UNIVERSITY
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Serious Games for Memory Training in Ageing Era

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TECHNOLOGY
AND ARCHITECTURE

Department of Information Science and Technology

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Resumo

Com o envelhecimento da população mundial, o declínio cognitivo tornou-se uma preocupação significativa de saúde pública, especialmente no que diz respeito às funções de memória, como reconhecimento, evocação e memória espacial. Isto afeta a qualidade de vida dos idosos, e as soluções disponíveis são insuficientes. Os métodos tradicionais de treino de memória têm falta de envolvimento e personalização, o que limita a motivação e a adesão a esses programas por parte da população idosa.

Este estudo propõe uma nova estrutura de treino de memória dedicada a adultos, utilizando jogos sérios de realidade virtual (RV) com o tema "Game of Life". A estrutura oferece "game tracks" personalizáveis, projetadas para atender às necessidades e preferências cognitivas dos utilizadores, incorporando recursos personalizados.

Um estudo piloto foi realizado para avaliar a estrutura proposta e demonstrou resultados promissores. Vários participantes foram selecionados e divididos em dois grupos. Os participantes do grupo ativo apresentaram um leve progresso, enquanto o grupo de controlo exibiu um leve declínio. Estes dados sugerem que os jogos propostos na estrutura não são apenas viáveis, mas também demonstram potencial para estabilizar ou mesmo melhorar ligeiramente a função cognitiva. Por meio da personalização, essa experiência foi considerada envolvente e benéfica ao final do estudo piloto.

A framework também aborda as potenciais barreiras existentes à RV que os idosos podem enfrentar, focando na simplicidade e na adaptação gradual. Ela foi concebida para manter as funções de memória dos idosos e melhorar o seu bem-estar.

PALAVRAS CHAVE: *Realidade Virtual*, *Jogos Sérios*, *Idosos*, *Treino Cognitivo*, *Aprendizagem Personalizada*, *Análise de Resultados*

Abstract

With the ageing of the global population, cognitive decline has become a significant public health concern, especially for memory function such as recognition, recall and spatial memory. It affects the quality of life of older adults and the solutions are insufficient. Traditional memory training methods lack engagement and personalization, therefore for the elderly population motivation and adherence to these programs is limited.

This study proposes a new memory training framework dedicated towards older adults, using serious Virtual Reality (VR) games themed as "Game of Life". The framework is provided with a customizable "game tracks" designed for the individual cognitive needs and preferences of it's users, by incorporating personalized features.

A pilot study was done to evaluate the framework and it demonstrated promising results, several participants were chosen and separated into two groups. Participants in the active group showed a slight improvement, while the control group exhibited a slight decline. These findings suggest that the games in the framework are not only feasible but also show potential for stabilizing or even slightly improving cognitive function. Through personalization, this experience was deemed engaging and beneficial at the end of the pilot study.

The framework also addresses the potential existing barriers to VR that older adults may have, by focussing on simplicity and gradual adaptation. The framework is designed to maintain the older adults memory functions and enhance their overall well-being.

KEYWORDS: *Virtual Reality*, *Serious Games*, *Older Adults*, *Cognitive Training*, *Personalized Learning*, *Outcome Analysis*

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CHAPTER 1

Introduction

1.1 Background

In the recent years, rapid ageing has led to a significant demographic shift in the world's population. In 2021, the global average life expectancy was just over 70 years [1] [2], indicating that over the years more and more people tend to live longer. In more developed countries, there tends to exist better living conditions, healthcare and nutrition. These factors suggest that the lifespan in those countries has extended. But there are several drawbacks to this change as well. For older people for example, who experience significant mental, physical and social obstacles as they age.

There is a serious problem with ageing, the deterioration of cognitive abilities. Memory, recognition and spatial awareness are the principal characteristics that worsen over time. For example, memory issues may make it challenging for older adults to perform everyday tasks, such as: maintaining their independence and needing someone to aid them, or engage in social activities on the outside world [3]. There's also various health problems that come with this issue, including exhaustion, depression, anxiety and even physical inactivity frequently are accompanied with cognitive decline [4] [5]. These older persons frequently feel socially isolated since after retirement when they no longer have the daily routine and social connections that come with employment, they tend to not have the urge to socialize in public with other people.

The issue of cognitive decline is that in the years to come it is expected to only increase. The number of individuals 65 and older in the world is expected to reach 1.6 billion by 2050 [6]. This demographic shift causes tension in healthcare systems, caregivers and multiple families, as the need for older adults to have support services only keeps increasing everyday[7]. The two conventional methods of treatment are medication and therapy in order to "treat" cognitive decline, but they only show limited success, since they only delay the inevitable. Furthermore, these methods tend to overlook the root cause of cognitive decline, which include insufficient social interactions, constant physical exercise and mental stimulation.

As for the response for these concerns, there has been a growing interest in creating a wave of new strategies that could revolutionize and help older adults preserve their cognitive capabilities longer. An area of research is the use of technology-based solutions, this shows promise as this provides stimulation while doing training exercises in computer programs, smartphone applications and also virtual reality (VR) [8] [9]. They have several advantages compared to the traditional methods, such as having the ability to deliver personalized, engaging and interactive experiences for any user, they could be customizable to fit the user's criteria and target the user's particular needs.

For this particular project, a decision was made to only work with an age range between the ages of 75-85. With this age range, it would be beneficial to work in the long run since these elderly still have a decent level of cognitive skills and can give clear feedback on the different games and experiences. This also helps in the personalization factor since the elderly were all born between 1940-1950 and the games can have references from those times that could make the different experiences more relatable and engaging since it references old memories from their past.

1.2 Motivation

Many existing solutions to combat cognitive decline have been implemented in the last decade, but most of them have significant limitations. There often exists a lack of personalization and engagement in most of these serious games, they have some effectiveness however they require long-term participation [10] [11]. But for long-term participation, the elderly need to constantly train under the same serious games, which becomes repetitive and quickly decreases their own motivation. These also are made with a more general approach, to work on most of the elderly people, however the cognitive training needs and preferences of the multiple uses is always different.

Another type of limitation is the reliance on external devices that the elderly have. The use of new technologies is foreign to them and require an adaptation time before they can use the technology properly, this also shifts if they have cognitive or physical impairments. The installation and utilization process of these devices may pose significant challenges, further reducing their effectiveness [8]. Some devices like phones and tablets also have their own limits, as they don't have the ability to simulate real-life situations, which are beneficial for effective cognitive training [12].

These approaches highlight the need for more solutions that have new unique characteristics that can address the challenges faced by the older adults. The usage of VR could be one of those solutions, it offers a unique opportunity to create immersive, interactive and personalized experiences if used in the right way [12]. The effectiveness of the cognitive training is due to the gamification elements of the VR serious games that can provide more engaging training experiences, which can lead into more motivation from the older adults, not only that but also adherence to the games and the framework itself, as well as long-term cognitive enhancement [11].

This study aims to investigate the real potential of VR serious games as a new technology for cognitive training, specifically for older adults. It has unique capabilities to develop specific frameworks in which they address the main limitations of the traditional methods used [12]. This new solution could have more effect and sustainability, for example by using the training methods, the quality of life for older adults could improve, also their own independence and overall their general well-being could benefit from these experience.

Regular training to train the cognitive capabilities could be the difference maker in delaying cognitive decline for older adults [9].

As a student that is deeply passionate about technology and helping others, there is a lot of motivation. This motivation is also fuelled by the potential that exist in creating VR serious games, to not only address cognitive decline as a whole but to also aid older adults in the best possible manner to maintain their independent and fulfilling lives. The interest for this research stems from observing and living next to people who had these challenges and realizing the lack of engaging, accessible tools that could support their cognitive health. This study represents an opportunity to bridge the gap between technological innovation and real-world needs, having a framework that prioritizes user engagement and personalization.

1.3 Research Questions

One of the main objectives of this research is to develop a VR memory training framework that is engaging and effective in maintaining cognitive abilities for older adults. The objective of this study is to answer the following research questions:

- What are the technical requirements and design characteristics in order to develop a VR memory training framework that is customized to older adults?

- What user interface (UI) and user experience (UX) design principles are the most effective to guarantee accessibility and simplicity for older adults in the VR environments?

- How can haptic feedback, visual cues and sound effects be optimized in VR serious games to enhance positively the experience of memory training for older adults?

- What methods and metrics can be used in order to evaluate in a quantitative way the effectiveness of the VR framework and the games associated to it in improving or maintaining memory functions for older adults?

- What tech barriers exist that could hinder the experience of older adults when using VR memory training games and how can these be mitigated?

1.4 Objectives

The suggested VR serious games framework has the goal to address these questions by creating a more engaging and personalized method to memory training in the different games. Certain objectives are required in this research, they are as follows:

- To identify and define the technical requirements for developing a VR memory training framework customized to older adults.

- To develop a user interface (UI) that is friendly and a user experience (UX) component that makes the tests immersive, ensures accessibility and is comprehensive for older adults in different VR environments.

- To add haptic feedback, visual cues and sounds in the VR games in order to enhance the experience during the memory training sessions.

- To establish metrics and methods in order to evaluate the effectiveness of the VR framework in quantitative way and test the improvements of memory functions for older adults.

- To identify and address technical barriers that could delay the process of using VR memory training for the older adults.

- To run some user tests with older adults to validate the usability, effectiveness and emotional engagement of the VR framework.

- To analyse the impact that the VR framework has on the well-being and quality of life of the older adults.

CHAPTER 2

State of the Art

2.1 Background Concepts

This section is composed of the principal concepts used in this dissertation. By examining them, the information obtained reveals how these elements are involved together to create a VR framework and how it can be used to create serious games for cognitive training.

2.1.1 Serious Games

A Serious game is designed to achieve certain educational goals instead of focussing on the entertainment part that is focussed by games in general. Training and learning objectives are defined, which makes them effective tools for skill development [10].

The main objective of these games is to be effective in cognitive training. In this case simulating real-life scenarios, makes them more interactive, personalized and immersive for the user. This engaging environment is beneficial for the user's learning experience [13].

These serious games provide various benefits that other educational methods couldn't provide. They maintain or even augment the user's motivation and interest in pursuing training. The performance of the user is also personalized which matches their cognitive skills with the challenge brought by the game [13]. And all of the feedback and experience gathered by the player is immediate, by simulating realistic environments their memory training is more effective and as they progress, their performance adjusts and improves [14].

2.1.2 Virtual Reality

Virtual Reality as a whole is a computer generated simulation that present to the user an environment where he can move around and interact with the world. The most common VR experience is immersive, where the user is fully engaged with the virtual world, but it can also be non-immersive, in this case, only a screen is being used as the form of interaction [10]. Special hardware is used for these scenarios and it can give access to multiple inputs for the user, apart from the headset that gives visual, audio and head movement input, there also exist gloves or joysticks that give the player more inputs to interact with the surroundings [15].

This environment is controlled, hence it's more efficient at grading or evaluating an user's actions, it also allows the scenarios to be more personalized towards the player. In [16] it's written that "components of perception (visual, tactile and kinesthetic) are the bases for interactivity, encouraging a sense of "being there"", meaning in this safe and interactive space the player can feel more immersive rather than being in front of a screen, which makes it a better experience for anyone but especially for older adults with mild cognitive impairment (MCI).

The adaptability of VR demonstrates the potential that it has, for example, VR simplifies complex task by providing spacial and visual cues, helping users understand their environment better, this also reduces the cognitive load compared to the real world, since the worlds are controlled by the developers. This control is also personalized to each user, which enables the developers to adjust the difficulty of the game to better fit the player. [10]

2.1.3 Unity

To create this framework, the main software used was Unity. It is a cross-platform game engine compatible with multiple platforms, including VR devices, which is the platform used for the serious games. Unity provides an Integrated Development Environment (IDE) that simplifies game development with a lot of features, for example, animation tools, an asset store with numerous assets and a physics engine [17].

Unity is very flexible, the multiple assets available allow for the creation of infinite different games. And with it's build-in VR structures, game creation for VR games is facilitated for the developers [17]. These capabilities create the ideal scenario for making an immersive memory training environments for elderly people.

Each user is different and unity gives the opportunity to customize the experiences of each user separately. The customization is endless, with every new feedback given to the game, it can adapt and diversify the trajectory of the training. The "Game of Life" is a priority to follow in this project, and with Unity's real-time rendering capabilities, it can allow the game to be personalized for any player [18].

2.1.4 User Interface

User Interface (UI) is an important part of every game, and for memory training using serious games, it is a big factor for engagement and motivation for the players. For this component to work in a positive way towards the users, interaction must be intuitive and it should be provided in a natural way. There are multiple forms of UI, such as 2D, 3D and even speech interfaces [19].

This can all be applied to memory training frameworks since the gesture recognition of VR allows the elderly person to manipulate virtual objects to complete memory tasks [20]. The controllers provided by the VR set track the hand movement and lets the user navigate through the environment using the UI as a form of bridge between the inputs and the virtual world.

Awareness in the Virtual world is very important for any game, and for this case, the elderly who are prone to less attention span need this to be reinforced. For example visual cues can guide the user throughout a memory training process, indicating correct/incorrect choices. Another example is color-coded objects which can be used to give instant feedback on their actions, helping them understand their progress and performance while in the memory training exercise [20]. Hence the design of the UI needs to focus on creating an immersive and intuitive experience.

However the familiarity of interaction techniques depends quite a lot on the UI. This takes into account that the users can easily adapt to said interface, which reduces the learning time by a big margin. The improvement of each player is different, but having a simple and clear structure for the UI makes the games more fluid and engaging [19] [20].

2.1.5 User Experience

The importance of UX in VR is at the same level for UI. In VR the overall experience the user has while interacting with the virtual world is determined by the pre-made track inside the game. This track has to have all of the necessary aspects such as immersion, presence, engagement and usability. The purpose of the programs relies deeply in the UX because it directly impacts it's effectiveness, so the results also rely on it by a big margin [21] [22].

The user's perception is what UX tries to enable, the characteristics of the game need to be enhanced, the device interactions need to be constant and engaging and all of the contextual factors given by the virtual environment highlight it's dependency on these elements [21].

The user's characteristics also need to be acknowledged, age, gender, physical and cognitive abilities and even prior experience with VR affects how the player foresees the environment they're in [21]. Elderly user, in this case, may require a more in-depth approach, in order for them to perceive the objectives given to them. Therefore the cognitive load in the different games needs to be reduced and personalized with the different players.

2.1.6 Life Story

Life Story can be defined as the narrative account of an individual's life experiences, memories and significant events, furthermore it serves as a powerful tool to understand the user's personal identity. This gives enough information to develop a personalized track that is best suited for the player's memory training sequence making it more meaningful and engaging [23].

The incorporation of multiple different elements taken from an individual's life story, allows the VR experience to evoke emotional resonance and nostalgia, which are known to further enhance memory retention and cognitive function [24]. By utilizing the life stories to personalize these experiences, for example simulating familiar places, objects or even events from the user's past, the experience as a whole would be more relatable and enjoyable, which would improve the effects of memory training.

Keeping someone's attention is always a challenge, and in the case of the elderly playing a VR game, it becomes a whole another level. This is why emotional connection and cognitive stimulation need to be addressed and set as a priority when creating and designing these games. For the program to be efficient, it needs some sort of challenge, so by combining the enhanced sense of presence and immersion in the virtual environment using the user's emotional connection and the cognitive stimulation that challenges the player step by step depending on the user's capabilities, the attention, memory and problem-solving should all improve as the challenges are completed [23] [24] [25].

To collect the life stories data, there exist several methods that gather detailed pieces of information. Interviews is one of them, the questions asked to the elderly give a lot of context and background about their life. Other important pieces are significant life events, hobbies and family related information. Questionnaires are also a method that can be structured to collect key information about the user's life story, this is particularly useful for gathering specific details about the person's daily schedule, to personalize even more the VR experience [23] [26].

2.2 Related Work

After thoroughly analysing various different works that had a relation with Serious Games, Virtual Reality, Cognitive Stimulation and as well as a bit of Life Story, there are 5 articles ([12], [27], [11], [28], [9]) that mention the importance and the value that VR serious games have and how they could be implemented.

Firstly, [27] should be mentioned since this project is a continuation of the AMELIA project. This project used a mobile game in order to train the cognitive functions of its users. This master thesis gives a detailed explanation about the development of a mobile application named AMELIA (Mobile Memory Training Interface for Older People). This app have the intent to combat cognitive decline in older adults by using different memory training exercises based on the "Life Story Work" concept.This concept involves for the user to think back about their own personal history in order to stimulate their cognitive functions. The thesis in the end concludes that AMELIA offers a promising and personalized approach to the theme of cognitive training, with a lot of potential that could be improved in the future if there is a broader application.

In the next one we have [12], it presents the VIRTRA-EL web platform, this platform was designed to evaluate and train cognitive skills of elderly people through the use of serious games. This platform main objective is to address cognitive decline all together, which includes symptoms such as memory loss, reduced problem-solving abilities and an overall difficulty maintaining focus. Cognitive stimulation through serious games has been proven to slow down intellectual decay and may potentially reverse age-related cognitive decline.

This paper highlights a 3D serious game that is played in the platform, it simulates real-life scenarios in order to train cognitive skills in a more engaging and immersive way. The game is ultimately designed to be user-friendly, requiring only a mouse or a touch input, it also avoids complex haptic to ensure it's accessibility for older adults. The game provides feedback on the user performance, allowing the therapists that are analysing the games to track the user's progress and adapt the difficulty level based on the user's cognitive abilities.

For future work, the paper states that the best way forward is to expand the platform with more and different games in order to makes more realistic tests and conduct a larger pilot study to evaluate the effectiveness and acceptance among the elderly users and therapists.

Thirdly, in the journal [11], the effectiveness of serious games is evaluated and shows how they aid at improving memory among older adults with cognitive impairment, including conditions like mild cognitive impairment (MCI), Alzheimer's disease and dementia. The study analysed 18 randomized controlled trials (RCTs) and found that serious games were more effective than no or passive interventions in improving non-verbal and working memory but not verbal memory.

In this case serious games were also more effective than conventional exercises in improving verbal memory, however they showed no difference in non-verbal or working memory at all. This was compared to conventional cognitive activities and the serious games were proven to be equally effective in improving all types of memory for older adults. In the review there was a highlight that showed that adaptive serious games were comparable to non-adaptive ones in enhancing working memory.

Key points include:

Non-verbal Memory: Serious games improved non-verbal memory compared to no intervention (SMD=0.46, p=0.02).

Working Memory: Significant improvement with serious games over no intervention (SMD=0.31, p=0.04).

Verbal Memory: No significant improvement over no intervention (p=0.13) but better than conventional exercises (SMD=0.46, p=0.003).

Adaptive vs Non-adaptive Games: No significant difference in working memory (p=0.08).

In this study it was concluded that the serious games show a promise only as a supplementary tool. They can improve memory for older adults but there's a need for a lot more evidence to show that it can benefit people with cognitive impairment. This demonstrates that it lacks robustness and cannot be considered as a real stand-alone intervetion to the public.

In hindsight there is also another study [28] which analysed 59 articles thought 2000-2019 on the utilization of the interactive technologies such as phones and tablets for cognitive stimulation. In the end the review showed the multiple technologies used and the functions they targeted for the cognitive functions and ultimately there was a gap: while there exist a lot of games that demonstrate potential, there's still a real need for more rigorous and large-scale studies to prove their effectiveness on the population and move this field from promise to a real practice in the future.

The review's main discoveries outline the current state of serious games that are aimed towards cognitive intervention. In the current landscape of things, tablets and PCs remain the most used technologies for this type of intervention due to their accessibility and overall intuitive designs for the population, while VR is gaining attraction, it's still a new and different technology that people aren't accustomed to.

In this study the cognitive functions addressed in it are those that have the most vulnerabilities against age related decline, for example memory, attentions, visual-spatial abilities and other functions. The document also regards the effectiveness in which the evidence is optimistic since various studies reported improvements in these cognitive domains, there still isn't anything conclusive. And as a result the future direction to take to have these studies attain a more conclusive result is to explore the VR technologies and use them for cognitive training, this technology has a lot of potential and is still under explored.

Lastly, in this document number [9] it is discussed about the usage of VR serious games as a tool for cognitive training for older adults. It specifically highlights how some VR-based games can provide engaging, immersive and interactive environments. The motivation aspect of these games comes from the personalization aspect of it and it's own relatability. In order for a user to engage more with a game it requires some sort of story that aligns with he user's personal story.

The document emphasizes the possibility of VR serious games to combat cognitive decline that is associated with ageing, such as mild cognitive impairment (MCI) or dementia, by promoting neuroplasticity and mental engagement. This method allows the user to be more active and adapt to difficult scenarios in the games, requiring the user to make an effort and train the brain.

It is also noted that the document refers to the benefits or VR comparing them to the traditional cognitive training methods, just like using tablets or computers to play serious games. The benefits of VR are portrayed in the document are "improved user retention", "real time feedback" and "The ability to simulate real scenarios", of which tablets and computer can't match.

At the end of the document it is stated that VR serious games and cognitive training are linked together since they have the capacity to add amusement and small health benefits. The designated objective in this document is to develop more and more these components to create frameworks that are frequently used by older adults due to their enjoyment for the practice. This all together could enhance the quality of life of the users by exercising their cognitive abilities and delaying cognitive decline.

CHAPTER 3

Development Process

3.1 Unity Framework Overview

As states previously, Unity was used as the main software to create these games. To be more precise, Unity 6 was the version that was preferred since it had better add-ons for VR. Unity is a technology to create all types of games that has an advanced amount of XR components such as: XR Interaction Toolkit for the controllers interactions with the virtual world and for example the XR plugin management which makes the connection for the different plugins used in the games to the VR headset. As seen in figure 1, this projects uses a couple of assets in order to make it clean, interactive and logical.

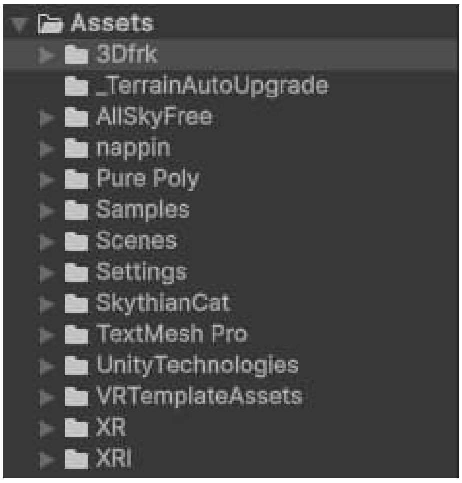

FIGURE 1. Unity Assets

Furthermore, Unity's C# scripts allowed this project to implement different game logic to make the games process the VR components and enable an engaging experience through game-like environment.

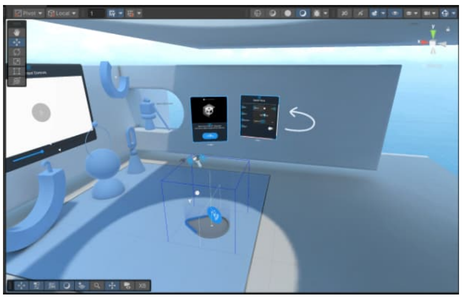

FIGURE 2. Unity Assets Tutorial

The main inspiration was taken from the VR tutorial scene, as shown in Figure 2, which had plenty of components already tuned for the user to experience a VR scene.The components can be seen in figure 4, the main one was the "Complete XR Origin Set Up Hands Variant", which was edited multiple times to better suit the elderly people. This asset comes with a "Camera Offset" which controls everything related to the visual objects connected to the user, so for example the controllers and the virtual hands. There's also "Locomotion" which allows the user, using the controllers and not the hands, the possibility of turning, moving, grabbing, teleporting, climbing and jumping. But for the sake of the simplicity of the exercises, the only gestures used and taught to the users were the "click" button for interacting with the world around them. All the other gestures were disabled. However the users could still use their physical body and the Oculus Quest 2 to look around and move freely as they pleased as long as they stayed in the designated area of the room. The Oculus Quest 2 was composed of one main headset and two controllers that allowed the user to move around and see the 3D virtual world around them.

FIGURE 3. Oculus Quest 2

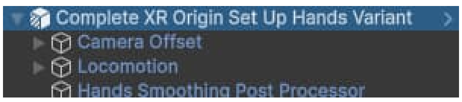

FIGURE 4. Complete XR Origin Set Up Hands Variant

This is a variant, since the "normal" setup had some issues with detecting the hands and the controllers at different times. This one used both input but once it didn't detect one of the inputs for a couple of seconds it would be removed from the screen and the user would be able to use the desired input freely without having to see the other input. As seen in Figure 5, the hands and controllers where at the same location, so the user could use both but only one or the other at a time.

There's also the URP for lighting, the principle behind this is that games with no design and care for the user make the whole experience bothersome and tedious. These games not only had to have a good design to engage the user into participating, they had to really make it a good experience in order for the user to enjoy these games. What's so important about having fun while doing something new is that that person has a different

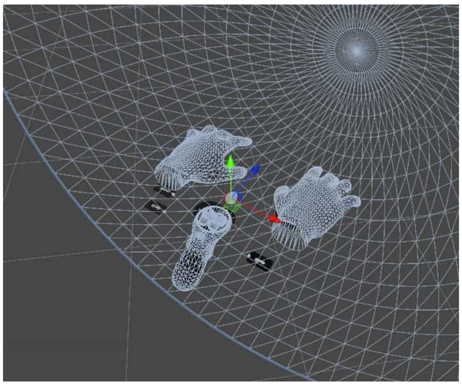

Figure 5. Complete XR Origin Set Up Hands Variant (Unity World)

outlook and is motivated and encouraged to do a new activity and makes it so they exercise themselves.

So during the game design, there was a 1 month process to build a house where the user would be placed and where the games would be played, set assets were used and a lighting process was made as well, to make it feel like it was a real house with real sunlight, to make it feel more immersive.

Furthermore along with the listed assets, there are also package dependencies for each asset. The most important to be listed are the XR related ones since they provided all of the necessary scripts to make this project possible.

For the development of the VR cognitive training system, the Design Science Research (DSR) methodology was followed [29], by employing three iterative cycles of development, demonstration and evaluation. This approach made sure that continuous refinement of the system based on the supervisor's feedback was applied before proceeding to the final pilot study with the elderly participants.

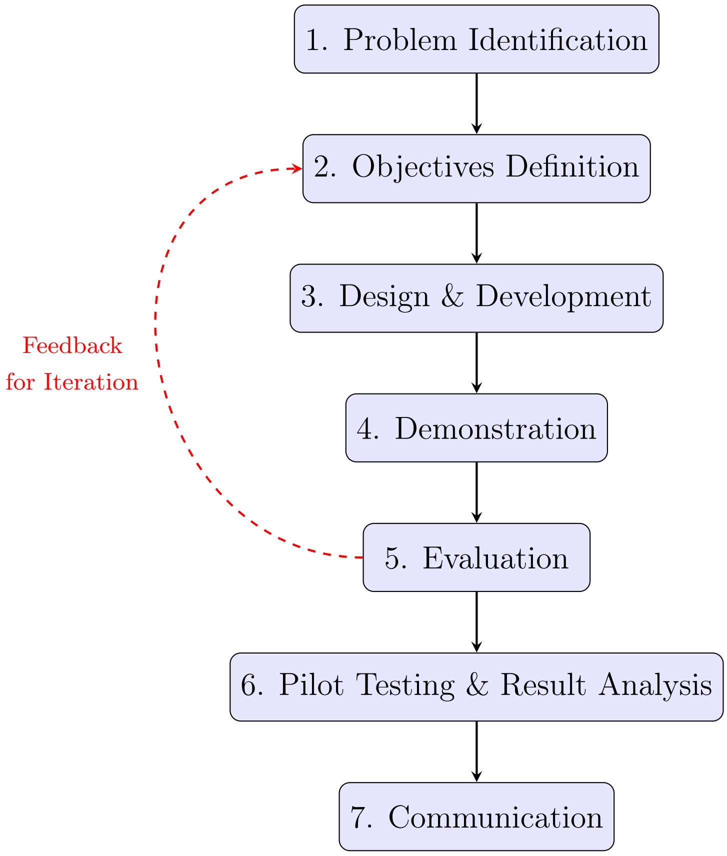

FIGURE 6. The iterative Design Science Research (DSR)

3.2 DSR Cycle 1: Core VR Functionality and Initial Game Concepts

3.2.1 Development Phase

Within the Unity engine, there are several mechanisms, one of which is the VR functionality which is fundamental to establish the development phase of this first part of the DSR. The VR hardware was configured for the user, focused on it's interaction, serving as the foundation for subsequent serious games. This involved:

- Setting up the tracking process for the XR Origin rig for head and controllers, this process came with the assets that were imported at the beginning of the unity project, each of these models let the program know that the Oculus Quest 2 was being used and therefore for the players to be able to navigate through the 3D ambient (Figures 4, 5).

- Implementing basic locomotion mechanisms using the controllers and the spacial location of the headset

- Designing simple low-poly environments to maximize user comfort and minimize the potential simulator sickness, this involved creating 3D scenarios that consisted of a small quantity of polygons in each asset.

- Developing scripts to create a fluid VR framework that has personalization and customizable options

Three initial game ideas were prototyped during this cycle:

Game Concept 1: Numeral Memory Challenge

In the first design, which was inspired by the games in the human benchmark website, all players were facing a canvas in which it would be briefly displayed a sequence of numbers, the users had to remember the numbers and then write them on the screen after they had disappeared. After each correct number the digit count would increase by one until the user reaches and beats level 10, at that point the game ends and the results screen would appear, showing that user their results.

After an amount of test were done, it was acknowledged that even for an young adults the writing on the virtual screen wasn't very practical, writing in VR is very slow and tedious, so for the older adults it would be tiring and would make the experience not enjoyable. This was then discarded and switched out to a selection of options: the user could select a button and choose the answer he though was correct out of other 3 options.

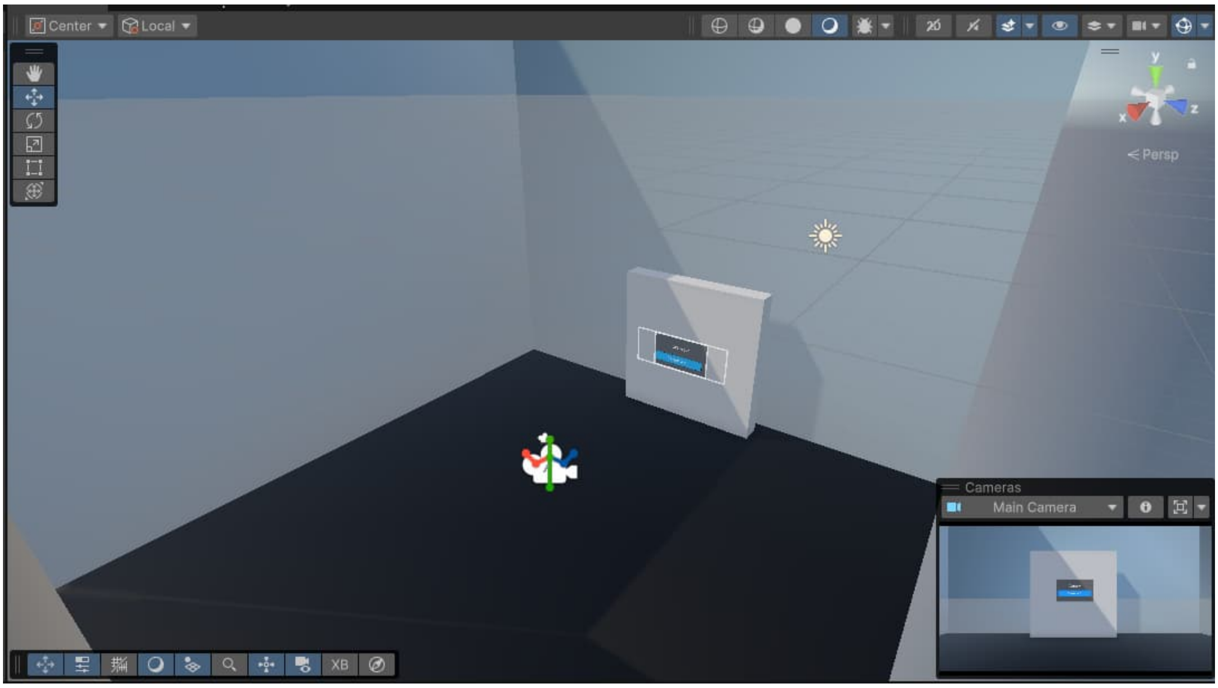

FIGURE 7. Numeral Memory Challenge Prototype

In this figure 7 the main concept was that the user would be spawned in the middle of the room and faced with the board in front of them. They would have their controller in hand

and point and click at the button on the display. The game would begin and would show a sequence of numbers for a brief moment and then show 3 possible answers as buttons, showing different numbers. If the player clicked on the correct answer, they would move on to the next level and if they choose incorrectly, they would restart the level with a different number.

Game Concept 2: Spatial Memory Assessment Players could choose between two distinct rooms to memorize object quantities, colors and specific locations. In this first prototype, the rooms were very simple, a square shaped room, four walls, certain items such as table, chairs, windows, plants. This exercise targeted multiple memory aspects including visual recall, spatial awareness and object-position association.

For the first concept of this game, the rooms were still being designed and the logic of the game was still being implemented. However the game worked around an enclosed space where the player would select the room they wanted to play the game and then they would be teleported to that room.

FIGURE 8. Spatial Memory Assessment

In this figure 8 it's shown the main game room, where the player can choose which game to play, but for the sake of this example, the main room and the Spatial Memory Assessment game room are very identical, instead of having "Jogos" it was "Rooms". In this game the user can select one of four rooms (games) to play. The concept idea was that the player would teleport to a room with the same walls and floor and lighting as this one, but with some objects in it, that the player had to memorize. Once they were done, they could click on a button that would be on a similar wall as in Figure 8 and so the user would be teleported out of the room and would have to answer some questions about the contents of the room. Then once the player responded to all questions and got a results, the player would be teleported back to the main room like in Figure 8.

Game Concept 3: Visual Memory Matching

For this concept, a traditional card-matching game was the inspiration, it included a four by four grid of cards with unique images and the intent to train visual memory and short term recall. The user had to get all of the two pair combinations, so eight in this case. The user had to select two different cards at a time to get a match and to then complete the game when the eight pairs were found.

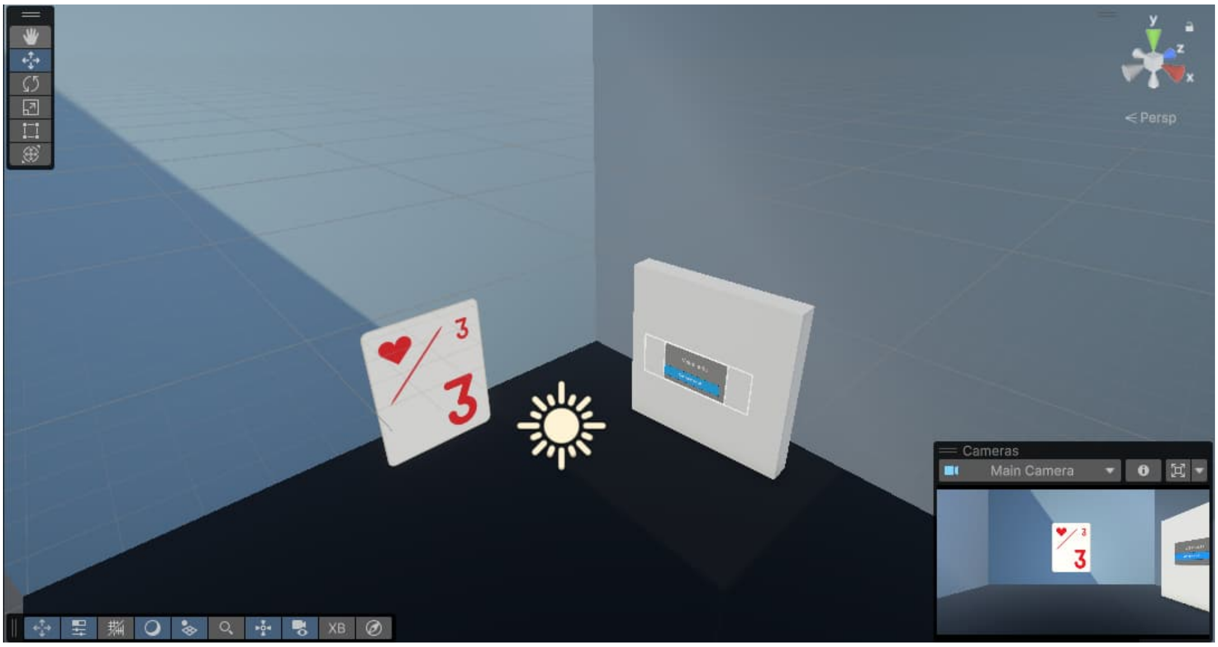

FIGURE 9. Visual Memory Matching

For this game, initially the user would find themselves in the same room and click on the start button, as seen in figure 9. The game would begin and a countdown would start. The user would have 3 minutes to get all the matching cards correctly and then the game would end, and the player would be teleported back to the starting main room depicted in Figure 8.

3.2.2 Demonstration and Evaluation

The first prototype was shown to project supervisors, who offered feedback on essential features and user experience.

The fundamental VR interactions were positively received, however there were some concerns that arose about the complexity of the numerical memory challenge and it's usability in this project. In particular, for older adults the timing of the numbers appearance and disappearance was too brief for the average level of the older adults. This demonstration made it so the specific recommendations for the interaction of the older adults were changed and the interactions were made easier for all users, the time was lengthened and the results were more detailed. Other changes were made such as the visual highlights in the buttons, some audio feedback for the buttons and a jump effect when teleporting to another room.

The feedback also suggested to change the third game, since it wouldn't benefit the user as much. There's not much change between a 3D world and a 2D world when it comes to that type of memory game. Instead a game suggestion was given, to make a game that contained the memorization of words or sentences.

3.3 DSR Cycle 2: Game Refinement and Accessibility Enhancements

3.3.1 Development Phase

Based on the review of the first cycle, there was a refinement of each game to further improve and achieve the main goal of accessibility and user-friendly design in the final Unity game. This cycle had these changes:

Game 1: Number Memorization

The changes in this adaptive digit span game where focussed in the difficulty mechanic and level progress of the game. The last level was changed from 10 to 12. There was also a change to the whole game itself. Before, the game ended as the last level was beat, now, this new version gives the player five minutes to do as many levels as possible and get the most correct answers possible. For each correct answer the number sequences increase in length by one up to a maximum of 12 digits at level 12. Each incorrect answer decreases difficulty by one level. At the end of the 5 minutes the player is shown their results and can choose to restart or exit the game to the main room.

```
          void Start(){}

    void InitializeGame(){}

    void StartGame(){}

  void GenerateNumber(){}

    void GenerateOptions()

    void Update(){}

    void EndGame(){}

    void TeleportToStart()
```

These functions served as the core of the game. To start, the Start function removed all previous listeners and created new ones and then, this is to avoid duplicate listeners, it connected the game interface with the database.

The InitializeGame() and StartGame() served to reset the data in the game to the default data and to start generating the numbers on the display.

GenerateRandomNumber() and GenerateOptions() created the numbers on the canva such as the main number and the numbers in the options. GenerateOptions() used the following helper functions for the options:

```
        // Helper methods
    string GenerateRandomNumber(int digits){}

    string GenerateSimilarNumber(string baseNumber){}

    string AlterOneDigit(string number){}

    string ReverseNumber(string number){}
```

The number generation is simple, by using GenerateRandomNumber(), the code gets from the canva what level the user is on and randomly gives out a number from 0 to 9. For the number of the level, is how many digits the function is going to give out. The other functions only change up the options displayed in the buttons as seen in figure 10. They alter one digit or reverse the entire number or only change one digit, this makes the game slightly more difficult since the number with only one altered digit is quite difficult to distinct from the real number.

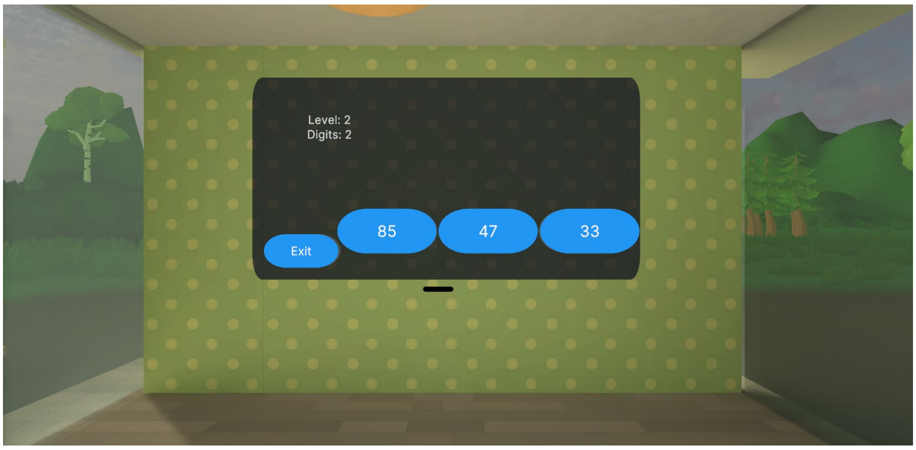

FIGURE 10. Number Memorization

During the game there's always the need to update the data such as the numbers and the time, for that Unity has the default Update() function.

After that, when the user chooses an answer these functions are called:

```
    IEnumerator ShowQuickFeedback(bool isCorrect){}}

    void CheckAnswer(string answer){}

    void UpdateScoreDisplay(){}
```

Each of these functions serves a purpose to check and give a visual response to the user, for them to know if they've answered correctly or not.

After all this, the game ends with EndGame(), which stores all the data into a separate storage dedicated to the player and the player is teleported back and the game is reset with TeleportToStart().

Game 2: Object Recall

Players are placed in a virtual room, once they're teleported to the room, they are facing a screen with a timer display, this exercise gives the player three minutes to memorize all of the objects in the room, including their quantity, color and location. Once the timer end, the player is teleported back to the same position he was before when he was first teleported into the room and has to answer multiple-choice questions about the room's content. At the end, the results are shown and the player has the possibility to return to the main room. The main idea is to use these objects and colors as personalization factors for the users, collecting data on the users life and input it into the game so there's a feeling of relatability when entering one of these rooms.

FIGURE 11. First Room

```
    void Start(){}

    void Update(){}

```

```
    public void StartGame(){}

    private void InitializeWeights(){}

    private void SelectRandomRoom()
```

Just like in the previous game, this game also has some initialization functions to enable all starting data and assets in the room. In this game the user starts in the main room as seen in figure 11, they choose the game and then the script is ran. The Start() function enables the main canvas in the room, it gives the option for the user to start the game or exit after he is teleported in. It also sets the position for the canva dialogue. Then the Update() function updates the time while the player is in the room.

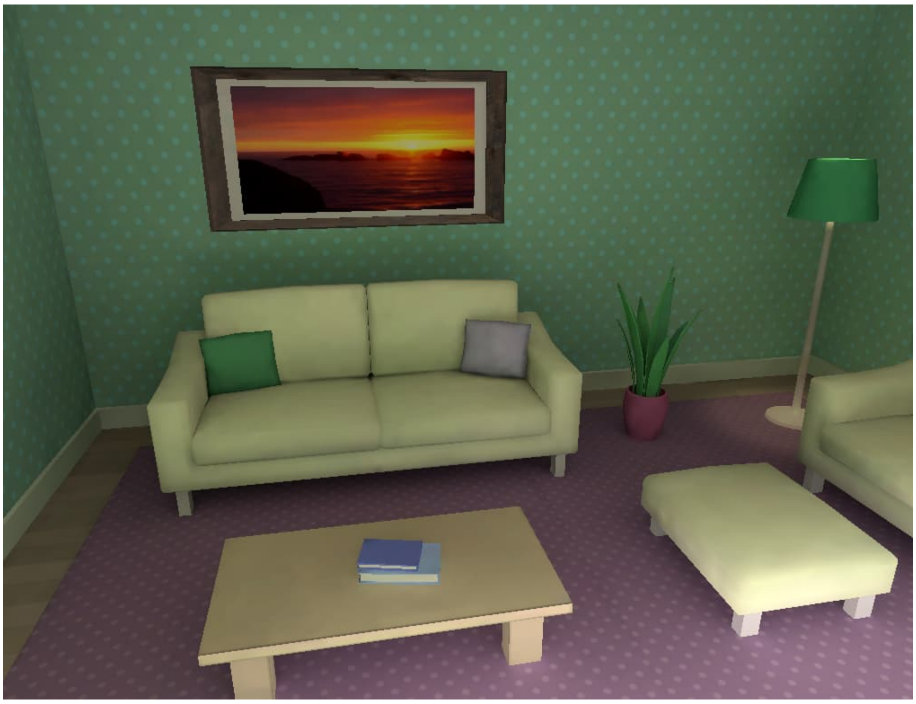

FIGURE 12. Room Details

The main start function StartGame(), calls of all the necessary functions to initialize the weights with the InitializeWeights function that dictates which room the user is going to according to a random percentage. Once the user is in a set room, the percentage for set room is lowered and it's increased for the other rooms, in order for the other three rooms to be selected for the next time the user tries this challenge, this way the user won't get the same room twice in a row.

```
    private List<Question> GetQuestionsForRoom(string roomName)

     private IEnumerator ObservationTimer()

```

```
      private void EndObservationPeriod()

      private void ShowNextQuestion()

    public void OnAnswerSelected(int answerIndex)
```

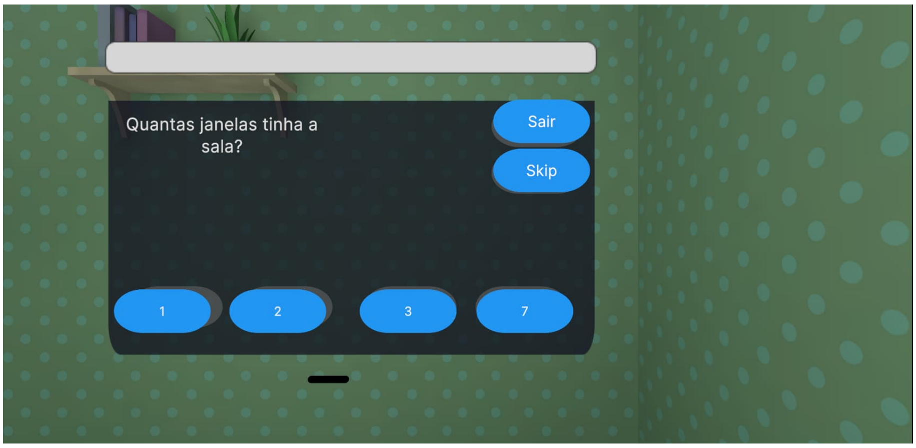

FIGURE 13. Object Recall

In this part the game has started and the canva gets the questions using the function GetQuestionsForRoom(), these questions are relative to the room and ask about the contents inside said room, such as the location, color, amount of some objects in the room. The user has to answer the questions until they've responded to all questions. These functions follow each other and then collect the data for the answered questions.

The data collected is then processed with EndGame(), which call all the functions to make an analysis on the game that was just played. The accuracy is instantly calculated, by getting the amount of accurate answers during the game divided by the amount of questions and then parsed into GetScoreMessage() and CalculatePerformanceRating(), which transfer the data into the database but also give a responsive feedback to the player once the game ends. Telling them what their score was and encouraging them for their score.

```
        private void EndGame()

    private string GetScoreMessage(float accuracy, string rating)

    private string CalculatePerformanceRating(float accuracy)

    public void ReturnToMenu()

    private void ResetGameState()

```

```
    private void ShowStartScreen()
```

The game ends, then the assets and functions and Coroutines that are functions that play all the time while the game is running, are all reset and finally the player is teleported back to the main room.

Game 3: Sentence Memorization

The new sentence memorization game starts by giving the player sentences briefly in a display screen. After that it is shown a yes/no question about a specific word presence. This game progresses through 12 levels of increasing complexity, each time the sentences get longer and its harder to memorize words. This game doesn't have regression for incorrect answers, so the objective is to answer correctly as many questions as possible out of the 12 levels. Once the game ends, the player is shown the results and they can choose to restart or leave to the main room.

```
        void Start()

        void Update()

        void ConfigurarBotoes()

         void MostrarTelaInicial()

         void IniciarJogo()
```

This game also starts with the two generic Unity functions Start() and Update() and in this case the start function calls for ConfigurarBotoes(), MostrarTelaInicial() and IniciarJogo(), which enable the canvas screen to see the display for the game and also enable the buttons for the game itself. IniciarJogo() firstly connects to the database and then begins the game by starting a coroutine using the GerarFrase() and ExibirFrase() functions.

```
        bool GerarFrase()

        IEnumerator ExibirFrase()

        void MostrarPergunta()

        void VerificarResposta(bool respostaJogador)

           void FeedbackFlash()
```

For said coroutine, GerarFrase() chooses a designated sentence by checking if that sentence hasn't been used before and if the game is on hard mode or not. Hard mode, is simply a mode with the same sentences but with more words. So in normal mode the sentences start of with 3-5 words, in hard mode it's similar sentences but with 7-10 words, it has longer words and more complex sentences formatting.

After each question, MostrarPergunta() is called and shows the corresponding question for the sentence shown on the screen previously. This question is something of the sort of: "The sentence contained the word "word"?". The user chooses a button, "yes" or "no" and then VerificarResposta() is called to verify if the answer is correct or not. FeedbackFlash() is called to show if the answer is correct or not, in a more visual way for the user.

FIGURE 14. Sentence Memorization Game Sentence

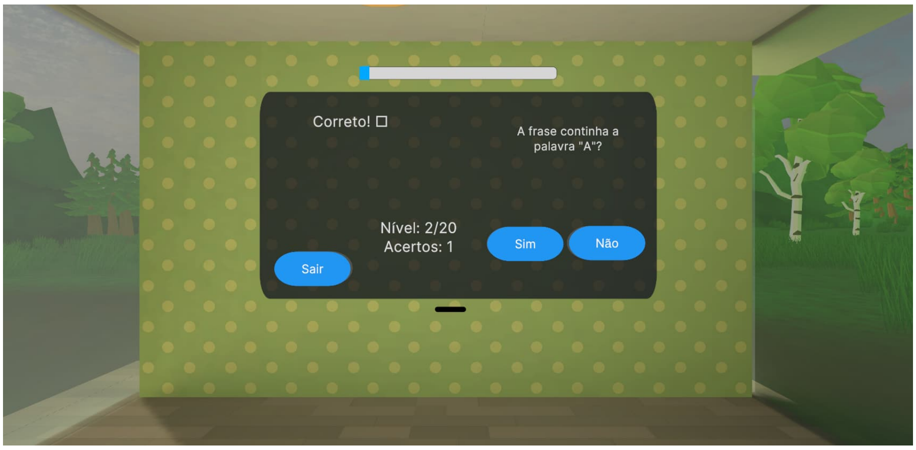

FIGURE 15. Sentence Memorization

```

void GameCompleted()

string CalculateWordRating(float accuracy)

void SairDoJogo()

```

```
        void ResetGame()
```

Once all 10 questions are answered the game shows the end screen with the results provided by GameCompleted() which gives the accuracy of the player and CalculateWordRating() which gives the final rating.

The user then has the option to leave or retry the game. Once the user leaves, they're teleported back to the main room.

For this cycle the accessibility enhancements included:

- A simplified interaction mechanisms (single button press) for most of the display canvas UI.
- Enlarged UI elements and text for better visibility
- Clear visual and audio feedback systems
- Automated data collection implementation (base version), it followed simple data management and stored the user data and the times and exercises that were played in one instance.

Room Designs and Lighting

Room designs and lighting were two components that required a lot of time and work put into them. In order to make the design appealing and engaging for the user, the scenario they would be in had to be somewhat pleasant. Both of these components where made at the same time, being first a test room, that was made using assets from the asset store for a starter room. The simple design was changed with the supervisors, but the room took area shape that wouldn't be nor too big nor too small for the user, therefore they wouldn't feel nor claustrophobic nor lost since they would be in a large area.

FIGURE 16. Lights and Room Design

FIGURE 17. Corner Light and Room Assets

The available assets the pack provided were good and enabled this project into having a room such as in 16. This room was mainly composed of a couch, a sofa, some plants, lamps and paintings (with some small assets in the mix). The walls, floor and sealing also came with the pack, the materials offered a vast canvas of creativity. This was taken into consideration mainly for the Object Recall game, where the rooms had to have some differences in between them so the users had some difficulty from room to room as seen in Figure 20.

FIGURE 18. Sun Light and Room Layout

FIGURE 19. Main Light (Sun Light)

The lighting served a lot of purpose for these games, from the exterior to the interior, the light inside and outside made the environment come to life and give the user a sense of ease while playing. If there was no lighting it would be a daunting dark room, which would make the users not really interested in playing the game. Every lamp has a light source and every display canvas also has one, in order to highlight what the user has to do when being teleported. All of this can be seen in 21.

FIGURE 20. Map Layout

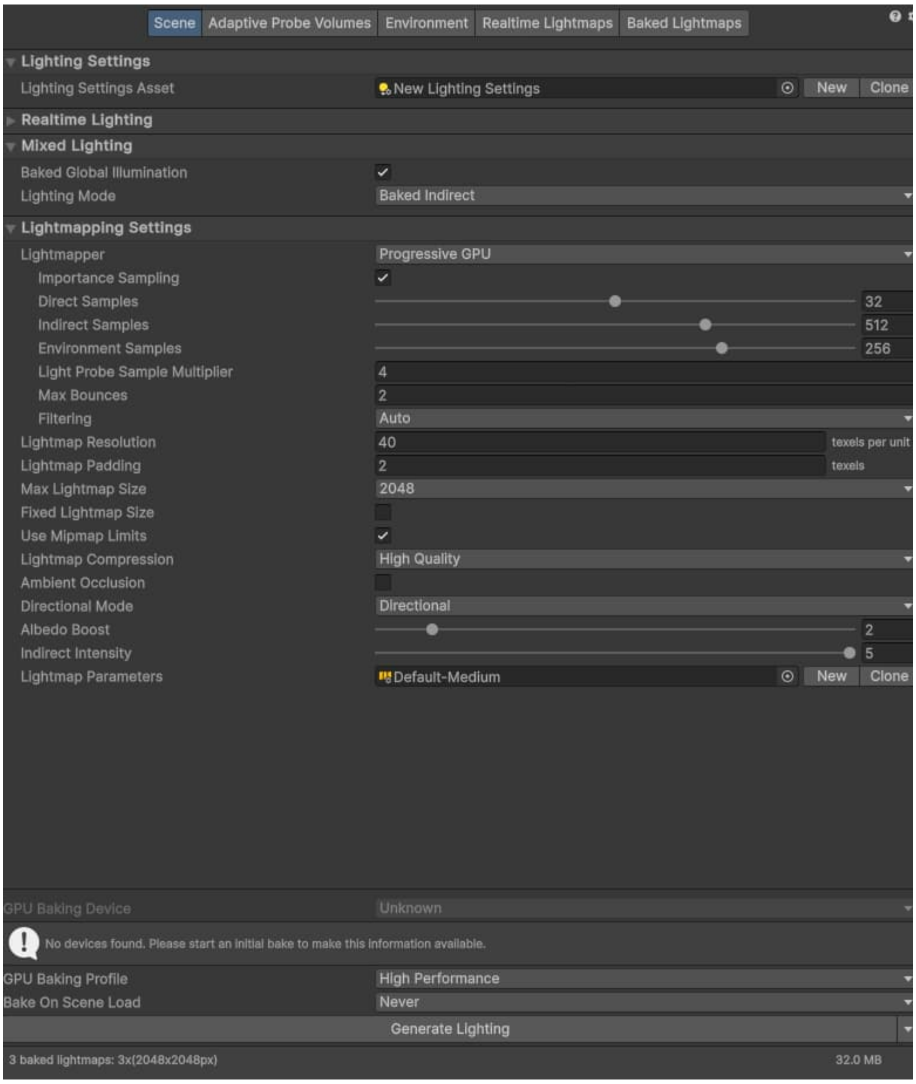

FIGURE 21. Light Settings

3.3.2 Demonstration and Evaluation

The final enhanced system was demonstrated to project supervisors, who noted significant improvements in accessibility and functionality. However, key feedback emphasized certain points:

- Game content was too generic and lacked personal relevance, this project needed the personalized content and the main suggestion was to apply the user's life stories, collected in a quiz used before the pilot tests

- Additional optimizations required for enhanced immersion, for example the various "outside" assets to make the world not feel empty but infinite.

- Importance of analysing time-on-task and user flow metrics for the data, in the end accuracy and other factors matter quite a lot to create the final analysis of these testing periods.

3.4 DSR Cycle 3: Personalization and Pilot Preparation

3.4.1 Development Phase

The final development cycle focused on implementing personalization features and polishing the user experience, in order to prepare for the pilot testing:

Personalization System Implementation

- Developed a centralized Personalization Component in every single game class. Every game had its own details from the users life story, such as words in sentences or numbers or colors or objects.

- Making a template-based content injection system to make every game interaction with a certain user unique for them.

- Implemented life story integration for the experimental group, in which parts of the questionnaire that was asked before the practical exercises, were used in order to make these experiences personalized.

- The games were still maintained, as in they were in equal difficulty level for all players and none of them had an advantage over anyone. The element that changed the most where the personalized contents as seen in Figure 22.

```
private List<string> frases = new List<string>()
{

    // User 1 sentences

    // Short sentences (3-5 words)
    "A matemática é muito difícil",
    "As festas de Natal são animadas",
    "Viajar para o México é um sonho",

    // Medium sentences (5-7 words)
    "A praia é um ótimo lugar para relaxar",
    "A culinária italiana é muito apreciada",
    "Muitas pessoas adoram a cidade de Veneza",
    "Alguns acham a psiquiatria uma carreira desafiadora",

    // Long sentences (7+ words)
    "A música clássica pode ser relaxante e inspiradora",
    "A literatura é uma janela para outras culturas",
    "Algumas pessoas sonham viajar para a Índia e experimentar comidas exóticas",
};
```

FIGURE 22. User's Custom Sentences

User Experience Enhancements

- Finalized visual and auditory experience with adjusted lighting and ambiance, for these elements, countless feedback from the supervisors was taken into consideration since the whole design of the Unity scene was highly relevant in order for the users to perform well. The colors, lighting, room design, space metrics and movement, where all elements that had to be well coded and implements in order to make the best experience for the older adults as seen in Figure 23.

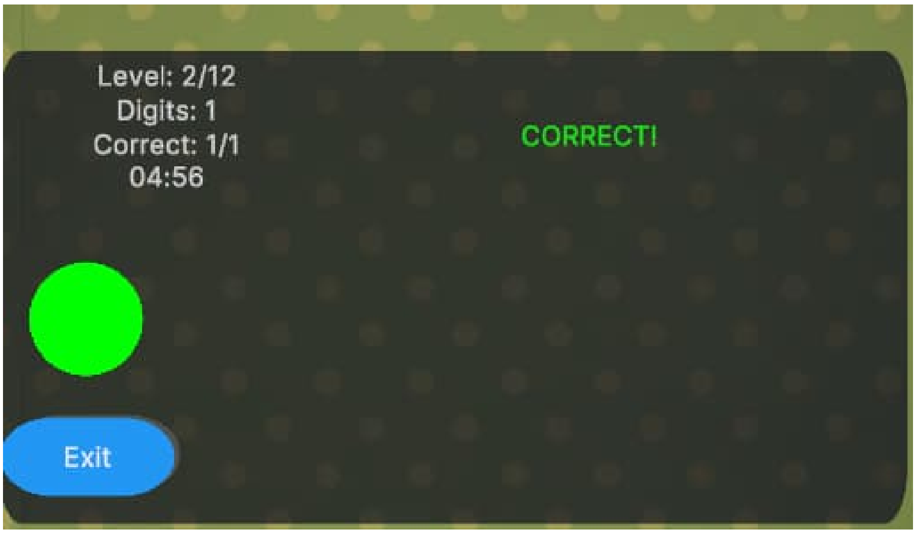

FIGURE 23. Correct Answer

These were the main changes:

- Implemented audio feedback for button presses increases the user's attention towards the correct and incorrect answers.

- Added color-coded responses for correct/incorrect answers.

- Incorporated clear time-remaining indicators for the user to establish a in real time plan to memory one last time the assets in the different rooms.

- Established cohesive color scheme throughout the scene and rooms for better integration in the games.

3.4.2 Database

To support this project a simple local database was implemented to aid the management of the data received during the sessions for data collection. It acted as the main hub for all user data from the beginning to the end and gave meaning to the data analysis ahead. The structure is as seen in figure 24 is drawn out to two main types of information:

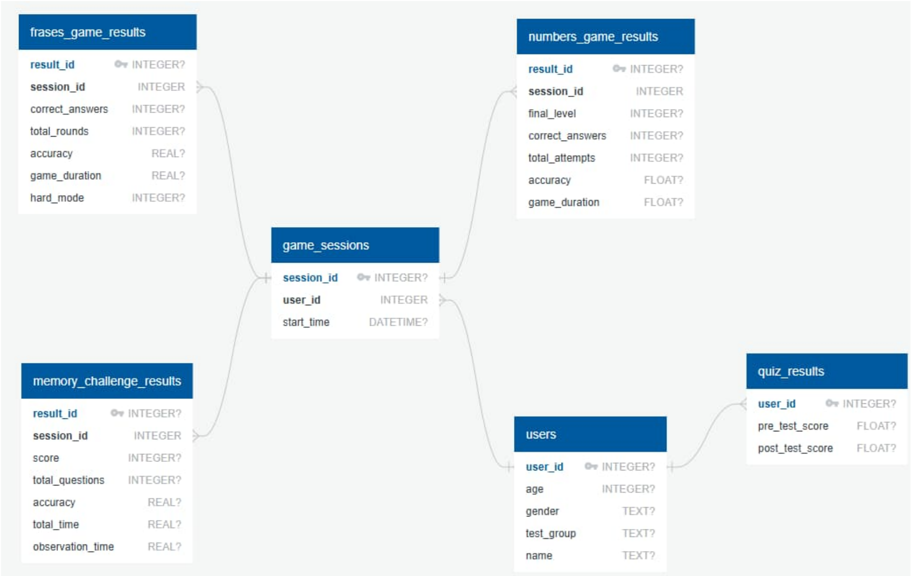

FIGURE 24. Database Schema

- **User Profiles and Session Data:** This had the participants ids, group designation such as Active or Control and the results for of the multiple training session, with the data such as completion times and accuracy.

- **Personalized Content Library:** This stored the pool of autobiographical information acquired during the Life Story quiz in 6. It was used to generate the custom environments for participants in the Active group. It was also used for the information in the games where some of the characteristics given in the quizzes would make their selves into the sentences and create a relatability factor when playing that game with the user's story.

The architecture of this database, shown in Figure 24, ensured the data integrity of information by the Unity application, which was very important and facilitated the sessions since the data was automatically imputed into the tables when the games ended for both the real-time operation of the VR experience and the subsequent research analysis.

3.4.3 Demonstration and Evaluation

For the final system it was shown to be prepared for user testing, the feedback collected in this demonstration phased insisted in making small modifications in order to get ready for the pilot testing. It was especially mentioned that the optimization of session length for the older participants and the definition of a clear user tutorial on how to use the VR headset during the sessions in order to make the sessions more pleasing and less complicated. After these refinements the framework was said to be complete by the supervisors and the start of the preparation began which is described in the next sections.

CHAPTER 4

Results and Discussion

This chapter is a comprehensive summary of the conducted analysis of the results obtained during and after the pilot study. The framework was tested in quantitative and qualitative ways to assess it's efficacy. This is shown by the tests used before and after the sessions. For this course of events, the participants were all older adults in the range of 65-83 years old, 4 male and 6 female, who accepted an invitation to partake in this experiment. Many findings are discussed in order to evaluate the framework's usability and also it's impact that uses the personalization factor, while also acknowledging the study's limitations.

4.1 Testing Methodology

This pilot study was designed with the aid of the supervisors to fully evaluate the framework's impact on the 10 participants of this experiment. It was done by using a mixed-methods approach to thoroughly answer the main research questions.

In order to do this task the volunteers where distributed into 2 groups:

4.1.1 Participants

This study involved a cohort of 10 older participants, an active group and a control group:

- **Active Group (N=5):** The participants of this group engaged with the full VR memory training protocol. They partook in 5 sessions each and during one week they played each game once. These games included personalization based on their life stories. For each game there were small details taken from the life story quiz that were put in forms of sentences, numbers or objects/colors.

- **Control Group (N=5):** The participants underwent the cognitive assessments but did not participate in the personalized VR training, serving as a baseline for comparison, partaking in their normal activities and giving their own perception at the end in vocal way in order to understand the cognitive load of their daily life.

For each participants, they had to take a test before and after the experimental sessions. These were crucial to understand the functionality of the framework and the difference it made between the groups.

For the purpose of this study, the structure was separated into three distinct phases:

(1) **Initial Assessment (Pre-Test):** For all participants a starting session over a video call was done in order to explain the details of the sessions and to conduct the pre-test cognitive assessment such as in 4 to establish their initial cognitive

performance levels. This test gave an abundance of information in regard of personal orientation, attention, memory and executive function. All of this data was then processed and inputted into the data base for further analysis.

Table 1. Scoring Scheme - Pre-Session Cognitive Test (Version A)

Cognitive Domain	**Points**	**Item Description**
1. Orientation	5 points	• Current year (1pt) • Current month (1pt) • Day of the week (1pt) • Complete date (1pt) • Current location (1pt) • Memory self-assessment (0pt - qualitative)
2. Memory	3 points	• Memorize 3 words: "Rooster", "Water", "Ball" • Recall after 5 min (3pts - 1pt per word) ***Problematic item**
3. Attention and Calculation	2 points	• Count 1-20 and 20-1 without errors (2pts) • OR Subtract 5 from 50 down to 10 (2pts - 1 error = 1pt, >1 error = 0pt)
4. Language	3 points	• Name key and pen (2pts - 1pt each) • Repeat sentence (1pt - no errors) • Verbal fluency: ≥8 fruits/1min (0pt - qualitative) ***Problematic item**
5. Visuospatial Skills	2 points	• Draw clock at 3 o'clock (1pt - correct numbers and hands) • Copy cube (1pt - connected lines and proportions)
6. Executive Function	3 points	• Fire solution (2pts - appropriate response) • Airplane-car abstraction (1pt - transportation concept)
7. Judgment and Insight	2 points	• Medical exams (1pt - adequate response) • Getting lost in mall (1pt - logical solution)
TOTAL	**20 points**	

(2) **Life Story Integration & Training:** A detailed life story quiz was also given for the members of the active group. In this quiz there were several questions that gave relevant information on the user's life story to use in the framework's games. The questionnaire as shown in Appendix F was the same for the 5 older adults and each one responded honestly and gave different answers which were not only helpful for the sessions ahead in terms of how to make the sessions enjoyable and effective but also they gave new ideas to add to the games, for example custom objects and the formatting of the sentences that could be used.

(3) **Final Assessment (Post-Test):** After all the sessions are done and the time of 1 full week elapsed, all of the participants where given a follow-up cognitive assessment 5, to measure the possible changes in their cognitive performance. This test was very similar to the first one, but all the questions where different and posed a slightly different challenge.

Table 2. Scoring Scheme - Post-Session Cognitive Test (Version B)

Cognitive Domain	**Points**	**Item Description**
1. Orientation	5 points	• Season of the year (1pt) • Previous month (1pt) • Previous day of the week (1pt) • Current president (1pt) • Country (1pt)
2. Memory	3 points	• Memorize: "flower, fork, window" • Recall after 5 min (3pts - 1pt per word) ***Problematic item**
3. Attention and Calculation	2 points	• Series: 3+8=11, 11+4=15, 15+6=21 (2pts) • OR Subtract 3 from 30 down to 9 (2pts)
4. Language	3 points	• Name glasses and coin (2pts - 1pt each) • Repeat sentence (1pt) • Fluency: ≥8 animals/1min (0pt) ***Problematic item**
5. Visuospatial Skills	2 points	• Draw house with 2 windows + door (1pt) • Copy triangle in circle (1pt)
6. Executive Function	3 points	• Solution for forgetting appointment (2pts) • Book-movie abstraction (1pt)
7. Judgment and Insight	2 points	• Sharing medications (1pt) • Witnessing street accident (1pt)
TOTAL	**20 points**	

4.2 Quantitative Results

4.2.1 Pre-/Post-Test Cognitive Scores

An analysis to compare the pre and post test scores was made after the end of the sessions and at the beginning of the analysis phase. For this phase the results are displayed at 1 and 4.1.1. But the main results are shown in 4.2.1, in these result we can positively see the difference in the test results from the two groups.

Table 3. Comparative Analysis of Pre and Post-Test Cognitive Results

User ID	**Pre-Test**	**Post-Test**	**Difference**	**Group**
1	19.0	20.0	+1.0	Life Story
2	20.0	18.0	-2.0	Control
3	20.0	20.0	0.0	Life Story
4	18.0	16.0	-2.0	Control
5	20.0	20.0	0.0	Control
6	15.0	16.0	+1.0	Control
7	20.0	20.0	0.0	Control
8	20.0	20.0	0.0	Life Story
9	19.0	20.0	+1.0	Life Story
10	19.0	20.0	+1.0	Life Story
Life Story Group (N=5)			**+0.4**	
Control Group (N=5)			**-0.4**	
Net Group Difference			**+0.8**	

Table 4. Items with Highest Difficulty in Cognitive Tests

Pre-Test (Version A)	**Post-Test (Version B)**	**Observations**
Memory: 3 words	Memory: "flower, fork, window"	**Common problem**: Recall after 5 minutes
Fluency: Fruits ($\geq$8/1min)	Fluency: Animals ($\geq$8/1min)	**Common problem**: Limited verbal fluency
Calculation: Subtract 5 from 50	Calculation: Addition series	Difficulty with mental calculations
Temporal orientation	Temporal orientation	Confusion with dates and temporal sequences
Abstraction: conceptual relations	Abstraction: conceptual relations	Difficulty with abstract thinking

- The **Active Group (Life Story)** demonstrated a slight average **improvement** of +0.4 points in their post-test scores.

- In comparison, the **Control Group** showed a slight average **decline** of -0.4 points.

The net group difference was +0.8 points, this suggests that the personalized VR training could have helped stabilize or slightly improve cognitive scores, whereas the control group exhibited a sort of mild natural decline over the period of this study, we can see this in 4 where the users struggled the most with remembering sequences of fruits or animals where they had to come up with names on the spot. For the hypothesis that personalized and also engaging cognitive stimulation can have a protective effect.

4.2.2 Game-Specific Performance Metrics

Each game script, as seen before, was provided with a function to conduct automated data collection via the integrated SQLite database. This provided detailed understanding on how all of the users performed within each specific game throughout the sessions.

- **Game 1 (Object Recall):** During this first game, the participants had to assess their visual and spatial memory. They achieved a success rate of approximately **78.2%** as seen in table9 in recalling correctly all of the characteristics of the items in the room, so object quantities, colors and locations. The data and the feedback after playing the game, showed that the users had a bit of a struggle and that this game presented a significant challenge. The feedback stated that memorizing everything in the time given got easier as the sessions went on and that this experience worked effectively targeting memory and recall. We can see this for example in table 9, where the users during the last days of this experience got better results than in the beginning.

- **Game 2 (Number Memorization):** In this second game, the users could choose to play sitting down or standing up. A lot of users chose to sit down since the VR headset was quite heavy and also this exercise require working with your memory and digit span, so sitting down was more beneficial in order for the older adults to concentrate. During this five minute game, user often got to maximum level possible as seen in table 8, but this level meaning the user had to remember 12 digits, also meant that it required the player to be really attentive. The results show us that the participants often achieved a positive result, answering on average 16 questions out of 20 correctly. The adaptive difficulty mechanic successfully adjusted the challenge to the user's performance and so the accuracy results varied based on the individual cognitive load.

- **Game 3 (Sentence Memorization):** For the third game, the users could also choose to sit down or stand up. During the game, the users needed to respond to the questions and for the most part it seemed as the game was straightforward and the questions were simple. As per the performance seen in table 7 yielding the highest average score of **96.0%** and also the fastest average completion time. However there was noted difference between the time it took to answer personalized questions as to non-personalized questions, these questions were made from the results of 6 and mentioned relatable moments to the different users during the games. During the tests various personalized questions in the pool of questions were mixed with non-personalized questions, this suggests that personalization was a key factor. Sentences based on a user's life story were recalled more easily and quicker than other generic sentences.

Overall engagement was high, with the system recording a total of 80 gameplay sessions, in 7, for example, it shows that 120 session IDs were recorded, however this is caused by errors when restarting the same games caused by the user not being ready or other causes. Averaging 16 sessions per user in the active group, all recorded in the time span of a week in the ISCTE University, this indicates a strong adherence to the training protocol and acceptance of the technology among the older adults.

4.3 Qualitative Feedback

Various results were used in order to compile all of the qualitative data. The feedback questionnaire in Appendix H, its results in Table 5 and also some observational notes provided rich context to the quantitive results, highlighting the user experience and user interface perceptions from the games. This qualitative feedback made it so the main points of the design were directly validated which were also implemented during the development phase. Features like UI and the personalized additions made the environment more accessible and engaging for the players all together.

Table 5. Average Responses from Feedback Questionnaire - Active Group

Question	**Average**	**Interpretation**
1. Overall Satisfaction	5.0	Satisfied
2. Ease of Use	4.5	Very Easy
3. Content Relevance	4.8	Very Important
4. Motivation	4.3	Motivating
5. Clarity of Instructions	4.6	Very Clear
6. Equipment Comfort	3.9	Comfortable
7. Game Difficulty	3.2	Appropriate
8. Perceived Benefits	4.1	Some Benefits
9. Interest in Continuing	4.4	Interested

4.3.1 User Reactions & Design Successes

The feedback results showed that the participants mostly responded positively to the overall design, some details here and there were mentioned during the sessions but everyone who was apart of the active group was very satisfied with the experience. Everyone was very motivated to be apart of this experience which made playing the games more engaging for each user. One note was that "the lighting felt comfortable for long sessions", which indicates that the work put in the room lighting was worth it to potentially mitigate the discomfort caused by the VR headset.

The UI was frequently praised for its intuitiveness, while being simple, it was engaging and the objective of the game was brought straight to the point. For example, comments such as "The dialogue prompts were clear" confirm that the accessibility enhancements from the multiple DSR cycles were effective. Also making changes specifically for user comfort demonstrated that the user-centered design successfully addressed the unique needs of the older participants during the sessions.

4.3.2 Areas for Improvement

The most common request during the pilot study was to enlarge the icons and text. While this could be done fairly easily, the problem surges from another point of view, since the VR headset had some flaws in the design, it was difficult for the older adults to align the headset well enough to sometimes not have distorted lines or blurry pixels. The headset was quite heavy and the users found it difficult to use it for a long period of time.

This is show in the feedback of comfort shown in 4.3 where the result was a 3.9/5.0 for the VR equipment, this physical design of the headset remains a barrier for extended use.

CHAPTER 5

Conclusions and Future Work

This thesis presented the design, development and evaluation of a custom framework with a novel approach to cognitive training for older adults using personalized Virtual Reality serious games. This chapter summarizes the most relevant findings that were taken into consideration from the pilot study. It also discusses the implications of the research and outlines potential directions for the future of this project.

5.1 Main Achievements

The development and pilot study of the framework, chapters three and four, revealed several significant discoveries that validate the research objectives set at the beginning of the thesis.

A primary achievement of this work was the demonstration that a carefully designed VR interface can both be accessible and engaging if made correctly for older adults. The development process, guided by the DSR methodology was crucial in order to accomplish this feat. The decisions for the design were the key to maintain a user-focussed environment, such as single-button interaction models, Comprehensive UI elements and creating a comfortable and low-poly environment. This directly contributed to high user adherence. This is shown by the metric of 16 sessions completed per user in the active group, confirming the fear of a new complex technology can be mitigated through user-centered designs.

The culmination of this research was to focus on personalization on the user's life story. This was thought out and believed it would enhance the player's experience during training session. What was found was that the quantitive results show us that the participants in this project had a net positive outcome of **+0.8 points**. The two groups didn't have an outstanding margin, however the Active group had an average **improvement of +0.4 points** and the Control group showed an average **decline of -0.4 points**. Due to this sample size there cannot be anything conclusive but this still indicates a positive trend none the less. Qualitative feedback tell us in the feedback reports that the relevance of personalized content was very highly rated with a score of (4.8/5.0), this reinforces that personalized VR training is meaningful and has some potential to improve and be present in many domains to take step into improving cognitive function. It may also play a role in mitigating the natural cognitive decline of the older adults.

The implementation of the framework using Unity and XR Interaction Toolkit shows the technical practicality of developing a customized VR cognitive training system for older adults. The integration of the database, the SQLite for automated data collection proved to be effective in delivering custom made experiences and capturing detailed performance metrics across all games, this formed a solid foundation for both user engagement and further analysis made after pilot testing.

5.2 Future Work

The positive results from the pilot study call attention to different strategic directions that the future of this development and research could take. Some aim to strengthen the impact that this framework has, others aim to change and create a new way in clinical practice. None the less, they all have the objective of making something grand that would help those in need. Personalization would evolve and would be expanded into different categories to create familiar environments for the users to play on. Multiple examples exist, such as eye tracking technology, heart-beat bands to have heart rate and stress data or even virtual interactions with familiar faces. Enriching the content and making the experience as immersive as possible should be the primary goal in order for the user to attain the most therapeutic benefits out of these experiences.

The most vital next step is to conduct a long term and with a large scale study. With a statistically more significant number of participants the study would also include an active control group (e.g., using non-personalized VR games or traditional pencil-and-paper exercises) to make sure and definitively isolate and quantify the added benefit of the impact of life story personalization. Then it could be compared to other forms of cognitive stimulation to better analyse the effect it has.

The scalability for this project is centered around the possible cloud database integration and the more advanced analytics that could be used. For one, migrating from a local SQLite database to a cloud-based one like for example MySQL would permit real-time, remote monitoring of each user's progress through the games.

For example, this could be used in care homes, and even online rehabilitation programs, the older adults wouldn't need to have the whole system come to them and could do the exercises with a VR headset of their own and still get the same possible benefits from the VR games.

For more sophisticated analytics, time, error and physiological patterns could be tracked and analysed in order to have a more responsive and adaptive difficulty system that would adapt to each user during the games. This could provide deeper insight into the cognitive process of each user for each different game.

This project could have more accessibility options and adopt new features in the future. In order for the games to be playable for each user in any space an accessibility menu would need to be created and allow users to customize the settings for font sizes, brightness levels, audio volume and more.

The personalization system could also have some improvements in order to have more realistic elements of a person's life, such as 3D objects and different environments from people's stories, such as childhood homes or different music.

At last, exploring other advanced technologies could be beneficial to better analyse the data during the games, such as biometric feedback with a heart rate monitor or sensors to monitor anxiety or excitement levels. This would allow the games to adapt the experience of the older adult to maintain an optimal state for learning and engagement.

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APPENDIX A

ATEE Website

https://atee.upb.ro/atee2025/

APPENDIX B

ATEE Certificate

The 14th International Symposium on
ADVANCED TOPICS IN ELECTRICAL ENGINEERING
Bucharest, October 9-11, 2025

A RESOLUTION OF APPRECIATION

TO

Pedro Fernandes, Octavian Postolache, Dalia Nogueira

FOR PRESENTING

SERIOUS GAMES FOR MEMORY TRAINING IN AGEING ERA

Be it therefore resolved that the Conference Chairs shall express, on behalf of ATEE 2025, it's deep appreciation for this outstanding contribution to the advancement of the electrical engineering industry's technology.

Laurențiu DUMITRAN,
Conference Chair

Alexandru MOREGA,
Scientific Conference Chair

APPENDIX C

ATEE Submitted Paper

Paper Submitted for Publication for ATEE 2025:

The 14th International Symposium on ADVANCED TOPICS IN ELECTRICAL ENGINEERING

Serious Games for Memory Training in Ageing Era

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***Abstract*—As the global population is ageing, cognitive decline, particularly in memory functions such as recall, recognition, and spatial memory, has become a significant public health concern, affecting the quality of life of older adults. Traditional memory training methods often lack engagement and personalization, resulting in limited motivation and adherence.**

This research proposes a novel memory training framework for older adults, leveraging VR serious games under the theme of "Game of Life". These games offer plenty of customization tailored to individual cognitive needs and preferences, integrating personalized training plans to enhance cognitive functions. A key innovation of the framework is its ability to evoke emotions by recreating meaningful life experiences in VR, tapping into long-term memories to foster engagement and motivation.

The gathered data is analysed in the work and tends to indicate that cognitive training using VR could aid to the prevention of cognitive decline.

Index Terms*—*Virtual Reality, Serious Games, Memory Training, Older Adults, Cognitive Training, Personalized Learning, Adaptive Framework, Outcome Analysis

I. Introduction

The world's population is undergoing a rapid demographic shift towards ageing. While increased global life expectancy is a sign of societal progress, it presents significant challenges, particularly the general decline in cognitive functions such as memory and spatial awareness among the elderly. This decline directly impacts quality of life, independence, and is often accompanied by social isolation and related health issues [1].

With the population aged 65 and older projected to reach 1.6 billion by 2050 [2], the strain on healthcare systems to provide adequate support is immense. Conventional interventions like medication and therapy have shown limited positive results in preventing cognitive decline, which is often linked to a lack of sustained mental stimulation and social engagement [3].

In response, technology-based solutions have emerged as promising tools for cognitive training. Serious games, defined as games designed with a primary purpose other than pure entertainment [4], offer structured, goal-oriented exercises that can improve cognitive functions like memory, attention, and executive control [5]. The advent of Virtual Reality (VR) has further enhanced this potential by creating immersive, controlled, and engaging environments that can simulate real-world scenarios for safe and effective training [6]. VR technology, leveraging headsets and motion controllers, provides multi-sensory stimulation through visual, auditory, and haptic feedback, which is crucial for enhancing memory encoding and recall [7] [8].

Current research demonstrates the efficacy of VR serious games in cognitive training for older adults. Studies have shown significant improvements in non-verbal and working memory compared to passive interventions. Platforms like VIRTRA-EL utilize 3D simulations of daily life activities to train cognitive skills in an accessible, user-friendly manner [9]. Furthermore, technologies like the Unity game engine have normalized the development of such experiences, providing powerful tools for creating cross-platform, customizable, and immersive environments [10].

However, a critical gap remains in many existing solutions: the lack of deep personalization that connects to the user's personal history. Life Story—the narrative account of an individual's experiences and memories—is a powerful catalyst for emotional engagement and memory recall [11]. Integrating personal narratives and cultural standards can transform generic cognitive tasks into meaningful experiences, significantly boosting motivation and adherence [12].

This work specifically targets adults aged 60-85, a group that retains a sufficient level of cognitive function to provide clear feedback while benefiting from early intervention. To address the gap in personalized cognitive care, this paper presents the development and a pilot study of a new VR-based memory training system. The system is uniquely designed using the Unity engine and integrates personalized life stories and cultural references from the user's past (1940s-2000s), aiming to enhance relatability, stimulate memory, and improve the overall efficiency and engagement of cognitive training exercises. In this paper Section II describes the proposed methodology, Section III details the development and evaluation, Section IV presents the results and discussions, and Section V provides the conclusion of this paper.

II. Proposed Methodology

This work adopted the Design Science Research (DSR) methodology [13] to guide the creation and refinement of the VR-based cognitive training system. DSR is a rigorous framework for constructing innovative artifacts (in this case, the VR application and its serious games) to address identified real-world problems (cognitive decline among the elderly).

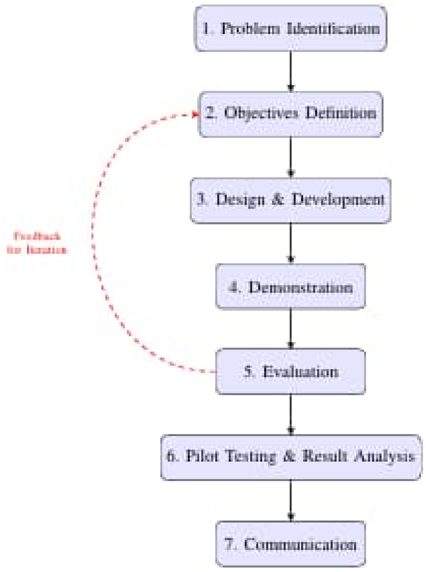

Fig. 1. The iterative Design Science Research (DSR) methodology process followed in this work [13]. The dashed red line represents the feedback loop driving design improvements across cycles.

The adopted methodology is composed of six phases. The initial two phases, as previously discussed, encompass problem identification and objective definition. Subsequently, the process involves iterative cycles of development, demonstration, and evaluation to progressively refine this framework. This iterative nature of DSR ensures the project is highly adaptable, allowing for necessary modifications and improvements to achieve a fully functional and validated design.

The next-to-last phase, critical for applied research projects, is dedicated to the pilot testing and results analysis. In this stage, a select group of users tests the games to provide feedback, enabling the collection of performance data essential for the final evaluation.

III. Development and Evaluation

The process, illustrated in Fig. 1, involved three iterative cycles of development, demonstration, and evaluation, allowing for continuous feedback and improvement before the final pilot study with users.

A. DSR Cycle 1: Establishing Core VR Functionality

Development: The initial development phase focused on establishing the core functionality within the Unity engine. The first objective was to configure the VR hardware for user interaction, serving as a foundation for the subsequent serious games. This involved setting up the XR Origin rig for head and controller tracking 2, 3, implementing basic locomotion, and designing a simple low-poly environment to maximize user comfort and minimize potential simulator sickness. All necessary foundational scripts were developed during this phase to create a stable and functional VR framework where users could interact within a controlled virtual world. The first iteration of this environment is depicted in the following figures.

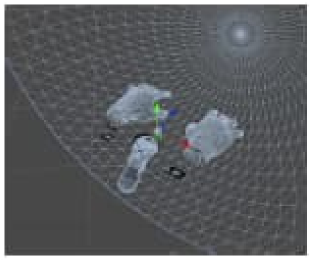

Fig. 2. Controler

Fig. 3. Controler 2

The initial concept for the first room 4 was a game where a number would be displayed briefly before disappearing, requiring the player to then write it down on a virtual screen. However, this mechanic was abandoned after recognizing that the act of writing in VR is a complex task, demanding a high degree of time and precision from users. This level of fine motor control was deemed overly challenging for the target demographic and risked creating frustration rather than focused cognitive engagement.

Fig. 4. VR Room 1

For the second room 5, the initial design presented the player with a choice between four distinct rooms to enter. Upon selecting one, the player was given a set amount of time to memorize the quantity, colour, and specific location of objects placed within the space. This exercise was designed to comprehensively challenge multiple aspects of the human memory, including visual recall, spatial awareness, and object-position association.

Fig. 5. VR Room 2

For the third and final room 6, the design concept featured a classic memory card-matching game. Upon initiating the game, the player would be presented with a grid of 16 cards, each featuring a unique image. Every image would have one exact match within the grid. The core objective for the player would be to sequentially select two cards at a time, with the goal of successfully identifying and matching all the pairs. This activity is designed to specifically target and exercise visual memory, short-term recall, and concentration.

Fig. 6. VR Room 3

Demonstration: The initial prototype was demonstrated to project supervisors to validate the core technical approach. And also the desired game design that would partake into the final framework.

Evaluation: Feedback confirmed the viability of the VR approach but highlighted critical accessibility flaws. The user interface (UI) elements were deemed too small for the target demographic, and controller tracking could be seen as "too difficult to learn" from the users. This evaluation concluded that the next cycle must prioritize accessibility features above all else as well as hand tracking for all users. It was also said that having an outdoor environment and lighting environment to match it could bring more ease for the users. The last game was removed due to it's lack of personalization.

B. DSR Cycle 2: Integrating Games and Accessibility

Development: Based on feedback from Cycle 1, the user interface was completely redesigned with a focus on accessibility, incorporating significantly larger buttons, text, and interactive elements. The three core serious games— Object Recall, Number Memorization, and Sentence Memorization —were fully developed and integrated into the VR environment. This environment is composed of one main enclosed room as seen in 11, it's also composed of 2 adjacent rooms as seen in 8 and 9, and finally, 4 rooms that are different variations of 11. A SQLite database was also implemented to automate the capture of user performance statistics, ensuring reliable data collection.

While the core gameplay and systems were finalized, the visual design and asset integration remained an ongoing process in this cycle. The initial aesthetic assets required further refinement to ensure a cohesive visual style with appropriate lighting, prefabs, and a colour scheme tailored to the preferences of the elderly demographic. This emphasis on a polished and engaging visual design was deemed critical for user acceptance and perceived value, directly impacting their motivation to engage with the games.

Fig. 7. Object Recall

Game 1: Object Recall: This game is designed to train visual and spatial memory. The user is placed in a virtual room similar to 11 and given three minutes to memorize all objects within it, including their quantity, colour, and location. Once the time elapses, the player is teleported away and must answer a series of multiple-choice questions regarding the room's contents ("How many chairs were in the room?" or "What colour were the pillows?"). The number of questions scales with the selected difficulty level. Upon completion, the player's results are displayed on-screen (Fig. 7), and they are returned to the starting room.

Game 2: Number Memorization: This game targets working memory and digit span. The user is transported to a room featuring a large central canvas (Fig. 8). Upon initiating the game, a number is displayed briefly before disappearing. The player then must select the correct number from five options. The game employs an adaptive difficulty mechanism: each correct answer increases the number of digits in the next sequence by one (Level 1: 1 digit, Level 2: 2 digits, up to a maximum of 12 digits). An incorrect answer decreases the difficulty by one level. The session has a five-minute time limit, after which the final score (highest level achieved & correct answers / total answers) is displayed before returning the player to the starting room.

Game 3: Sentence Memorization: Focused on verbal and semantic memory, this game presents players with a sentence on a canvas (Fig. 9) for a short period. The sentence then vanishes, and the player is asked a yes/no question about its content, regarding the presence of a specific word ("Was x present in the sentence"). The game progresses linearly through 12 levels of increasing complexity (larger sentences) without a regression mechanic for incorrect answers. Each error is simply recorded. After completing all levels, the score (number of correct answers) is displayed, and the player is returned to the starting room.

Demonstration: The enhanced system, featuring accessible design and functional games, was demonstrated to the project supervisors.

Fig. 8. Number Memorization

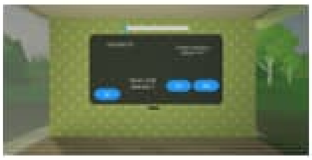

Fig. 9. Sentence Memorization

Evaluation: The accessibility improvements and automated data collection system were positively received by evaluators. However, a critique emerged: the game content was deemed too generic. The key feedback emphasized that for effective memory training, the system needed to incorporate personalized content rooted in the user's life story to maximize both engagement and cognitive relevance.

Furthermore, supervisors suggested that the games required additional optimizations and more sophisticated feedback mechanisms to enhance user immersion and provide a greater sense of accomplishment. It was also noted that future iterations should analyse time-on-task and overall user flow. This needed a fluid user experience (UX) designed to prevent boredom, minimize confusion, and mitigate potential negative emotions—such as frustration or discouragement—related to performance scores.

C. DSR Cycle 3: Personalization and Pilot Preparation

Development: The final development cycle was dedicated to personalization and polish. The core game logic was adapted to incorporate personalized content, such as specific names, historical events, and personal details collected from users. The visual and auditory experience was finalized, with adjustments to the lighting, ambiance, and a cohesive colour scheme. To enhance usability, numerous user experience (UX) refinements were implemented, including audio feedback for button presses, colour-coded responses for correct/incorrect answers, and clear time-remaining indicators for each game.

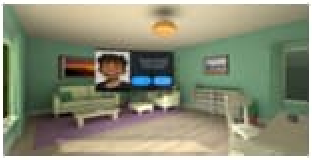

Fig. 10. Main Room Design

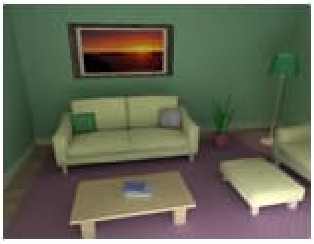

Fig. 11. UI

Demonstration: The final, personalized system was demonstrated as ready for user testing.

Evaluation: Feedback at this stage shifted from design to practical deployment, focusing on the pilot study protocol, session length, and usability guidance. The artifact itself was deemed complete and ready for rigorous evaluation with the target user group, the results of which are presented in the following section.

IV. Results and Discussion

This section presents an analysis of the quantitative and qualitative data gathered from this evaluation. The next subsections detail the methodology employed for pilot testing, followed by a presentation and discussion of the key findings related to system usability, participant performance across the three serious games, and a comparative analysis of the outcomes between the personalized Life Story group and the control group.

A. Pilot Testing Methodology

The developed VR system was evaluated through a pilot study with a cohort of 10 elderly participants (N=10), with a mean age of 74.6 years, split into two experimental groups:

- **Life Story Group (N=5):** Users #1, #3, #8, #9, #10. This group received cognitive training personalized with their life stories.
- **Control Group (N=5):** Users #2, #4, #5, #6, #7. This group didn't participate in the cognitive training.

The study consisted of a pre-test cognitive assessment, multiple VR training sessions where all performance statistics were automatically stored to the SQLite database, and a post-test assessment. The goal was to evaluate usability, game performance, and the specific impact of personalization.

B. Quantitative Analysis of Game Performance and Engagement

- The **'users'** table stored participant profiles, including a unique user ID, their assigned experimental group (Life Story or Control), and demographic information such as age.
- The **'sessions'** table logged every interaction within each gameplay session. Each record was linked to a user ID and contained the following fields:
  - **SessionID:** A unique identifier for each gameplay instance.
  - **UserID:** Foreign key linking to the users table.
  - **Timestamp:** The date and time the session was completed.
  - The other tables contained the results for each individual game, as well as the time and accuracy.

Fig. 12. UI

1) Overall Usability and Engagement:

- The database recorded a total of **80 gameplay sessions** across all users.
- Users completed an average of **16 sessions each**, demonstrating strong engagement and adherence to the training protocol.
- This high level of repeated use indicates the VR system was well-received and usable for the elderly demographic, with no major technical barriers.

2) Performance by Game Type: Analysis of the performance metrics across the three serious games reveals distinct profiles for each, as summarized in Table I.

```
// Example from NumbersGame.cs on how to
    calculate the accuracy
    float accuracy = totalAttempts > 0 ? (
        float)correctAnswers /
        totalAttempts * 100 : 0;
```

TABLE I
AVERAGE PERFORMANCE METRICS BY GAME TYPE

Game	Accuracy (%)	Time (s)	Score
Numbers Game	81.9	300.0	11.6 / 12
Memory Challenge	76.4	218.1	4.1 / 5
Frases Game	95.2	140.2	11.4 / 12

- The **Sentence Memorization** game demonstrated the highest average accuracy (95.2%) and fastest completion time (140.2 sec). Qualitative feedback suggests this superior performance is likely due to the personalization of content; players reported that sentences correlated with their own life stories triggered their own memories, making them significantly easier and quicker to recall compared to new, generic sentences. This indicates the game was not only intuitively understood but also benefited from the cognitive ease of retrieving familiar, personal information.
- The **Numbers Game** required the full 300 seconds per session, indicating a consistently high cognitive load that engaged users for the entire duration.
- The **Memory Challenge** shows a lower accuracy (76.4%), which is expected for a game focused on working memory and recall, confirming it could've effectively targeted its intended cognitive domain.

3) Life Story vs. Control Group Analysis: The most significant analysis compares the cognitive improvement between the experimental groups.

- Participants in the **Life Story group** showed an average **improvement of +0.6 points** on the post-test quiz.
- Participants in the **Control group** showed an average **decline of -0.6 points**.
- This preliminary result suggests that personalized, life story-based cognitive training may not only improve cognitive scores but also potentially may help mitigate natural decline, whereas no training may not be sufficient. This emphasizes the potential value of the personalization aspect of the developed system.
  It is important to note, however, that these observed effects could be influenced by other variables not controlled for in this pilot study, such as the users' overall lifestyle, social interactions, or other concurrent activities. While the results are promising, a larger, controlled study is necessary to isolate the specific impact of the personalized VR training from other external factors.

C. Qualitative Feedback and Observations

In addition to quantitative data, positive subjective feedback was collected:

- Users reported that "the lighting felt comfortable for long sessions" and that "the dialogue prompts were clear."
- These reports verify the quantitative data, which showed high engagement (4 days/user) and high accuracy rates (e.g., 95.2% in the Sentences Game), indicating that users

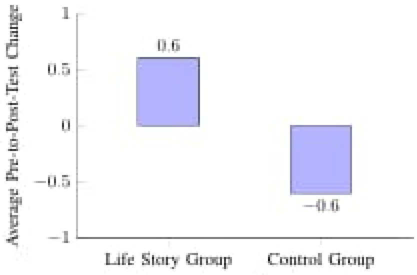

Fig. 13. Average change in cognitive assessment scores from pre-test to post-test, grouped by experimental condition. A positive value indicates improvement.

found the system not only enjoyable but also effectively manageable and non-frustrating. They also gave feedback on how interactive the games were, how enjoyable they were to play and how hard they were. All of which summed up to a mean score of 4.8/5 in the interact-ability category, 5/5 in the enjoyment category and 3.4/5 in the difficulty category (1 being the easiest and 5 being the hardest).
- Some users requested "larger text/icons" and "lighter headset" providing valuable feedback for future interface iterations.

D. Limitations

- The primary limitation is the **small sample size (N=10)**, which limits the statistical power and generalizability of the findings.
- Furthermore, the control condition wasn't an **active control** (they still could've used engaging VR games), which may underestimate the true effect of personalization when compared to the passive control group (no intervention).
- Future work with a larger similar group is necessary to confirm these results and achieve statistical significance.

V. Conclusion

This study successfully achieved its objective of designing, developing, and evaluating a Virtual Reality-based cognitive training system tailored for the elderly. The system was built using the Design Science Research methodology, resulting in an accessible framework featuring three distinct serious games—Memory Matching, Sequence Recall, and Word Association—integrated within an low-poly VR environment. The key innovation of this work lies in the personalization of these games using the user's life story, a feature designed to enhance engagement and memory recall by connecting cognitive exercises to personal historical context.

The pilot study with ten elderly participants yielded promising results. However for the older participants, this new technology wasn't as easy to master as the younger participants. But in the end everyone got accustomed to the technology as shown with the quantitative data that revealed strong user engagement, with participants completing sixteen sessions each. Performance metrics showed high accuracy rates across all games, confirming the system's usability and effectiveness. Most significantly, a comparative analysis between the experimental groups indicated a clear positive trend: participants who trained with life-story-based content showed an average improvement in post-test cognitive scores, while those in the control group showed a slight decline. This finding underscores the potential value of personalization in cognitive training tools, suggesting they may not only improve function but also may help mitigate natural cognitive decline.

The broader implication of this research is the demonstration that VR technology, when thoughtfully designed with a user-centered approach, is a feasible and engaging project for non-pharmacological cognitive intervention in ageing populations. It moves beyond traditional screen-based applications by offering a heightened sense of presence and novelty that can stimulate users more effectively.

For future work, the logical next step is to conduct a large-scale study with a more statistically significant cohort to validate these preliminary findings. Furthermore, based on user feedback, enhancing the accessibility options, such as customizable font sizes and more diverse difficulty settings, would make the system applicable to a wider range of cognitive abilities. Finally, technical development should focus on implementing a cloud-based database architecture to replace the local SQLite system, enabling remote monitoring of patient progress and facilitating deployment in distributed clinical trials.

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APPENDIX D

Pre Test Form

Mini Teste Cognitivo **Pré-Sessão (Versão A)**

(Pontuação máxima: 20 pontos)

Idade: ____ anos

Escolaridade: ___________________

Data: ___/___/_____

1. Orientação (5 pontos)

- Em que **ano** estamos?
- Qual é o **mês** atual?
- Que **dia da semana** é hoje?
- Qual é a **data** de hoje?
- Onde estamos agora (ex.: cidade, bairro ou nome do local)?
- De 1-10 como avaliaria a sua propria memoria?

2. Memória (3 pontos)

- Peça para repetir e memorizar 3 palavras:
- Após 5 minutos, peça para lembrar as palavras (sem dicas).

3. Atenção e Cálculo (2 pontos)

- Conte de **1 a 20** e depois conte de volta de **20 a 1**.
- OU: Subtraia **5 de 50** (45, 40, 35... até 10).

4. Linguagem (3 pontos)

- **Nomeação**: Mostre uma **chave** e uma **caneta** – "Como se chamam estes objetos?"
- **Repetição**: Peça para repetir: **"O céu é azul e o sol é amarelo."**
- **Fluência verbal**: Cite o máximo de **frutas** em 1 minuto (≥8 é normal).

5. Habilidades Visuoespaciais (2 pontos)

- **Desenho**: Peça para desenhar um **relógio marcando 3 horas**.
- **Cópia**: Copie um **cubo simples** (avalie se as linhas estão conectadas).

6. Função Executiva (3 pontos)

- **Solução de problemas**: "O que tu farias se visses um incêndio em casa?"
- **Abstração**: "Como são relacionados um **avião e um carro**?" (ambos transportam pessoas).

7. Juízo e Insight (2 pontos)

- "Por que é importante fazer exames médicos regularmente?"
- "O que tu farias se se perdesse no centro comercial?"

APPENDIX E

Post Test Form

Mini Teste Cognitivo Pós-Sessão (Versão B)

(Maximo 20 pontos)

Idade: ____ anos

Escolaridade: __________________

Data: ___/___/_____

1. Orientação (5 pontos)

- Em que **estação do ano** estamos?
- Qual foi o **mês passado**?
- Que **dia da semana foi ontem**?
- Qual é o **nome do presidente atual**?
- Em que **país** nós vivemos?

2. Memória (3 pontos)

- Memorize: **"flor, garfo, janela"**. Lembre após 5 minutos.

3. Atenção e Cálculo (2 pontos)

- Some **3 + 8**, depois **11 + 4**, depois **15 + 6**.
- OU: Subtraia **3 de 30** (27, 24, 21... até 9).

4. Linguagem (3 pontos)

- **Nomeação**: Mostre **óculos** e **moeda** – "Quais são os nomes?"
- **Repetição**: "O gato preto dorme no sofá quente."
- **Fluência verbal**: Cite **animais** em 1 minuto (≥8 é normal).

5. Habilidades Visuoespaciais (2 pontos)

- **Desenho**: Desenhe uma **casa com duas janelas e uma porta**.
- **Cópia**: Copie um **triângulo dentro de um círculo**.

6. Função Executiva (3 pontos)

- **Solução de problemas**: "Se você esquecesse um compromisso, o que faria?"
- **Abstração**: "Como são parecidos **livro e filme**?" (ambos contam histórias).

7. Juízo e Insight (2 pontos)

- "Por que não devemos partilhar medicamentos?"
- "O que fazer se alguém cair e se maguar na rua?"

APPENDIX F

Life Story Questionnaire

A Minha História

1. Dados Essenciais

- **Nome Completo:**
- **Prefere ser chamado(a) de:**
- **Data de Nascimento:**
- **Naturalidade (onde nasceu):**

Auto-Retrato:
"Descreva-se em 3 palavras ou uma frase curta:"

2. Raízes & Família

- **Pais:**
  - Mãe: Nome, profissão e uma característica marcante:
  - Pai: Nome, profissão e uma história engraçada:
- **Irmãos/irmãs:** (Do mais velho ao mais novo + uma lembrança única)
- **Avós ou familiares especiais:** Quem te inspirou?

Tradições de Família:
"Qual era a melhor festa ou comida da sua infância?"

3. Memórias de Infância

- **Escola:**
  - Matéria favorita? E a que você detestava?
  - Um professor ou amigo inesquecível.
- **Brincadeiras:** Bolas de gude, bonecas, futebol na rua?
- **Momento mais marcante (ou engraçado):**

4. Trabalho & Realizações

- **Primeiro Emprego:** O que fazia? Salário? Uma história engraçada.

1

- **Carreira:** Empregos, sonhos e mudanças de rumo.
- **Se pudesse voltar no tempo...** Escolheria outra profissão?

5. Amor & Relacionamentos

- **Parceiros de Vida:** Nomes e como se conheceram.
- **Casamento/União:** Detalhes do dia (vestido, música, clima).
- **Filhos/Netos:** Nomes + uma loucura que fizeram juntos.
- **Pets:** Nomes e travessuras dos bichinhos.

6. Lugares com História

- **"Casa é..."** (Sua casa de infância? Onde viveu mais tempo?)
- **Top 3 Lugares:** Sua cidade favorita, uma viagem inesquecível.
- **Sonho de Viagem:** Um lugar que ainda quer conhecer.

7. Paixões & Hobbies

- **Música:** Cantava no chuveiro? Qual música tocou no seu casamento?
- **Filmes/Séries:** Favoritos de todos os tempos.
- **Passatempos:** Costura, pesca, jardinagem, colecionar algo?
- **Vício Confesso:** (ex.: "Não vivo sem novelas!")

8. Momentos que Mudaram Tudo

- **Maior Desafio:** Como superou?
- **Conquista Mais Orgulhosa:**
- **Conselho para os Jovens:**

APPENDIX G

Life Story Data

Table 6. Life Story Data Summary - Active Group (N=5)

Participant Characteristics	**Part. 1**	**Part. 2**	**Part. 3**	**Part. 4**	**Part. 5**
Age	65	69	70	68	77
Place of Birth	Lisbon	Lisbon	Lisbon	Luanda	Barcelona
Profession	Psychologist	Psychiatrist	Doctor	Teacher	Secretary
Marital Status	Divorced	Divorced	Divorced	Divorced	Married
Children	1	0	0	0	2
Grandchildren	0	0	0	0	1
Main Hobby	Painting	Reading	Reading	Piano	Sudokus
Memorable Memory	Child's birth	Visit to Italy	Trip to Paris	Trip to Mozambique	Child's birth
Biggest Challenge	Being a Mother	Medical School	City Move	Asking for Help	Broken Ankle
Achievement	Being a Mother	Overcoming Shyness	Family	Independence	Being Optimistic

APPENDIX H

Sentence Game Results

TABLE 7. Sentence Memorization Game Performance Results

ID	Sess.	Corr.	Total	Acc. (%)	Time (s)	Hard
1	3	12	12	100	167.2	Y
2	7	12	12	100	145.7	Y
3	11	11	12	92	123.5	Y
4	15	11	12	92	117.5	Y
5	19	11	12	92	112.7	Y
6	23	11	12	92	101.9	Y
7	27	12	12	100	162.9	Y
8	31	12	12	100	149.3	Y
9	35	11	12	92	138.5	Y
10	39	10	12	83	104.9	Y
11	43	12	12	100	171.3	Y
12	47	12	12	100	154.0	Y
13	51	11	12	92	108.7	Y
14	55	11	12	92	131.6	Y
15	63	12	12	100	134.5	Y
16	67	11	12	92	165.1	Y
17	71	12	12	100	159.4	Y
18	100	12	12	100	132.7	Y
19	104	12	12	100	149.8	Y
20	120	12	12	100	121.8	Y
Total	-	**227**	**240**	-	**2828.1**	-
Median	-	**12**	**12**	**96.0**	**138.0**	-

Note: ID = Result ID, Sess. = Session ID, Corr. = Correct Answers, Total = Total Rounds, Acc. = Accuracy, Time = Game Duration (seconds), Hard = Hard Mode (Y = Yes)

APPENDIX I

Number Game Results

Table 8. Number Memorization Game Performance Results

ID	Sess.	Level	Corr.	Total	Acc. (%)	Time (s)
1	2	12	16	21	76.2	299.99
2	6	12	17	19	89.5	299.99
3	10	12	17	20	85.0	299.99
4	14	11	17	21	81.0	299.99
5	18	12	16	21	76.2	299.99
6	22	11	15	19	78.9	299.99
7	26	11	16	19	84.2	299.99
8	30	12	16	19	84.2	299.99
9	34	12	16	20	76.8	299.99
10	38	12	16	22	72.7	299.99
11	42	12	18	21	85.7	299.99
12	46	12	17	19	89.5	299.99
13	50	11	15	22	68.2	299.99
14	54	12	17	19	89.5	299.99
15	62	12	16	17	94.1	299.99
16	66	12	16	21	76.2	299.99
17	70	12	19	22	86.2	299.99
18	95	11	15	20	75.0	299.99
19	101	12	16	17	94.1	299.99
20	111	11	18	21	85.7	299.99
Total	-	**229**	**327**	**401**	-	-
Average	-	**11.5**	**16.4**	**20.1**	**82.1**	**300.0**

Note: ID = Result ID, Sess. = Session ID, Level = Final Level, Corr. = Correct Answers, Total = Total Attempts, Acc. = Accuracy, Time = Game Duration (seconds)

APPENDIX J

Memory Game Results

Table 9. Object Recall Game Performance Results

ID	Sess.	Score	Qs	Acc. (%)	Time (s)	Obs. (s)
0	0	3	5	60	234.4	180
1	1	4	5	80	225.6	180
2	4	3	5	60	211.1	180
3	5	3	5	60	217.5	180
4	8	4	5	80	233.5	180
5	9	1	5	20	197.0	180
6	12	4	5	80	222.2	180
7	13	2	5	40	207.0	180
8	16	2	5	40	210.4	180
9	17	2	5	40	202.5	180
10	20	1	5	20	198.8	180
11	21	4	5	80	226.8	180
12	24	4	5	80	224.7	180
13	25	4	5	80	216.0	180
14	28	5	5	100	234.6	180
15	29	5	5	100	227.4	180
16	32	5	5	100	222.5	180
17	33	4	5	80	223.8	180
18	36	4	5	80	219.4	180
19	37	5	5	100	229.1	180
20	40	5	5	100	219.4	180
21	41	5	5	100	231.0	180
22	44	3	5	60	199.0	180
23	45	5	5	100	235.7	180
24	48	5	5	100	230.0	180
25	49	4	5	80	222.0	180
26	52	5	5	100	240.0	180
27	53	5	5	100	232.8	180
28	60	3	5	60	197.7	180
29	61	5	5	100	229.1	180
35	64	5	5	100	236.7	180
36	65	5	5	100	236.1	180
37	68	5	5	100	209.5	180
38	69	5	5	100	203.8	180
40	96	5	5	100	232.0	180
41	97	4	5	80	224.9	180
42	102	4	5	80	238.2	180
43	103	2	5	40	253.7	180
44	106	5	5	100	207.3	180
45	119	5	5	100	200.4	180
Total	-	**176**	**225**	-	**9631.9**	-
Average	-	**3.9**	**5.0**	**78.2**	**214.0**	**180.0**

Note: ID = Result ID, Sess. = Session ID, Qs = Total Questions, Acc. = Accuracy, Time = Total Time (seconds), Obs. = Observation Time (seconds)

APPENDIX K

Feedback Questionnaire Form

Questionário de Feedback – Grupo Ativo

Data: ___/___/_____

Instruções: Por favor, avalie a sua experiência com o treino cognitivo em Realidade Virtual, assinalando com um X a opção que melhor reflecte a sua opinião.

1. Satisfação Geral com a Experiência

Como classifica a sua experiência geral com os jogos de treino cognitivo em RV?

( ) Muito Insatisfeito
( ) Insatisfeito
( ) Neutro
( ) Satisfeito
( ) Muito Satisfeito

---

2. Facilidade de Utilização

Os jogos foram fáceis de entender e utilizar?

( ) Muito Difíceis
( ) Difíceis
( ) Neutro
( ) Fáceis
( ) Muito Fáceis

---

3. Relevância do Conteúdo Personalizado

O conteúdo personalizado com a sua história de vida tornou a experiência mais significativa?

( ) Nada Significativo
( ) Pouco Significativo
( ) Neutro

( ) Significativo
( ) Muito Significativo

---

4. Motivação e Envolvimento

Os jogos motivaram-no a completar todas as sessões?

( ) Nada Motivador
( ) Pouco Motivador
( ) Neutro
( ) Motivador
( ) Muito Motivador

---

5. Clareza das Instruções

As instruções fornecidas foram claras e compreensíveis?

( ) Muito Confusas
( ) Confusas
( ) Neutro
( ) Claras
( ) Muito Claras

---

6. Conforto com o Equipamento

O headset e os comandos foram confortáveis de utilizar?

( ) Muito Desconfortáveis
( ) Desconfortáveis
( ) Neutro
( ) Confortáveis
( ) Muito Confortáveis

---

7. Dificuldade dos Jogos

O nível de dificuldade dos jogos foi adequado?

( ) Muito Fácil
( ) Fácil
( ) Adequado
( ) Difícil
( ) Muito Difícil

---

8. Benefícios Percebidos

Acredita que esta experiência trouxe benefícios para a sua memória ou outras capacidades cognitivas?

( ) Nenhum Benefício
( ) Poucos Benefícios
( ) Neutro
( ) Alguns Benefícios
( ) Muitos Benefícios

---

9. Interesse em Continuar

Teria interesse em continuar a utilizar este tipo de treino cognitivo no futuro?

( ) Nenhum Interesse
( ) Pouco Interesse
( ) Neutro
( ) Interessado
( ) Muito Interessado

Obrigado pela sua participação e feedback!
A sua opinião é fundamental para melhorarmos esta experiência.