial stability and prevents unintended behaviour due to falling or loss of interaction.



(a) Scene recognition of a room (b) Object positioning example of Meta [12]

Figure 2: Scene recognition and understanding

4.2. TINALP

The work presented in this master's thesis has been developed in collaboration with FifthIngenium and relies upon the TINALP platform's functionalities [14]. Designed as a multidisciplinary tool, TINALP offers key features such as content customisation and the ability to upload personalised materials. As described by the FifthIngenium team, the platform aspires to function as a "PowerPoint for Mixed Reality."

TINALP provides users with access to a web-based, no-code visual editor that allows trainers to independently drag and drop the materials they wish to use during their lectures. These lectures are structured into sequential steps, each of which can incorporate both 2D and 3D elements. This setup enables trainers to easily design well-organised and interactive lessons. Furthermore, lectures can be published and made available to students for self-paced study sessions.

Instead of modifying the existing platform, our work uses it as an interface for downloading the media assets (such as texts, images, videos, and 3D models) that are needed to instantiate the corresponding MR learning activities.

Although not required for the scope of this thesis, it is worth noting that the TINALP project offers additional functionalities for creating new types of experiences. These include shared physical spaces and real-time synchronisation between users within the same session. Moreover, TINALP supports remote augmented classrooms across different physical locations, enabling a wide range of collaborative and immersive learning scenarios.

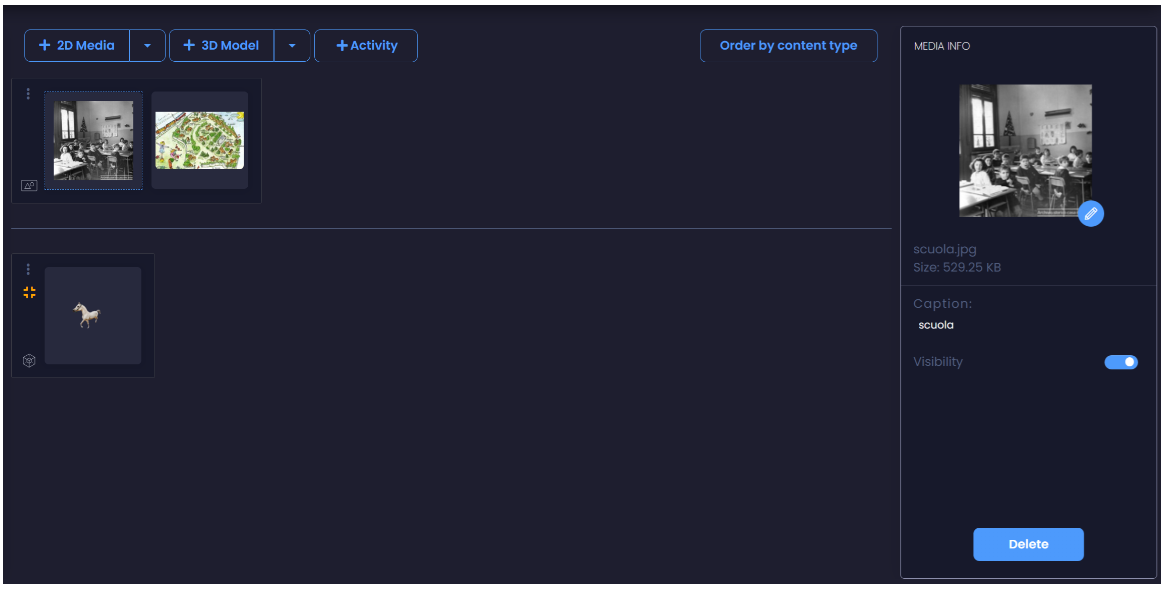


Figure 3: Puzzle content selection

4.3. Activities

The activities we developed are designed to reinforce student learning by engaging them in interactive puzzles and questions while simultaneously allowing them to relive and reflect on the experiences they had during their school trip.

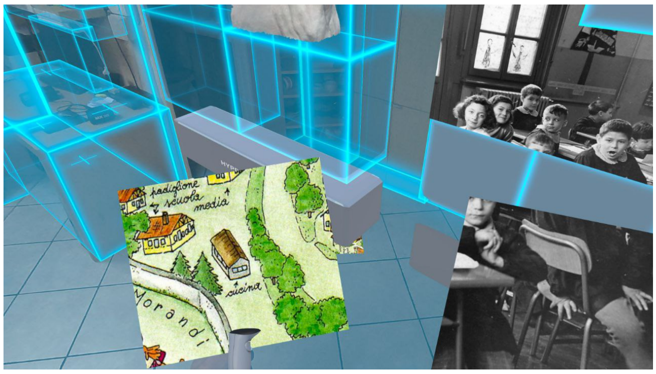
4.3.1 Puzzle 2D

Activity Overview

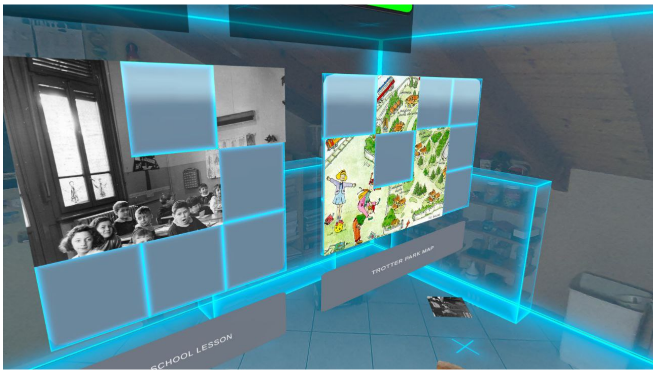
This activity is inspired by the globally recognised jigsaw puzzle game (figure 4a), focused on reconstruction. In our application, the objective is to reassemble one or more images taken during the school trip, making the experience both educational and personally meaningful. In the physical version of the jigsaw puzzle, pieces typically have irregular shapes. However, in this implementation, all puzzle pieces are rectangles for consistency, ease of interaction, and facilitating the development. The activity is divided into two main phases:

1. The image is selected by the teacher
2. Pieces are spawned and distributed throughout the play area where the student navigates the space and collects the pieces (figure 4b)
3. The student reconstructs the image (figure 4c)

(a) Jigsaw puzzle game



(b) Collection of puzzle pieces



(c) Puzzle sockets with some missing pieces of a school photo and of a map

Figure 4: Puzzles 2D

The student might find the task challenging because they don't have a clear memory of the original photo, forcing them to rely on recall and pattern recognition to complete the puzzle. The teacher delivering the experience can properly adjust the difficulty of the game by choosing the number of pieces of the puzzle a priori.

Classes abstraction

The Puzzle 2D activity is structured as follows: To implement this activity, we produced these classes:

1. `Puzzle2D`: This class is responsible for converting a complete 2D image into a grid of discrete, rectangular tiles. It inherits from `PuzzlePiece`, ensuring each tile behaves as a standalone, spawnable unit.

Internally, `Puzzle2D` is composed of `PuzzleData2D`, which supplies all required sprite references (file paths, extensions, media IDs) and rendering parameters. Upon initialisation, it reads its data, loads the source image, computes tile dimensions, performs sprite slicing, and instantiates each tile as a separate `PuzzlePiece`.

2. `PuzzlePiece`: This class represents the individual puzzle tiles that can be instantiated and manipulated at runtime. By inheriting from `Puzzle`, it gains access to global puzzle parameters and behaviors, such as snapping, alignment, and validation logic.
3. `Puzzle`: This class models the entire puzzle assembly, orchestrating all pieces into a coherent layout. It is composed of `PuzzleData`, which defines overarching configuration details—such as total tile count, grid dimensions, and scale factors. On startup, `Puzzle` uses this data to establish the puzzle's framework and enforce layout constraints.
4. `PuzzleData`: A pure data container that defines the static parameters of the puzzle before runtime. It includes fields such as the number of rows and columns, overall image width and height, tile size, scale factor, and alignment offsets. This data ensures consistent proportions and correct placement for both 2D and 3D puzzles.
5. `PuzzleData2D`: A specialized data class that holds all metadata required for rendering 2D puzzle tiles. It specifies properties like the source image file name, file extension, media identifier, and any additional parameters (e.g., transparency settings) needed during rendering.

Look at the fig. 7a for a visual understanding.

Activity implementation

To develop this activity, we followed five steps:

1. The teacher selects activity-specific content from the Tinalp portal, which results in the generation of a structured JSON configuration file. This file is parsed by the application at runtime to dynamically instantiate all required data structures, asset references, and interaction logic for the specified activity.
2. The application verifies the presence of the required image asset on the local device. If not found, it performs a network operation to download the image and caches it for future use.
3. The image is converted into a texture and then subdivided into a 2D grid based on the defined difficulty (e.g., 3x3 grid = 9 segments). Each grid cell is converted into an individual Sprite object, using UV coordinate mapping to crop the appropriate region of the original texture. We provide the extraction code:

Algorithm 1 Sprite extractor algorithm

Require: `sprite`, integer coordinates (x, y), sprite dimensions (w, h)
Ensure: A new sprite extracted from a larger sprite sheet // The (x, y) coordinates are the positions of each piece in the grid and sprite reffering to the full original image

$i \leftarrow y \times w$ // Horizontal offset based on column index
$j \leftarrow x \times h$ // Vertical offset based on row index
`rect` $\leftarrow$ rectangle with top-left (i, j) and size (w, h) // Define region to extract
`pivotDef` $\leftarrow (0.5, 0.5)$ // Center pivot for the new sprite
`s` $\leftarrow$ Create new sprite from `sprite.texture` using `rect` and `pivotDef` // using Sprite.Create
return `s` // Return the extracted sprite

4. For each sprite segment, the system programmatically creates a GameObject in the Unity scene. Each object is configured with:
   - A SpriteRenderer component to display the sprite.
   - A Rigidbody component with appropriate mass and drag values for physics simulation.
   - A BoxCollider component matching the sprite's bounds for collision detection.
   - XR Interaction Toolkit components such as XRGrabInteractable to enable spatial manipulation and user interaction via VR/AR input.
   - A custom utility script, DontFallUnderFloor, was developed to prevent pieces from falling outside the room boundaries or beneath the floor, whether due to user errors or inaccuracies in room recognition.
5. The generated GameObject instances are randomly or strategically placed on recognised planar surfaces (e.g., floor, table tops) using the MRUK room recognition tool. The system ensures appropriate spacing and orientation to optimise both playability and immersion in a mixed-reality environment.

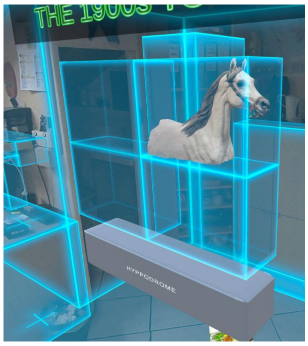
4.3.2 Puzzle 3D

Activity Overview

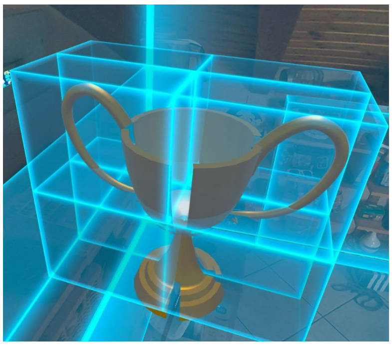
This activity was conceived as a natural progression from the previous one. To maximize the capabilities of the mixed-reality environment, we aimed to extend beyond 2D objects and explore the reconstruction of 3D objects. While this adds complexity to the implementation, we successfully developed a solution that enables interactive 3D object reconstruction within the MR space. Similarly to before, the activity is divided into two main phases:

1. The model is selected by the educator
2. Pieces are spawned and distributed throughout the play area, where the student navigates the space and collects the pieces (figure 5a)
3. The student reconstructs the 3D model (figure 5b and 5c)

(a) Collection of puzzle pieces



(b) Puzzle socket with some missing pieces of a horse



(c) Reconstruction of a trophy

Figure 5: Puzzles 3D

Classes abstraction

The Puzzle 3D activity is structured as follows:

1. `Puzzle3D`: This class is responsible for converting a complete 3D model into a set of discrete, grid-aligned pieces by cutting the mesh into parallelepipeds. It inherits from `PuzzlePiece`, ensuring each fragment behaves as a standalone, spawnable unit. Internally, `Puzzle3D` is composed of `PuzzleData3D`, which provides all necessary model and texture references (file paths, extensions, and media IDs) as well as rendering parameters. Upon initialisation, it reads its data, loads the 3D asset, computes grid boundaries, performs mesh slicing, and instantiates each resulting piece.
2. `PuzzlePiece`: This class represents the individual puzzle fragments that can be instantiated and manipulated at runtime. Inheriting from `Puzzle` grants it access to global puzzle parameters and behaviours.
3. `Puzzle`: This class models the entire puzzle assembly, acting as the orchestrator for all pieces. It is composed of `PuzzleData`, which specifies overarching configuration details—such as total piece count, grid dimensions, and scale factors. On startup, `Puzzle` uses this data to establish the puzzle's structure.
4. `PuzzleData`: A pure data container that defines the static parameters of the puzzle before runtime. It includes properties such as the number of rows and columns, overall width and height, scale factors, and alignment offsets. This data ensures that both 2D and 3D puzzles maintain consistent layout and proportions.

5. `PuzzleData3D`: A specialised data class that holds all metadata required for rendering 3D puzzle pieces. It defines fields like the model file name, file extension, media identifier, and any shader or texture parameters needed during rendering.

Look at the fig. 7a for a deep understanding.

Activity implementation

The implementation of this activity can be seen in 5 macro steps as before, but it's more complex due to the fact we are now handling 3D models and we have to work with meshes:

1. Load configuration parameters from the Tinalp portal, where the teacher selects features for both the puzzle 3D models and the sockets.
2. Download the models to the device, or load it locally if it has been previously downloaded.
3. Convert the model into a GameObject with an attached mesh. Subdivide the mesh into a 3D grid, extracting the requested number of parallelepiped meshes (e.g., dividing the mesh into 9 equal pieces yields 9 parallelepiped meshes). We provide the extraction code:

Algorithm 2 Parallelepiped mesh extractor algorithm

```
Require: Integer coordinates (x, y, z), vector stepSize, vector minBounds, mesh originalMesh   // The (x, y, z) coordinates are the positions of each piece in the 3D grid; originalMesh is the mesh of the full model, minBounds is the minimum bounds size of the puzzle piece and stepSize tells how large each grid cell should be depending on the coordinates
Ensure: A new mesh containing only triangles that lie completely within the parallelepiped defined at position (x, y, z)
parMin ← minBounds + (x · stepSize.x, y · stepSize.y, z · stepSize.z)   // Calculate lower bound of the parallelepiped
parMax ← parMin + stepSize   // Calculate upper bound of the parallelepiped
Extract originalVertices, originalTriangles, originalUVs from originalMesh
Initialize empty lists: newVertices, newTriangles, newUVs   // These will store the new mesh
Initialize empty dictionary: vertexMap   // Maps old vertex indices to new ones
for each triangle T in originalTriangles (step by 3) do
    Initialize empty list: insideIndices   // Holds indices of triangle vertices inside the parallelepiped
    for each of the 3 vertex indices i in T do
        v ← originalVertices[i]   // Get vertex position
        if v lies within parMin and parMax in all axes then
            if i not in vertexMap then
                Add v to newVertices   // Add vertex to the new mesh
                Add originalUVs[i] to newUVs   // Preserve corresponding UV coordinates
                vertexMap[i] ← index of v in newVertices   // Store mapping
            end if
            Add vertexMap[i] to insideIndices   // Use new vertex index
        end if
    end for
    if length of insideIndices is 3 then
        Add triangle defined by insideIndices to newTriangles   // Only add enclosed triangles
    end if
end for
Create newMesh with newVertices, newTriangles, newUVs   // Assemble the new mesh
Recalculate normals and bounds of newMesh   // Ensure lighting and bounding box are correct
return newMesh   // Return the extracted sub-mesh
```

4. For each parallelepiped mesh, the system programmatically creates a GameObject in the Unity scene. Each object is configured with:
    - A MeshRenderer and a MeshFilter component to display the mesh with its original texture (the cut part of the mesh has a black texture, as you slightly see in the figure5a).

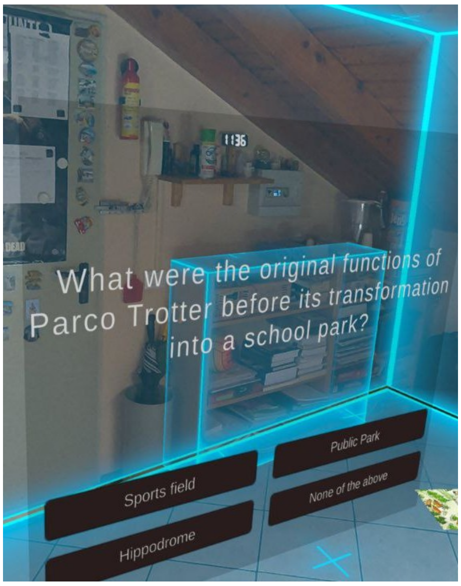
- A Rigidbody component with appropriate mass and drag values for physics simulation.
- A BoxCollider component matching the sprite's bounds for collision detection.
- XR Interaction Toolkit components such as XRGrabInteractable to enable spatial manipulation and user interaction via VR/AR input.
- A custom utility script, DontFallUnderFloor, was developed to prevent pieces from falling outside the room boundaries or beneath the floor, whether due to user errors or inaccuracies in room recognition.

5. Spawn the puzzle pieces all around the room on the floor, tables, or other flat surfaces.

4.3.3 Quiz

Activity overview

The quiz activity represents a different approach, an assessment tool for educators. Following a school trip, a teacher may wish to evaluate whether students have met specific learning objectives. This activity offers an alternative to the traditional pen-and-paper questionnaire by leveraging the mixed-reality environment to enhance interactivity and immersion. Within the MR setting, questions can take multiple forms—not just text, but also images or videos—creating a richer and more dynamic experience. Similarly, responses can go beyond multiple-choice selections. For example, an answer might involve completing a task, such as retrieving a specific virtual object within the environment. This flexibility allows the creator of the experience to choose the best-fit activity for each learning objective.



(a) Classical multiple-choice quiz

(b) Image question with three answers

(c) Video question with two answers

(d) Text question with object retrieval task

Figure 6: Quiz

Classes abstraction

To implement this activity, we produced these classes:

1. `Quiz`: This is the main controller class responsible for managing the quiz activity. It uses both the `quizQuestionFeature` and `quizAnswerFeature`, to handle questions and answers.
2. `QuizQuestion`: An abstract class that defines the interface and shared behaviour for all types of quiz

questions. It is associated with `QuizDataQuestion`, which provides the question's metadata.

3. `QuizDataQuestion`: A data class that stores question-specific information such as text, media content, or configuration options for a quiz question.
4. `QuizTextQuestion`, `QuizVideoQuestion`, `QuizImageQuestion`: These are concrete classes inheriting from `QuizQuestion`. Each one specialises in handling a specific type of question content—text, video, or image.
5. `QuizAnswer`: An abstract class that defines the base behaviour for different types of quiz answers. It is linked to `QuizDataAnswer`, which holds data for answer options.
6. `QuizDataAnswer`: A data class containing the actual answer information that can be displayed and selected in the quiz.
7. `QuizTwoAnswers`, `QuizThreeAnswers`, `QuizFourAnswers`, `QuizObjectAnswer`: These are concrete subclasses of `QuizAnswer`, each representing different answer formats, such as multiple choice with two, three, or four options, or object-based answers.

Look at the fig. 7b for a visual understanding.

Activity implementation

To develop this activity, we followed three steps:

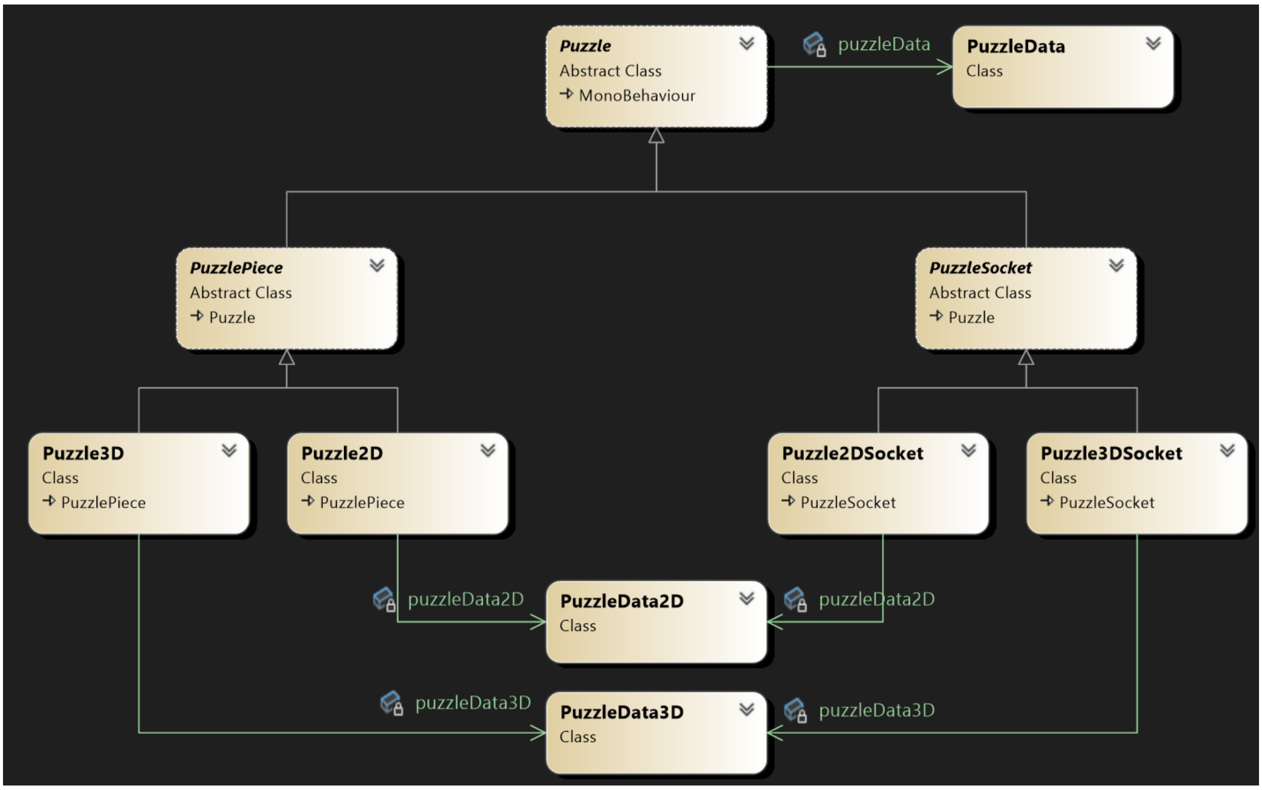
1. The teacher selects activity-specific content from the Tinalp portal, which results in the generation of a structured JSON configuration file. This file is parsed by the application at runtime to dynamically instantiate all required data structures, asset references, and interaction logic for the specified activity.
2. The application verifies the presence of the required image asset on the local device. If not found, it performs a network operation to download the image and caches it for future use.
3. The application then instantiates elements as interactive GameObjects in the Unity scene. Each question is associated with a multimedia component, depending on its format (text/image/video). Similarly, the answers are instantiated based on the JSON parameters. For each type of answer and question there is a class managing that feature (i.e., for the image question there is the `QuizImageQuestion`)

4.4. Code organization

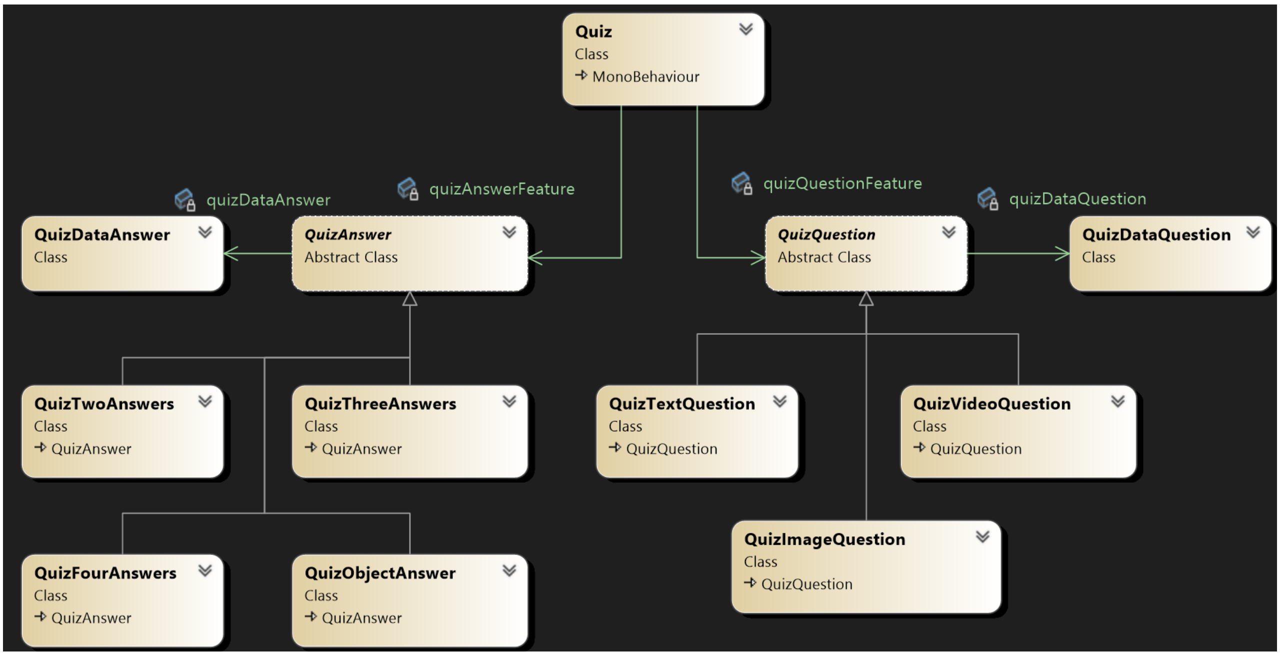
This section presents a comprehensive overview of the class structure of the application. It highlights the hierarchical organisation of the core activities, specifically focusing on the `Quiz` and `Puzzle` components. Additionally, it outlines the overall application flow, emphasising the roles and responsibilities of various manager classes. These classes serve as the backbone of the application's logic, coordinating the interaction between different modules and ensuring seamless execution of tasks. The goal is to provide a clear understanding of how different parts of the application are structured and how they interact to deliver the intended user experience.

4.4.1 Activities charts

We provided the class diagrams illustrating the structure of the two main activities: Puzzle and Quiz. Each activity follows an object-oriented hierarchy, with abstract base classes defining core behaviour (Puzzle, PuzzlePiece, Quiz, QuizQuestion, QuizAnswer) and multiple specialised subclasses extending functionality for different formats (e.g., 2D/3D puzzles, text/image/video quiz questions, and varied answer types). Data classes support each component by supplying the necessary configuration and content.



(a) Puzzles class diagram



(b) Quiz class diagram

Figure 7: Activities hierarchy (green arrows = "composed of"; white arrows = "inherits from")

4.4.2 Manager Classes for Application Flow

To orchestrate the functionalities of the application, a set of manager classes has been implemented using the Singleton design pattern. These managers handle specific subsystems and coordinate the core workflow shown in Figure 9. Each manager operates as a centralised controller for its domain, ensuring consistent state management and global accessibility throughout the application lifecycle. The key managers and their responsibilities include:

- **Application Manager**: Serves as the entry point for the application and handles high-level initialization. It maintains a singleton instance of the API Manager.
- **API Manager**: Manages data retrieval from external services. Downloads the experience configuration

(including puzzle data and activity definitions) from the Tinalp portal in JSON format.

- **Game Manager**: Controls the global game state of the game. Handles transitions between core states: `Playing`, `Paused`, and `PuzzleSolved`.
- **Puzzle Manager**: Coordinates puzzle-related activities. Spawns and manages interactive objects (puzzle pieces, sockets, quizzes) and checks how many puzzles have been solved.
- **Download Manager**: Manages local media assets. Downloads required files on first launch and handles subsequent local loading of resources.
- **Controller Manager**: Processes user input devices. Detects and routes interaction events (e.g., menu button presses, piece selection).
- **UI Manager**: Controls interface rendering and state. Manages display of pause menus, progress indicators, completion dialogues, and other UI elements.
- **Audio Manager**: (Not shown in flow, but it's paired with many functionalities, such as giving feedback) Central controller for all sound effects and background music.

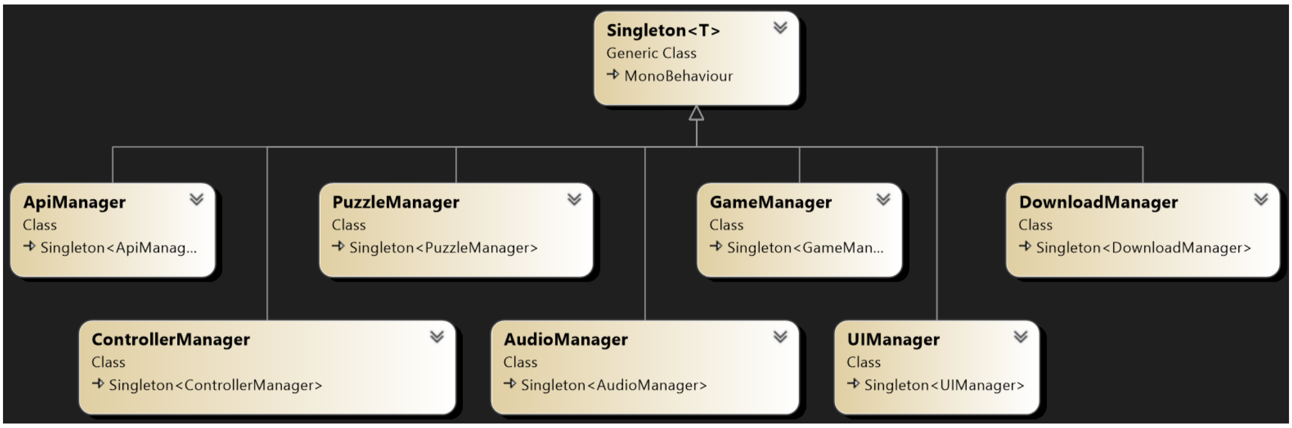


Figure 8: Class diagram of manager components implemented as Singletons

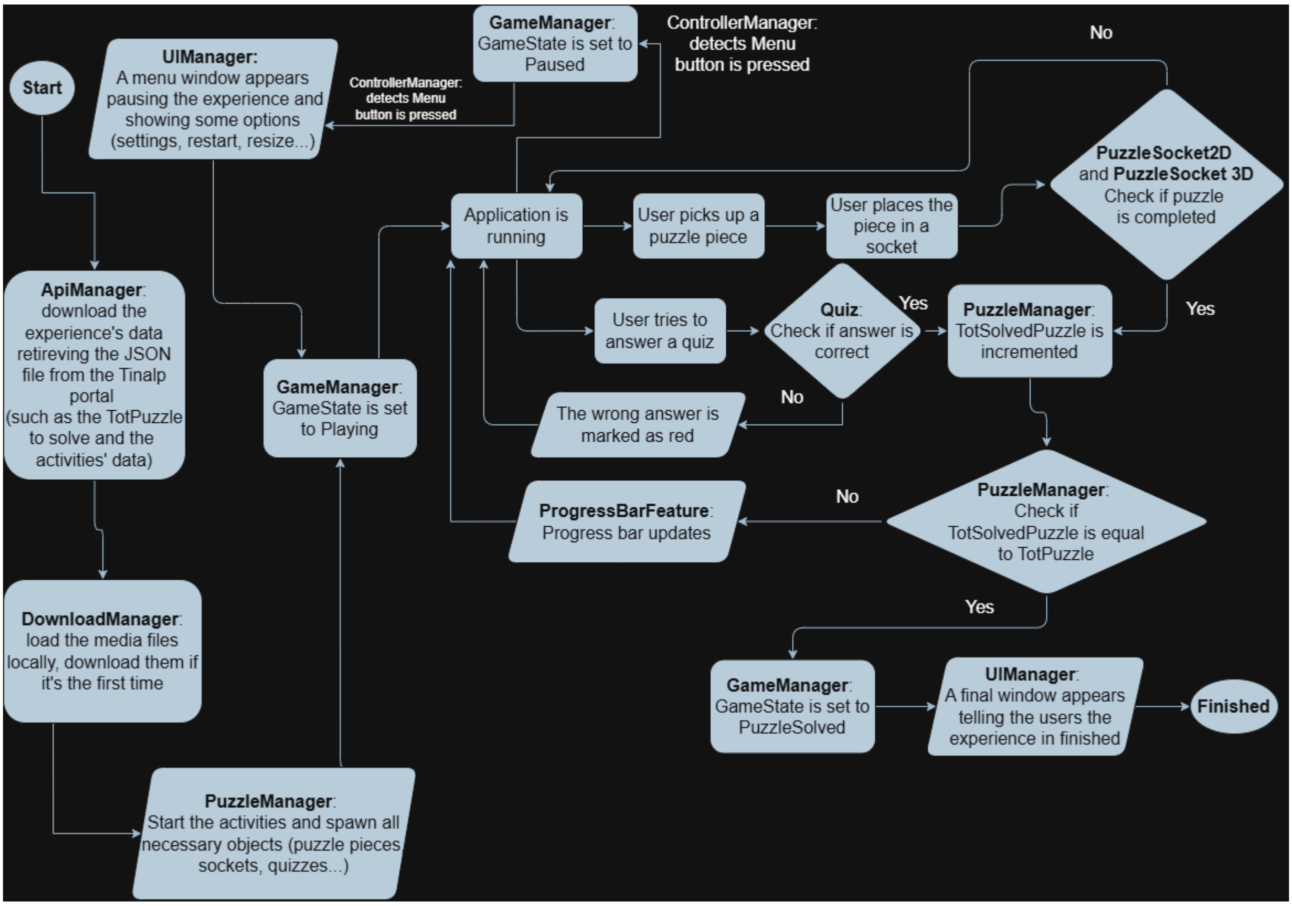


Figure 9: Application workflow showing manager interactions

5. Evaluation

This chapter presents the experimental evaluations conducted to test the application's usability, assess participant engagement, and gather perceptions of its usefulness. We conducted two distinct evaluations at the Politecnico di Milano: a demo test with 30 students during the open day at the stand of Computer Science and Engineering and, two months later, a focus group with 7 master's degree students in class. In the final section, we present charts illustrating the results of the completed questionnaire for all the 37 students.

5.1. Demo at the Politecnico di Milano Open Day

A demo was conducted in Milan with 30 participants (aged 17–27). The activity focused on reconstructing historical images and a map of Milan's Trotter Park, along with a 3D model of a horse serving as a historical reference to the park's former function as a hippodrome. These materials had been originally created by high school students as part of a research project exploring the local area and were therefore perfectly fitting for the intended use scenario of the project. Two activities involved reconstructing images of the school from the 1920s (4 pieces to recompose), while another focused on an image of the park map (6 pieces to recompose). The final activity, which referred to the time when the park was a hippodrome, required users to complete the reconstruction of a horse. The demo lasted approximately 5 to 10 minutes, depending on the user's ability to solve the puzzles. Participants ranged in age from 17 to 27, most between 18 and 22, which is our target, and were predominantly male (around two-thirds). Roughly 60% reported having used an AR headset before, but even among those with no prior AR exposure, the experience was rated as highly comfortable (mean comfort score $\approx$ 4.6/5), easy to use (mean ease-of-use $\approx$ 4.67/5), and pedagogically useful (mean perceived utility $\approx$ 4.4/5). Every respondent (100%) answered "Yes" when asked if they found the experience positive overall, and one-word summaries (e.g., "nuova"-> "new", "divertente" -> "fun", "particolare" -> "peculiar") strongly convey enthusiasm, novelty, and engagement. In short, this first testing not only navigated the AR interface without significant discomfort or confusion but also recognised clear educational value in an MR approach to revisiting a cultural school trip.

5.2. Focus Group

The evaluation was conducted with 7 participants on May 5, 2025. Each participant tested the application, completed the same open-day questionnaire, and then took part in a group discussion to share their impressions. The questionnaire results confirmed the sensations perceived on the open day as highly comfortable (mean comfort score $\approx$ 4.71/5), ease of use (mean ease-of-use $\approx$ 4.57/5), andpedagogically usefuls (mean perceived utility $\approx$ 4.57/5).

On this occasion, we took the opportunity to conduct a slightly more comprehensive evaluation. Since it wasn't feasible to simulate a full school trip with real users, we devised a demo experience involving two participants at a time. The roles were divided as follows: one person acted as the *Explorer*, wearing the headset and navigating the experience, while the other played the role of the *Master*, who had access to the information needed to solve all the puzzles (we provided printed materials with the relevant clues).

We found this setup particularly effective, as it created a natural asymmetry of knowledge: the Explorer was unaware of the correct placement of the puzzle pieces, while the Master had that information. Both participants had to collaborate and communicate to solve the quizzes and complete the challenge, making teamwork an essential part of the experience.

The demo featured the same three puzzles presented during the open day, but with an increased level of difficulty, requiring users to assemble approximately 12 to 15 pieces. In addition, four quizzes were included. Each session lasted around 15 to 20 minutes, depending on the participants' problem-solving abilities. We introduced the experience as an educational escape room to the users, as we believed it adhered to the core principles of the escape room format.

In the final half an hour, we had the occasion to receive feedback about the application along the 2 critical aspects we are focusing on:

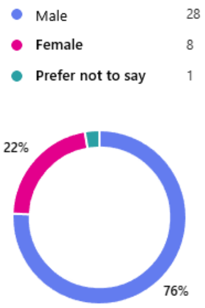
- **Usability**: everyone mentioned that the interactions felt really smooth and engaging, creating a strong sense of immersion in the environment. One comment stood out as both fun and accurate—comparing the ray cast used for picking up puzzle pieces to Spider-Man's web shooter, making the user feel a great response by the system.

  One student with a hearing disorder shared that she enjoyed the immersion of the experience, thanks to the good sound isolation and the low-volume background music provided by the headset, which reproduced a focus music playlist.

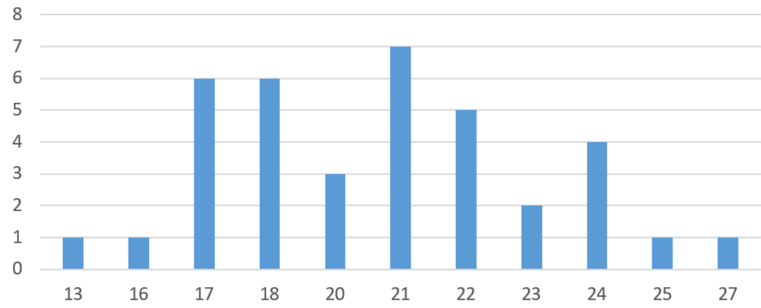
As an improvement, another appreciated comment suggested finding a way to resize the puzzle socket because it sometimes might appear too big to some users.
Another important comment made us realise that the way we introduced the activities to the focus group might have been misleading; in fact, we referred to the application as an "educational MR escape room," and while it does include some features typical of such applications—like a sequence of puzzles to solve within a time limit, collaboration, and skill development—we agreed that it currently lacks the complexity and investigative clues necessary to fully qualify as this type of project. With further development, however, it has the potential to evolve into one.

- **Utility**: Another important aspect was asking whether this work could be implemented in a real use case scenario. The majority of respondents gave a strong yes, mentioning that they would have appreciated applications like this during their secondary school years. They also noted that it could serve as an effective assessment tool for teachers across multiple subjects.
One student added that while he sees the application's potential, it might be more suitable for some subjects than others—particularly humanities (art, history, ...), due to the multimedia content involved.
In conclusion, the consensus was that this project could definitely find practical use by providing a fun experience that helps students recall and retain the content of a school trip.

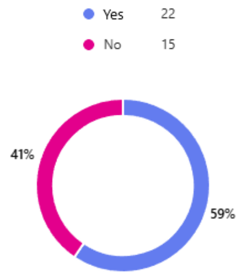
5.3. Questionnaire and charts of all respondents (37 total participants)



(a) Gender of the participants



(b) Number of participants by age group

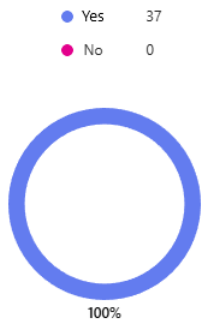


(c) Number of participant which had arleady tried a VR/AR headset

(d) Comfort of the experience. A score of 5 represents a comfortable experience.

(e) Ease of use of the application's functions. A score of 5 represents very easy use.

(f) Usefulness of this kind of applications in school. A score of 5 represents high usefulness)



(g) Number of participants which found the experience positive

(h) One-word first impression after trying the application

6. Conclusions and future work

6.1. Conclusions

The primary objective of this study was the development of "Making Memories Stick," a Mixed Reality (MR) application designed to enhance learning reinforcement following school trips. A central goal was to empower educators by enabling them to create personalized learning activities using their own digital content.
In pursuing this objective, the design process specifically sought to address certain challenges often present in educational technology, such as limited opportunities for customization, potential usability hurdles, and minimizing user discomfort.

The application features modular and reusable 2D and 3D puzzles and quizzes, which enable students to playfully recall and reconstruct key moments from their trips. The design prioritized intuitive interaction and user comfort to overcome common usability problems associated with other MR tools.

The effectiveness of the application was assessed through a public demonstration involving 37 students and a subsequent focus group. The feedback obtained was predominantly positive, with participants describing the experience as highly engaging, user-friendly, and educationally valuable. Nonetheless, it is important to acknowledge the potential influence of biases, such as the participants' inclination to support a perceived peer and the novelty effect typically associated with emerging technologies. A necessary direction for future development is the implementation of testing with a larger and more diverse sample to ensure more robust and generalizable findings.

6.2. Future work

Based on the positive feedback from the evaluations, the thesis outlines several opportunities for future extension and evolution of the project:

- **Develop Advanced Collaborative Features:** A major future step is to integrate true multi-user functionality, which would allow several students to interact in the same mixed-reality space at the same time. This would shift the experience from a single-user activity to a fully shared, collaborative learning environment. The idea stems from the promising "Explorer" and "Master" role-playing setup observed during the focus group evaluation.
- **Evolve as an Educational Escape Room:** The application could be further developed to more fully embody the concept of an "educational MR escape room"—that is, a sequence of interconnected challenges leading to a final solution—in order to enhance user engagement.
- **Expand the Variety of Activities:** The existing framework supports 2D/3D puzzles and quizzes. This can be broadened by designing and implementing new modular activities. Suggested examples include interactive timelines, digital storytelling modules where students can build MR presentations with trip media, or even activities for other subjects like science that incorporate simple physics simulations.
- **Refine and Extend Educator Tools:** The thesis envisions teachers creating experiences via the Tinalp portal. A key future direction is to make this portal more powerful and user-friendly. This would involve offering educators advanced tools to sequence activities, track student progress in real-time, and customize learning paths without needing technical skills.
- **Conduct Broader User Testing**: While initial feedback from a public demonstration with 37 students was largely positive—highlighting the application's engaging, user-friendly, and educational nature—future development should include evaluations with larger and more diverse user groups. This will help mitigate potential biases, such as peer influence and the novelty effect, and support the generation of more robust and generalizable insights.

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Abstract in lingua italiana

La Realtà Mista (RM) sta mostrando un potenziale significativo in ambito educativo; tuttavia, le applicazioni esistenti rimangono in gran parte limitate alla riproduzione di entità specifiche—come oggetti difficili o complessi da maneggiare in contesti di vita reale—e a contenuti statici che non possono essere facilmente riadattati. Questa tesi propone un approccio innovativo alla RM, non semplicemente come strumento di rappresentazione, ma come mezzo per progettare esperienze di apprendimento personalizzabili e basate sulle attività.

Questa tesi adotta una prospettiva innovativa in cui la RM non è utilizzata semplicemente per rappresentare elementi del mondo reale, ma piuttosto per creare esperienze di apprendimento basate sull'attività che possono essere personalizzate in base ai contenuti desiderati dagli utenti. Nello specifico, si propone di supportare la memorizzazione e il consolidamento delle conoscenze acquisite durante un evento pedagogicamente significativo nell'esperienza educativa degli studenti: la gita scolastica.

L'applicazione sviluppata consente agli insegnanti di creare attività di RM personalizzate e riutilizzabili—come puzzle e quiz 2D e 3D—utilizzando contenuti (immagini, video, modelli 3D) raccolti dagli studenti durante una gita scolastica, con l'obiettivo di supportare la rievocazione della memoria attraverso un approccio giocoso. Il sistema è di facile utilizzo e l'esperienza è completamente personalizzabile in termini di contenuti, direttamente dai docenti.

L'efficacia dell'applicazione è stata valutata attraverso due studi con un totale di 37 studenti. I risultati di una demo pubblica e di un focus group sono stati positivi, evidenziando che i partecipanti hanno trovato l'esperienza molto coinvolgente, confortevole, facile da usare ed educativamente valida. I risultati dimostrano che un'applicazione di RM progettata con cura può servire come strumento efficace e ludico per rafforzare i ricordi e i risultati di apprendimento derivanti da attività culturali, superando i limiti comuni delle attuali applicazioni educative di RM e fornendo in futuro un'applicazione scalabile e altamente personalizzabile.

Parole chiave: Realtà Mista, Educazione, Gita scolastica, Puzzle, Rievocazione, Gamificazione

Acknowledgements

Il cammino è stato lungo, ma ora sono qui al traguardo. Se ce l'ho fatta, è merito di tante persone. So che poche righe non potranno esprimere appieno la mia gratitudine, ma cercherò comunque di trasmetterla al meglio.

Grazie alla mia famiglia, a mamma e papà che hanno sempre creduto in me e mi hanno supportato in tutto, nelle mie scelte e con affetto. So di non essere una persona di molte parole, per via del mio carattere, ma vi sono profondamente grato per tutto ciò che mi avete insegnato e per la persona che sono diventato, anche con i miei difetti. Grazie alla mia sorellina—che ormai tanto "ina" non è più—ma che con orgoglio ho visto crescere come adulta e considero una spalla con cui potersi confrontare su ogni argomento. Un grazie speciale va anche a tutti i miei parenti—nonni, zii e cugini—che non sono mai stati da meno nel mostrarmi il loro affetto, interessarsi al mio percorso e farmi sentire il loro supporto. Un grazie speciale alla zia Luigia che, all'età di quasi 100 anni, riesce ancora a dimostrarmi quanto la curiosità e il desiderio di conoscere siano tra le meraviglie più autentiche della vita. Grazie a tutta la famiglia, mi sento davvero fortunato.

Grazie ai miei amici, con cui sono riuscito a staccare la spina dagli impegni e che mi hanno fatto vivere esperienze che mi hanno arricchito personalmente. Con alcuni ho condiviso più tempo, con altri meno, ma con tutti si è creato un legame che ormai fa parte di me. So di poter contare su ognuno di voi, così come voi potete contare su di me.

Agli amici di Casletto con cui sono cresciuto, Kev e Pico in particolare, voi che vedo quasi più della mia famiglia e ogni uscita sforniamo meme di qualità, con voi non mi annoio mai e vi dico grazie. Nick, anche tu sei incluso nelle parole di prima, pur non vivendo qua, però grazie di darmi punti di vista mai banali. Ele, grazie anche a te, anche se purtroppo ci si vede poco, ogni volta si ritorna con quella sintonia che avevamo da bambini.

Agli amici di Cantù – Lele, Ale, Fra, Paky, Den e Tiziano – con cui magari un tempo uscivamo più spesso, ma ogni volta che ci ritroviamo riusciamo sempre a tirar fuori il nostro lato più spontaneo e divertente, senza filtri né vergogna. Mi fate capire che ci tenete a me, e per questo vi ringrazio di cuore.

Agli amici del gruppo “ahmed,” non sapevo davvero come raggrupparvi, ma so che capirete—Yoggy, Manu, Manny, Lombo, Condo, Dp, Fabio, Gerbo, Angelina, Filo, Sigi, Rob e Tia—con voi ho vissuto esperienze molto diverse tra loro, tutte significative. C’è chi viene da altre parti d’Italia, chi mi ha fatto scoprire e condividere la passione per il gioco di ruolo, chi mi ha seguito in dei viaggi, e chi semplicemente ha passato del tempo con me tra chiacchiere e videogiochi. Con ognuno di voi ho condiviso qualcosa di prezioso, e di questo vi sono grato.

Agli amici delle superiori che, purtroppo, come è normale che sia con tutti gli impegni, ci si perde di vista, ma comunque anche quelle poche volte all’anno che ci rincontriamo riconosciamo che non è cambiata una virgola e ci si diverte come un tempo. Grazie anche a voi, Fiore, Teddy, Bolla, Pare, Zamp, e Vale.

Un altro grazie doveroso ai miei amici dell’uni che hanno condiviso con me questo percorso. Parte dei risultati raggiunti son grazie a voi e per quanto molti esami fossero difficili, affrontarli assieme ha alleggerito davvero tanto il peso. Grazie ai miei amici di magistrale: Carlos S, Vale, Scacca, Luca, Righini, Borro, Chioe, e Bagge. E a quelli della triennale: Andrew, Carlos R, Ariel, Matias e Ale Pozzo. Infine, ringrazio tutte le persone che non ho citato, ma con cui ho anche solo condiviso un progetto o un esame.

Avrei davvero qualcosa da dire per ognuno di voi, ma rischierei di scrivere un’altra tesi. Mi limito quindi a dire grazie, di cuore, per essere stati parte del mio percorso fino a qui, e non so se continuerete a farne parte in quello che verrà, ma un ricordo di voi sarà sempre presente.

E, per concludere, il grazie più grande va a me stesso del passato. A quella parte di me che, nonostante tutto, non ha mollato. E fidatevi, di ostacoli ce ne sono stati tanti, e in più di un’occasione lasciare tutto sarebbe sembrata la scelta più semplice.
Eppure eccoti qui. Sì, magari in ritardo rispetto ai tempi “canonici” e meno bravo di altre persone, ma sei arrivato alla fine di questo percorso, mentre studi e fai finalmente qualcosa che ti appassiona.
E ora, un messaggio al me del futuro: quando ti sentirai bloccato o smarrito, rileggi queste righe. Ricorda che sbagliare fa parte del cammino, e anche se fa paura, è giusto così. Segui sempre la strada della passione e della curiosità, perché è quella che dà le soddisfazioni più vere.

Quindi grazie. Grazie per non aver mollato.