Development of an Inclusive Multiplayer Serious Game for Deaf and Blind

Nuno Neto[1], **Bruno Galasso**[2], **Dirceu Esdras**[2], **Paula Escudeiro**[1]

[1] Games, Interaction and Learning Technologies R&D Center, Instituto Superior de Engenharia do Porto, Rua Dr. António Bernardino de Almeida, 431, 4249-015 Porto, Portugal
nunoarneto@gmail.com, pmo@isep.ipp.pt

[2] Instituto Nacional de Educação de Surdos, Rua das Laranjeiras, 232, 22240-003 Rio de Janeiro, Brasil
{galasso.bruno, diresdras}@gmail.com

Abstract. *The paper presents the development of an inclusive serious multiplayer game with Morse code as its theme, as well as describing methodologies and architectures for developing a serious game through specific concepts for the deaf (sign language) and blind (audio description). The preceding case has three game modes: classic one versus one, a cooperative mode between two players and a four-player game mode all. To validate this serious game performance and quality, a Quantitative Evaluation Framework was used. In that context, the final product has three dimensions: pedagogical, ergonomic, and technical. From the obtained data, it was possible to conclude that this game was proof that using accessibility guidelines during software development helps to promote not only an efficient integration of excluded communities, but also social inclusion and equity between players.*

Keywords. Serious games, accessibility, bloom cognitive model, development methodologies, assistive technology

University of Maribor Press

DOI https://doi.org/10.18690/um.3.2022.7
ISBN 978-961-286-658-7

1 Introduction

Promote equal opportunities and social inclusion for people with disabilities is a concern of modern societies (FCT/ COMPETE2020 – project ACE[1] ref: PTDC/IVC-COM/5869/2014, POCI-01-0145-FEDER-016584). Science evolution and new available technologies allowed for the development of solutions to chronical problems, such as effective communication by digital means with the deaf (sign language) or blind (braille) people.

As reported by the World Health Organization [1], the number of people with visual impairment or blindness is 2.2 billion worldwide, while people with hearing loss is 466 million [2]. In Portugal, according to the 2011 censuses, there are nearly 533.000 people with hearing problems, and it is estimated -in accordance with information provided by Serviin (Video interpretation service provided by the Deaf Citizen Portal) that 120.000 are born-deaf or became deaf in early childhood [3].

Within this context, most of the population suffers from a lack of accessibility means, hence digital literacy has become increasingly relevant. Education, another critical area, presents even more worrying data. Education barriers faced by people with specific needs limit future opportunities, resulting in inequality. Any contribution to eliminating this inequality promotes equity.

Thus, it is possible to argue that direct contact with the area of serious games stimulates learning and critical thinking, making serious games at the communicational and social inclusion level relevant, even though there is no panoply of choice for people with disabilities.

Not too long ago, communication between the community of deaf and blind people was almost an unreachable challenge, especially when there were not enough technological advances to create easy contact between them. Nowadays, there are several tools such as motion sensors, text-to-speech, and speech-to-text that, being well implemented and tested with the intended audience, can enhance this communication. However, sign language differs from country to country, making the development of complex software for such a small niche market unattractive due to the high operational cost.

For this reason, the aim of the following article is to present the development of a multiplayer serious games for deaf and blind people, focused on teaching and learning Morse code.

2 Games, Serious Games and Learning

The game concept can be classified as an activity where there are time limits, a restricted area for this practice, rules that serve to keep the rights and responsibilities of the participants undamaged, as well as providing a competitive environment different from the usual [4]. According to Avedon and Sutton-Smith, it is a voluntary exercise where there is a competition between powers confined by a set of rules to produce an unbalanced result [5].

[1] ACE - Assisted Communication for Education

From Salen and Zimmerman's [6] point of view, the game is a system in which players are involved in an artificial conflict, defined by rules, which determines a quantifiable result. However, a serious game is a mental challenge, where the player usually plays against a computer within a set of rules, that uses entertainment as the aim to enhance education, health, public policies, and strategic communication goals [7]. For this project, the aim is to create a multiplayer game, different from the common serious games that usually involves a man versus a machine, developing a level of learning defined by the capacities of the intervenient.

According to Michael Zyda, the main objective of a serious game is to create practical simulations of everyday life, offering training for professionals, critical situations in companies and/or institutions, as well as raising awareness among children, young people, and adults on matters such as education. They also consist of a combination of digital games with entities, resulting in a theoretical-practical educational teaching. Learning is the keyword and includes educative games, business games, simulation games, among others, covering a broad set of contents, contexts, and audiences [8].

Associated to serious games, the concept of Inclusive Design [9] can be described as an approach to include the maximum of possible people, particularly the population with special needs and older people. Despite having similar points of view to Universal Design, where "one size fits all", the Inclusive Design aims to include users with more specific needs. This project, however, focuses on deaf and blind communities, hence the interfaces designed are in line with the specificities foreseen and intended by the target audience.

To promote learning through a serious game among the deaf and blind communities it is necessary to understand which method is better to develop a means of interaction. The taxonomy developed by Bloom, can be applied to various areas and not only to knowledge [10]. This taxonomy has been applied to areas such as learning or specific objectives of knowledge, psychomotor or individual skill-based goals, and value or emotion-based goals [10].

In a reviewed version of Bloom's taxonomy [11], there are six levels for the basic domain of knowledge in the cognitive model (Fig.1): remember, understand, apply, analyse, evaluate, and create.

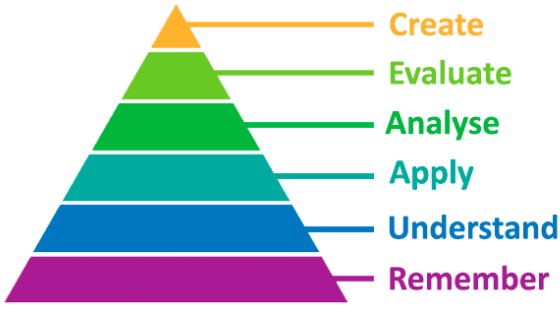

Figure 1. Bloom's taxonomy adapted from Bloom et al. [12]

These levels increase in complexity as the level of abstraction also increases. The first level, *remember*, allows us to ascertain whether the target audience has acquired some basic knowledge by asking questions about some of the concepts presented. Once the student shows that his or her knowledge is valid, it is possible to move on to the next point in the taxonomy.

In the next level, *understand*, the target audience can explain the acquired knowledge through their own words. The type of questions to test that knowledge must be clear so it can be possible to conclude that the target audience understood the content instead of memorizing it. The third level, *apply*, requires the previous matters to be applied. Through a learning-based serious game, it is possible to put that knowledge in action. For the time being, the area of serious games is an interesting theme which has been growing in importance in recent years.

The fourth level, concerning the analysis of a concept, enables the target audience to communicate properly and to explore other ways of learning in a way that such knowledge can be induced to other users, enabling learners to take control over their development process. Thus, the guidance received has a greater significance and, above all, a greater impact [13]. The following level, *evaluate*, states if the student can tutor other students who are at lower levels. They can express opinions about information, ideas or the quality of the work presented to them.

Finally, *create*, means that the student is capable of exercise the responsibility to innovate or plan ways to explain the information obtained along its learning process. The Morseline (game title for the developed multiplayer game) uses partially Bloom's taxonomy as methodology in the learning stages during its gameplay.

To solve the proposed problem, it was necessary to conceptualize a high-level architecture able to unravel the communication between the different components inherent to a practical solution.

3 Solution architecture

As such, the architecture implemented for the developing serious games can be accessed in Fig. 2, through a representation of the system/framework components diagram that will be further described. The architecture proposes three main components: (1) component referring to the game interface, in which the user can access the serious game either through a PC or mobile device with Android system; (2) the component that relates the four main implementations that are constantly interconnected with the business logic of the serious game; and (3) component related to the game server that includes the multiplayer implementation through sockets and a REST API together with a database in order to make the serious game endure.

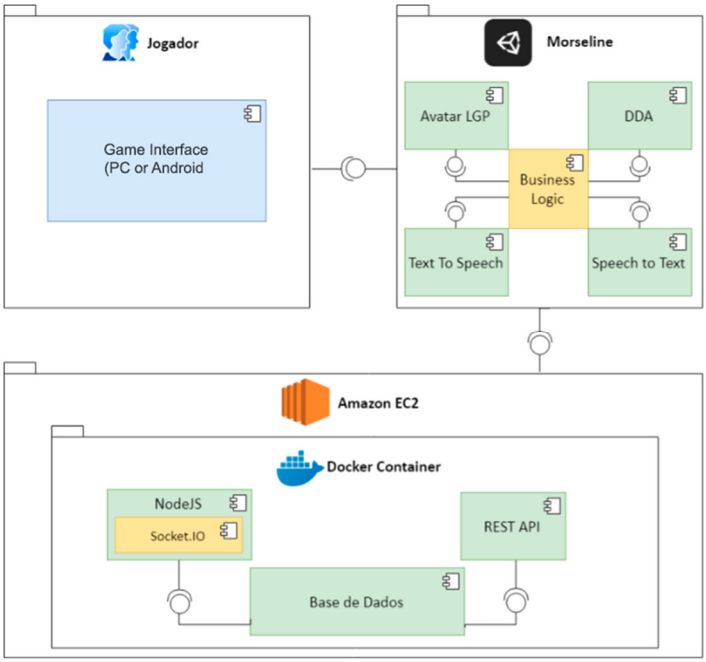

Figure 2. Diagram of components representative of the system/framework

3.1 Implementation view

The "player" component shows the starting point for any action between the game and is parts. The user will be able to access the game through a computer, preferably one equipped with Windows operative system, or through a mobile device with an Android system.

Next we have the component related with the game developed, Morseline, that introduces four subcomponents related with the used implementations for players accessibility, and the Dynamic Difficulty Adjustment (DDA) component, related to the difficulty presented to players. The fifth subcomponent, business logic, is composed of scripts in C# (programming language) developed in Unity (game engine) to manipulate the actions and data that make up the game.

About the implementation of the DDA, note that this allows to adjust the difficulty presented to the player, considering the user skills as the game evolve. Thus, the player won't be bored if the game becomes easier, nor anxious if the complexity of the game becomes too high. One of the indicators to assess the difficulty of the game is the succession of correct answers provided by two or more players. Considering that this multiplayer serious game works with an online component, the difficulty is balanced between the players, making it harder to reach an impractical difficulty. By adapting the difficulty, it is possible to control the progression margin and thus offer an interesting challenge to the player so that the user develops his skills at his own pace.

Every player starts with 1000 points, a mediated value that allows to match players with greater aptitude, while players who have some difficulty play with others of their learning level.

This assessment is done through the results obtained in the games. During the search of an opponent in game modes, the maximum difference between two players can never be over 200 points, to prevent disparities in their skill level. This classification system was designed based on a worldwide system known as *rating ELO*, that is used on chess and created by Arpad Elo. The following figure (Fig. 3) presents the evolution of a player in the game using the DDA.

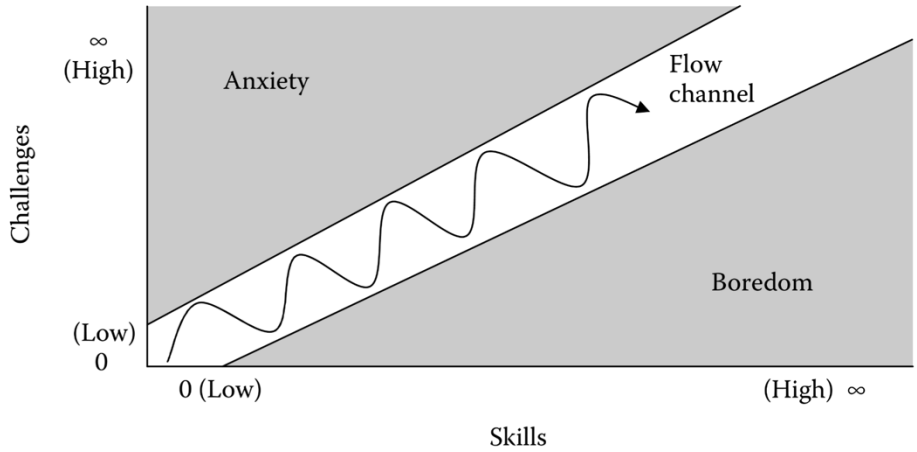

Figure 3. Evolution of a player over time playing the game [14]

The book "The Art of Game Design" by Schell [14] mentions that the cycle of 'tension and release' appears several times in design. It seems to be something inherent to human satisfaction. Too much tension wears the player out. Too much relaxation tends to bore the player. So, when we vary between the two, we enjoy both relaxation and excitement, and this oscillation provides the pleasure of multiplicity as well as the pleasure of anticipation [14].

As for the subcomponents of text-to-speech and speech-to-text, these allow the implementation and use of Portuguese language using the synthesized voice of Cortana in case the game runs on Windows. On Android mobile device, the text-to-speech engine also allows for that in case the device can provide the European Portuguese.

Another subcomponent used is the Avatar of Portuguese Sign Language, an avatar developed by GILT (Games, Interaction and Learning Technologies), that aims to support deaf users and those who understand Portuguese Sign Language. The user can click or select the text presented in the game to obtain a real-time translation operated by this avatar.

The server component is divided into two main components, a virtual machine (Amazon EC2) hosted on Amazon's cloud platform, called Amazon Web Services, and the Docker container which provides an image-based deployment model. It makes it easy to share an application or set of services, including all their dependencies across multiple environments.

Docker also automates the deployment of the application (or set of processes that constitute an application) within the container environment [15]. In this project two images are deployed, one with NodeJS that not only enables the integration of the online component of the game through socket communication, but also the creation of a REST API to obtain data regarding the ratings on the game server. The second image that makes up the Docker container is the database, which through NodeJS will receive the data that must be endured between the players and the server.

To define the essential functional requirements to the serious game, 10 essential requirements were determined for the development of the game, in particular the focus on the player. These functional requirements are actions or tasks accessible to the players: (1) The serious game should allow to choose the accessibility need by the player; (2) The player should have a means to authenticate/associate the device; (3) The player can enter any queue for a particular game mode; (4) The player can learn Morse code before testing the knowledge against an opponent; (5) The player can check several times the possible answers until giving a final answer; (6) The player has unlimited response time; (7) The player has dynamic adjustment of the game difficulty; (8) The player should have access to his current score; (9) The player has access to a chat room; and (10) The player can leave the game.

Regarding the database used in this serious game, its purpose is the preservation of data, namely those concerning the player. Some preferences such as the chosen accessibility are stored in the memory of the device that the user uses during the gameplay of this serious game. Using PlayerPrefs, a class that belongs natively to Unity, it is possible to store this data in memory.

3.2 Game rules and mechanics

The Morse code is a system represent by letters, numerals and punctuation using sound signals. These signals can be short or long, and they translate into a visual scheme of dots (short signals) and dashes (long signals). Afterwards, in a first phase it was necessary to divide the digits into different degrees of difficulty (Table 1). To simplify it for the players, the punctuation was removed from the learning process.

Table 1. Morse code associated to each difficulty

Difficulty Levels	Morse Code characters
Easy	"T", "E", "M", "N", "A", "I", "H", "S"
Medium	"G", "K", "D", "W", "R", "0", "6", "U", "O"
Hard	"Q", "Z", "Y", "C", "X", "B", "J", "P", "L"
Very Hard	"F", "V", "1", "2", "3", "4", "5", "7", "8", "9"

The levels of difficulty were distributed from the letters and numbers with the least number of sounds to memorize to the most complex that contemplated five signals. However, some of the letters or numbers such as "H" were selected for the lowest difficulty level because the short sound is repeated four times, which allows this letter to be memorised more easily.

During the game, whichever game mode is chosen, the player will have four checkpoints that the user must pass. At each one, the player will hear a telegraph emitting the sound of a signal in Morse code. The player will have two options at each checkpoint, one being the correct answer.

4 Implementation of the Serious Game

Since blind and deaf people have different needs, at the beginning of the game a short introduction through sound is given about the basic mechanics. This way, at the beginning of the game it is possible for players to choose which type of accessibility they need, with hearing or visual support (Fig. 4). Based on their choice, the game interfaces are adapted.

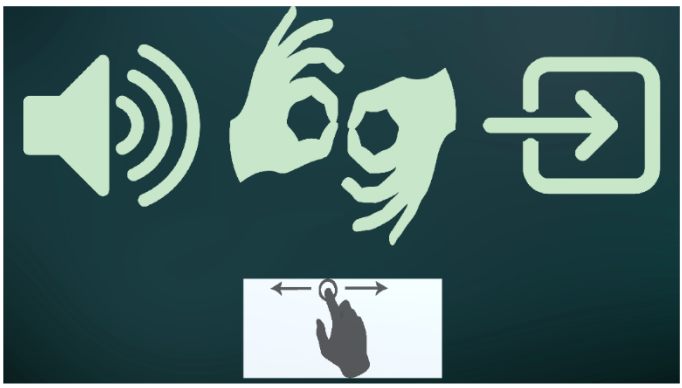

Figure 4. Choice of hearing support (left), sign (centre), or no additional support (right)

4.1 Development of the Initial Interface

The start menu of the game (Fig. 5) is the first screen presented to the player that allows him to interact with the implemented functionalities, from making changes relevant to the player type of accessibility (e.g., text to speech speed, sign language avatar size), enjoy interaction with other active players on the server through conversations, learn more about the history of Morse code, learn the Morse code corresponding to each alphanumeric value or test his knowledge by playing multiplayer in three available game modes. All information on the screens is available with audio description and Portuguese Sign Language.

Figure 5. Start menu with sign language accessibility

A section was developed for the player to have a first contact with Morse code. In this section, the player can go through all the alphanumeric digits that constitute the Morse code. Although there is a correlation with other digits such as comma or question mark, at this stage of the project it was preferable to forget punctuation due to the added difficulty degree given for the player to memorize that could vary between the short beep or long beep. In total there are 36 digits with a corresponding Morse code, being them 21 consonants, 5 vowels and 10 numbers (Fig. 6).

In the case of using voice accessibility, as the player scrolls through the digits, he will hear the sound of the letter he is exploring, possible after pressing the space bar or, if he is on an Android device, through double tapping to access the correspondence to the letter selected. By using Portuguese Sign Language as a means of accessibility, you will have information about the letter or numeral you want to know in Morse code. If they do not choose any accessibility, the Morse code will be presented on sound and visual form corresponding to the alphanumeric value chosen. If the player, however, decides to remove the sound from the game, he will not be under any disadvantage during learning.

If the player decides to be self-taught, he has an option to learn Morse code without being dependent of a second player. Here is given the first step of Bloom's cognitive model, where memorizing is done by the player associating the Morse code sounds to the letter or number. Making a parallelism with the first step, we check if the target audience were paying attention on the presented content and if they have acquired some knowledge by asking questions while the player explores the digits.

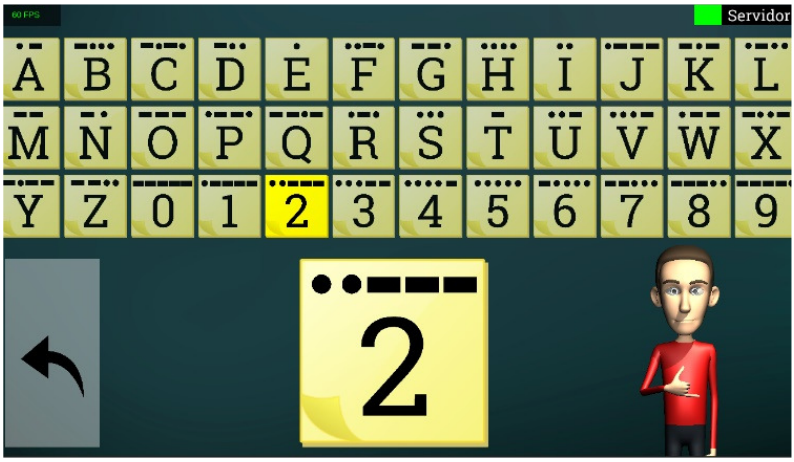

Figure 6. Menu layout of Morse code learning

4.2 Development of the Initial Interface

Three game modes were developed: the traditional 1 versus 1, a cooperative mode between two players and a game mode for up to 4 players simultaneously. Using environmental assets, it was possible to organize a scenario where it was possible to implement the objects associated with the game. In what follows, Fig. 7 shows a general view of the scenario used. In red we can see the small portion of the map where the player will navigate, corresponding to the four checkpoints developed for this game. The scalability of the game is high since there is enough room to incorporate other environmental and sound components to create a more pleasant experience. With the purpose of keeping the game functional and with good quality in terms of performance, the resources used in a context outside the use of the computer are the minimum ones since the rendering of 3D objects is high.

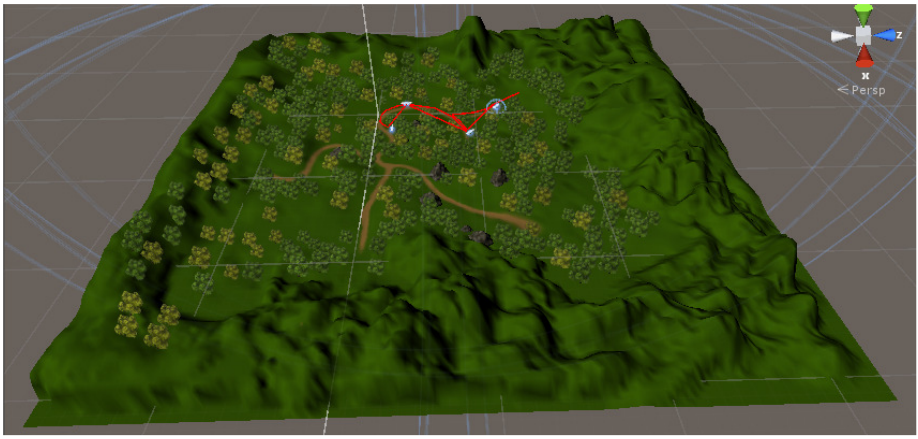

Figure 7. Overview of the game map with the four checkpoints

To incorporate the dynamic difficulty adjustment component in these game modes, four checkpoints were implemented, consisting of a Morse code being emitted by a telegraph and two possible responses, and can be scalable through new checkpoints and levels (Fig.8).

Figure 8. Example of a checkpoint through the interface presented to a user without accessibility when using a PC (left) and the interface presented with sign language (right) using an Android device

As proof of concept and since this is a multiplayer game, considering the initial complexity in learning and after feedback obtained with the target audience, it was preferable to implement a short and functional path. In this route, the difficulty will be dynamically adjusted according to the performance of both players since the Morse code presented will be the same. If both players reach the first checkpoint, when they get to the second checkpoint the difficulty will increase slightly, i.e., adding one alphanumeric value to the Morse code. Although, to be reasonable, if one or both players miss, the difficulty is maintained at the next checkpoint. This way, the more skilled player will receive a victory score at the end, allowing them to be paired up with more skilled players in the next game. When the passage through all the telegraphs present is over, the server calculates the new score acquired by the players, displaying the result obtained in the game and the new points in the league table. This calculation is based on the ELO rating system, as mentioned above.

The team game mode is similar to the previously mentioned game modes, where initially a short tutorial is presented with audio description, sign language or text according to the active accessibility needs of the player. The difference that gets the player's attention is that the communication between the two players is active, i.e., both can communicate with each other in the way that is most convenient. If the player is blind and assuming he chooses the voice accessibility mode, using the defined controls, he will be able to communicate with the other player by voice. In turn, the other player receives the message in text, although how it is played depends also on their accessibility choice. That said, both players can share their opinion on the correct choice for the Morse code broadcast via telegraph.

5 Evaluation Methodology

In order to verify if the serious game with Morse code and sign language contributed for the improvement of social inclusion and access to education of deaf and blind people, the game was evaluated with a total of 14 respondents.

To evaluate the final solution, the following dimensions were defined to assess the quality of the serious game:

- Technical - In the technical aspect of the game it is possible to conclude if the functionalities and accessibilities provided meet the player's requests;
- Ergonomics - On the ergonomics dimension, it is intended to obtain comments about the player's interaction with the serious game on the platform intended by the player. In this case, the factors to be evaluated are usability, playability and socio-cultural;
- Pedagogical - The pedagogical magnitude allows to access if the serious game had a positive effect on learning, in this case, through the Morse code theme. The factors to be assessed are learning and critical thinking.

5.1 Quantitative Evaluation Framework

To validate the quality and performance of the developed serious game, an analysis using the Quantitative Evaluation Framework (QEF) was performed.

The QEF is a generic tool that allows evaluating any platform at any stage of its development [16]. It usually presents three dimensions, and each of these dimensions presents a set of factors, each of which is formed by a group of requirements [17].

In accordance with the requirements of this project, it is possible to define the QEF in three dimensions: pedagogical, ergonomic, and technical. These dimensions allow assessing the objectives intended with this project.

Regarding the pedagogical dimension, the two factors that are intended to be assessed are learning and the accessibility provided for that purpose. The types of requirements assessed refer to Bloom's taxonomy and the theme of Morse code.

In the ergonomic dimension three factors are assessed: usability, playability and sociocultural. Regarding usability, the requirements assessed include the interaction between the player and the serious game, as well as factors external to the player, but relevant to usability, such as server performance and the platforms where the game can be executed.

Finally, the technical dimension allows assessing the functionalities implemented in the serious game and if the types of accessibility implemented are used conveniently so that the target audience feels that it is not invasive, but an added value in the game.

In total there were 57 requirements defined in the QEF (Table 2), in which the requirements were evaluated using the use of the game by the target audience. To this end, a survey was developed to address these factors. In the general contingent of the QEF and using the feedback obtained during the experimentation phases of the project prototype with the target audience, the QEF allowed obtaining a compliance rate of 88%, which is an interesting result given the target audience with accessibility needs implemented to provide them with a pleasant experience. Overall, the users were pleased with the experience and recommended the serious game for Morse code learning purposes.

Table 2. Quantitative Evaluation Framework (QEF) for Morseline

Dimensions	Qi	Pij (Weight of factor j in Dim i) [0,1]	Factors	prjk (Weight of requirement k in Factor j) {2, 4, 6, 8,	Requirements	pck (% fulfilment of requirement k) [0,100]
Pedagogical	87,07	0,55	Learning	10	The game promotes an incremental educational line	75
				8	The game rewards players who best identify the Morse code presented	100
				10	At each checkpoint, players receive a comment whether the answer was correct or not	75
				10	The learning context follows the guidelines presented in Bloom's taxonomy	100
				10	The learning context for Morse code is appropriate	75
				10	The game enables recognition of patterns interlinked with Morse code	100
	79,17	0,45	Critical thinking	10	Game promotes self-directed learning	100
				8	The game allows for the collection of information about Morse code before the player enters a game	100
				10	Through response possibilities, the player can make the most correct decision	75
				10	Through audio about Morse code and the corresponding character, the player can make a mental association	75
				10	The feedback received on the answers, allows the player to identify the correct one in a next attempt	50
Ergonomic	82,07	0,45	Usability	10	The navigation interface is intuitive	100
				10	In-game instructions are clear, precise and concise	50
				10	The user can easily start and exit the game	75
				10	Navigation between menus is consistent	75
				10	The game content contains no grammatical or syntactical errors	100
				10	Game is cross-platform	75
				10	Visual and auditory feedback is provided on player actions	75
				10	Server performance is acceptable	100
				6	Game takes advantage of native platform features	75
				6	Game can be updated without affecting current settings on the device	100
	81,55	0,45	Pl av	10	Appropriate supports for accessibility needs enhance gameplay	100

Dimensions	Qi	Pij (Weight of factor j in Dim i) [0,1]	Factors	prjk (Weight of requirement k in Factor j) {2, 4, 6, 8,	Requirements	pck (% fulfilment of requirement k) [0,100]
				8	The game is challenging	100
				10	Morse code is understandable	100
				10	The main objective of the game is made clear at the start of the game	75
				10	The difficulty is adapted according to the players' responses	75
				10	The player pairing system is fair	75
				4	The history of Morse code is inserted to enrich the knowledge of the subject	100
				8	The game provides hints during gameplay	0
				8	The game features several checkpoints available at each game scenario	100
				6	The scores obtained reflect the level difference between the players	100
	78,57	0,1	Sociocultural	6	Game is available in several languages	50
				8	Game does not contain offensive content or violence that may offend any community	100
Technical				10	User chooses the type of accessibility	100
				10	User is able to create an account	0
				10	User has account associated with device	100
				8	User enters any game mode queue	100
				8	User logs out of game mode queue	100
				10	User logs into game after server has found the required players	100
	88,39	0,58	Functionality	8	User chooses which character of the Morse code he/she wants to learn	100
				10	User can see or hear the Morse code	100
				6	User can make changes related to his accessibility type	100
				6	User can repeat Morse code within the game	100
				10	User can repeat the possible answers to decipher Morse code	100
				2	User is given a rating in the game	100
				6	the user can check the global scores	50
				8	User can leave the game	100

Dimensions	Qi	Pij (Weight of factor j in Dim i) [0,1]	Factors	prjk (Weight of requirement k in Factor j) {2, 4, 6, 8,	Requirements	pck (% fulfilment of requirement k) [0,100]
	85	0,42	Accessibility	10	The synthetic voice communicates conveniently with the player	100
				10	Instructions given by the synthetic voice were clear	75
				10	The speed of the synthetic voice is appropriate	75
				10	The audio or visual cues during menu navigation are adequate	75
				10	The audio is balanced	100
				10	Sound should not be intrusive to navigation and gameplay	75
				10	Sign language avatar communicates appropriately with the player	75
				10	Instructions given by the avatar are clear	75
				10	Produced gesture speeds are appropriate	100
				10	Avatar should not be intrusive to the navigation and playability of the game	100

5.2 Testing and Assessment

When the players were asked whether they had gaming habits in the last year, 85,51% (N=12) answered yes and 14,29% (N=2) answered no. When asked about their favourite platform to play in (PC or smartphone), 64,29% (N=9) chose PC and 35,71% (N=5) chose smartphone.

Afterwards, the first component of the questionnaire related to the pedagogical dimension and the questions focused on the theme Morse code, in relation to its learning or application in a game. This component was composed by 5 questions that included five choice options. A Likert five points standard scale was used: totally agree (5), partially agree (4), neither agree nor disagree or neutral (3), partially disagree (2) and totally disagree (1). In the second part of the questionnaire, the questions focused on the ergonomics dimension, placing questions about usability and playability of the serious game. In this component of the questionnaire there were 6 questions. Some of the answers given also served as support to the technical dimension of QEF.

Finally, the placed questions focused on the technical dimension of the game, its functionalities and online component. The questionnaire was made available online through the Google Forms platform, in the format of open-ended questions to understand if the respondents were regular gamers and what type of games they were interested in. In the end of every survey, a comment was asked to the users their suggestion about new functionalities and improvements that they would like to see implemented.

In a first phase of testing, that lasted two days, there were 5 people in the first group that tested the solution, where there were two blind female people from birth, two blind male people and a young male with low vision. ACAPO was very important to carry out these tests because it offered very proper conditions and enough time to accurately test the game. Still during the first phase of testing, which mainly contemplated the gameplay limited to two checkpoints instead of the four presented in the final solution and which served mainly to get feedback from the development, the game was tested with random users. Most of them did not have any kind of hearing or visual impairment, but they preferred to try the game with hearing support or without any kind of accessibility. Even though the target audience are the blind and deaf communities, these respondents still tested the game, and they are still able to play this serious game as long as they do not choose the hearing or visual support option at the beginning of the game. In this group, there was one female and four male players.

In the last phase of tests, ACAPO again offered the chance for assessment, in which some of the respondents also participated in the first phase of tests. As such, it was possible to assess if the development was in accordance with the comments received in the first phase.

6 Results

The response rate was 100%, meaning that all users that tested the game replied to the final questionnaire. It is important to note that the population sample tested the game on both platforms, and the answers are based on the gameplay experience on both devices (PC & Android). In this results analysis it is intended to verify if in fact the tested hypothesis is valid or null.

In the three dimensions analysed, the vast majority of respondents gave a favourable answer, predominantly marking options 4 and 5, based on the Likert scale described above. The ergonomic dimension was the most appreciated by respondents, with the average response corresponding to 4.81. It is possible to state that, given that this dimension aims to meet the target audience's accessibility needs, respondents usually evaluated the points referring to the type of accessibility chosen by them with the maximum score.

6.1 Pedagogical Dimension analysis

The pedagogical dimension was supported by the answers given to this component of the questionnaire to fulfil the QEF. This dimension ended with a compliance rate of 83.38%.

The fact that all respondents agreed, even if in some cases partially, makes it possible to state that the objective of the serious game to promote education in the target audience already defined was fulfilled. The respondents in their great part had knowledge about Morse code but did not know how to apply it. Respondents who during the gameplay of the serious game chose the hearing support offered a lot of feedback regarding information that could be placed to enhance it, namely in the synthetic voice lines and insertion of new didactic content

with the use of Morse code. Of the three groups of respondents, they were the only ones in which all totally agreed.

In order to validate the tested hypothesis, the result obtained in this question allows the hypothesis to be accepted. Together with the multiplatform implementation of this serious game, respondents develop learning skills and enhance their digital literacy.

6.2 Ergonomic Dimension analysis

The ergonomic dimension was also supported by the answers from this component in order to fulfil the QEF. This dimension ended up with a compliance rate of 82.23%, which despite being the one that fulfilled the least requirements in its entirety, was also the most complex to assess with the QEF since it considered the accessibility components in gameplay for blind and deaf users.

During the planning phase, there was a special consideration to never reveal what type of accessibility the opponent or teammate had active. This result was corroborated with the opinion of the respondents, where 92,86% (N=13) chose "totally agree" and 7,14% (N=1) "partially agree" about omitting the type of accessibility used by the participants. In this case, being a multiplayer serious game, whose aim was to promote learning to its users, there is no interest in knowing whether the players they face are blind or deaf for example, except for statistical purposes. Even during the team game mode or while using the chat room, users communicate in the most convenient way for them, and the message sent is handled according to the accessibility chosen by the users receiving it. Consequently, the vast majority of users gave the maximum score during this question.

Regarding equity, only one respondent did not agree that the game promoted it. A possible justification may be that this respondent is a user who has not tested the accessibility component for the blind or deaf. In other words, not being aware how all the implemented interfaces worked and what the intended needs were for users from these communities, he chose to give a score of three (Indifferent) on the Likert scale.

6.3 Technical Dimension analysis

The technical dimension, which encompassed the game functionalities, relied on the answers given by the respondents in order to complete the QEF. This dimension ended with a compliance rate of 86.98%.

During the development of the game, one of the plans was to allow users to easily access the preferred accessibility choice. As previously stated and demonstrated, the controls are simple for any type of user and the ways to navigate the game are well explained. That's why in the question "Can you easily choose the type of accessibility?" the respondents were unanimous in answering "I totally agree". The fact that the users were unanimous was important to validate the development about accessibility needs to promote the best possible experience while using the game.

7 Conclusion

At the core of this work was the almost non-existence of games that were accessible to the blind and deaf communities at the same time. Even though the population with these specific accessibility needs are a minority, they should not be forgotten. At a time when technological advances are greater than ever, the remoteness of technologies created for people with disabilities is increasing.

In light of this situation, the system/framework was developed using a practical example that offers a learning theme that sets almost all its users at the same level, regardless of whether they have some kind of disability or not, due to the fact that few people have practical knowledge of how Morse code works, even if having a brief idea of what it might be.

As such, during the research phase, information was collected regarding methods of applying accessibility tools, as well as design architectures that follow appropriate guidelines for specific accessibility cases along with models that promote learning. Also, during this phase it was not possible to find any game, irrespective of whether it was a serious game, that was prepared to provide means of accessibility to blind and deaf people simultaneously.

During the design and development phase of the solution, good engineering practices were adopted from project planning to the use of a project version control system using GitLab and the use of QEF to assess the quality and intended evolution of the final solution. In the end, the compliance rate was 88%, leaving room for improvement in order to make the developed project a useful tool for learning Morse code or even for other education-related topics.

The solution was tested, improved, and validated with the support of the Association of the Blind and Visually Impaired of Portugal (ACAPO) and with the help of randomly chosen users for testing. By the end, 14 survey responses were collected. University students tested the serious game without any active accessibility, which also allowed to include a larger amount of population that can use the game for learning purposes and at the same time for entertainment while trying to get the highest score on the server.

As already mentioned, the initially proposed objectives which were to improve social inclusion and access to educational themes to promote learning for blind and deaf people were achieved after the hypothesis put forward during the experimentation and evaluation phase was validated. The aspects related to accessibility, namely through a voice assistant (text-to-speech), the use of the capabilities of the devices in which the serious game was executed to allow the conversion from voice to text and a Portuguese sign language avatar were only implemented with due success given the improvements made during the development of the project by means of essential comments that were provided during the testing phase of the solution.

Considering those comments, improvements in the avatar would be an important step in supporting people who use Portuguese sign language, as it can sometimes disrupt the context of some of the words it translates or else translate letter by letter instead of translating a word in its entirety. The use of machine learning to improve speech to text would be an

important advance, because currently some of the words identified using the library provided by Unity are not correctly detected.

In conclusion, the inclusive game on screen allowed the team to prove that the use of accessibility guidelines during software development, which in the case of this work was a serious multiplayer game, permits the inclusion of communities previously excluded. To do so, it is enough to carry out a commitment with these communities during development, as well as to realize that a small gesture can change their lives.

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