

Design and development of an educational memory game solution for players with and without visual impairment

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***Abstract.** As games have risen as one of the most popular forms of entertainment, they have also been proved to be good educational resources. However, because this media often focuses on the visual aspects, people with visual impairments are often unable to make use of them. Thus, the aim of this study is to propose a design solution of a multiplatform memory game that targets people with and without visual impairments. For this, studies on design solutions for accessible memory games on different platforms are analysed. A design proposal is presented, which is based on these solutions, as well as on guidelines of accessibility and playability. Finally, a low fidelity prototype is used to test the interaction of a visually impaired player.*

1. Introduction

Through the last decades, digital games have become one of the most popular forms of entertainment, and this growth has impacted many areas. In education, games bring a ludic approach to the field by integrating educational goals with fun, and thus have proven themselves excellent educational resources, aligned with new learning styles (PRENSKY, 2012). However, people with disabilities face many issues when trying to play games (BIERRE et al., 2005), which hinders their experience for entertainment and access to new ways of learning. This situation is especially true for people with visual impairments, as the inadequacies this group experiences are associated to the fact that games often rely heavily on visual content for stimuli (ARCHAMBAULT et al., 2007).

In order to ensure that visually impaired people have the opportunity to experience games and to be able to use of them as educational resource, this study aims to propose a design solution of an educational Memory game that has people with and without visual impairments as target group. The design took into account studies made with this game genre, as well as a set of accessibility, playability and learning recommendations that is being proposed in a master's degree project. To validate the proposal, a prototype of the game was developed and evaluated with the recommendations and tested by members of the target group. The final product aims to be an open multiplatform memory game with customizable content (according to educational goals), and it will be available on the online platform REMAR¹, which hosts customizable educational games that can be used as open educational resources.

¹ <http://remar.dc.ufscar.br/>

The following sections describe the methodology used during the study, as well as a systematic review conducted to find related works about memory games accessible for visually impaired people. Previous works done by the research group are presented as further input sources for the design of the game, followed by an evaluation of available solutions. Finally, this study's design is proposed, as well as a description of the prototyping and user testing process.

2. Methodology

This study uses exploratory research in order to propose a design solution of a memory game for the target group of people with and without visual impairments, so that the game experience for any member of the group would be as similar as possible.

As a first step, a systematic review of existing solutions for accessible memory games was conducted, in which the focus was to analyse how other solutions were implemented and evaluated. A Think Aloud (TA) user testing was conducted in which a player with vision impairment tested one of the solutions found in the systematic review. In addition, a previous work at our research group analysed a non-accessible memory game and proposed a redesign to make it accessible for people with visual impairments (SATO, 2015). This work results were analysed and contributed as input to this study's design proposal.

A design proposal was then defined, and a low fidelity prototype was created. The prototype was evaluated through a TA user testing. The outcomes were used to refine the prototype and to analyse the proposed solutions effectiveness.

3. Related works

In order to find the state-of-the-art of digital memory games designed with visually impaired people as part of the target group, a systematic review was conducted. The review aimed to answer the following research question: ***What are the design solutions for digital accessible memory games that have visually impaired people as part of the target group proposed in the studies?*** From this research question, the following search string was made:

Game AND (Concentration OR Memory OR "Match Match" OR Pairs OR "Match Up" OR Pelmanism OR Pexeso) AND ("Vis* Impair*" OR "Vis* Disabilit*" OR Blind OR Accessib* OR "Vision Loss")*

The searches were conducted on IEEE, ACM, Scopus digital libraries and the proceedings of SBIE and SBGames, two major Brazilian conferences related to this topic. All the searches took place between March and April 2018. They were based on title, keywords and abstract.

The systematic review started with 126 entries, out of which 18 were duplicates. 12 of the remaining studies were selected to the extraction phase, applying exclusion and inclusion criteria. From these, 5 were relevant to answer our research question.

Raisamo *et al.* (2007) proposed a memory game to be played using a D-pad controller with vibration function. Horizontal positioning was informed using stereo audio variation (often called pan), while vertical positioning presented different notes of a xylophone. Empty spaces were presented with the corresponding pan and pitch, but 50% of the volume. A high-contrast graphical interface was also used. The developed game used only tactile feedback as a card's content.

In their study, Usui and Yairi (2010) tested five sound properties being paired with each other, in order to evaluate which set would allow players to better recognize the elements' positions. The game was played in touchscreen devices. After testing, the selected pair was pan variation for horizontal navigation and octave scale (Do Re Mi Fa) for vertical navigation.

Delić *et al.* (2010) intended to use binaural audio for positioning recognition, but the design was restrained to only two sound channels to allow the game to be played with regular phones. Pan was also used in this study to localize horizontal position of the elements, while sound pitch (frequency) was used for vertical position. The player could give the coordinates via automatic speech recognition (ASR) or use the keyboard to navigate the game field.

The memory game present within the Audio Game Hub, *Animal Farm*, was evaluated by Fizek *et al.* (2015). For their tests, the game was played on the iOS platform. *Animal Farm* uses binaural audios to localize each element on the board. The evaluation had good results, as the players were able to find the cards on the touchscreen interface.

At last, Pucher's proposal (Pucher *et al.* 2017) consists of associating each card to one key in the keyboard, enabling a more tactile experience. The auditory feedback didn't use localized sounds.

In all the studies' solutions, every action was associated with a different feedback (correct pairs, wrong pairs, end of game, field edges, etc.). Additionally, except from the tactile memory game proposed by Raisamo, the theme most commonly used as content for the cards were animal sounds.

This work intends to contribute by proposing a design solution for a customizable and multiplatform memory game that has people with and without visual impairments as target group. Our solution integrates some related works and our previous studies outcomes.

4. Previous works

Some research has been conducted at our research group to provide accessible educational games. Sato (2015) analysed *Quimemória*, a chemistry educational memory game, and proposed a redesign to make it accessible for people with visual impairment. The proposal was validated through a paper prototype tested by blind and low vision players and included some important suggestions. A set of colours is suggested so that colour blind players are able to access all information. In the case of partially sighted players, the suggestions included adjustable fonts, high-contrast texts and bigger images. On the other hand, for completely blind players, the game would also have all information given via audio through the use of screen readers. She suggested that the game's interaction should also be adapted to suit the needs of visually impaired players. While still allowing the use of mouse, she suggests full keyboard support, including the possibility to navigate the cards using arrow keys or direct access with specific keys. Sato also recommended four distinct audio feedbacks (correct pair, wrong pair, empty space and end of game). According to her, the game should permit sufficient time for the player to get the information from the cards, taking in consideration that navigating through keyboard takes more time than using the mouse,

and that a card's content must be read by the screen reader. In addition, an option to disable the time limit was recommended.

Furthermore, an ongoing master's degree project proposes a set of recommendations that covers playability, accessibility and educational aspects (Fontoura Junior, 2017). The set is intended to help developers make better accessible educational games by integrating Game Accessibility Guidelines (GAG, 2018), Desurvire's heuristics for good usability in games (DESURVIRE; WIBERG, 2009) and Gee's good games learning principles (GEE, 2007). Taking into account that not every development team has the resources to make complex games completely accessible, this set is divided in Basic, Intermediate and Advanced, recommended according to their relevance and cost. For this study, the Basic set was used to guide the design and to validate the low fidelity digital prototype.

5. Evaluation of an available solution

With the purpose of evaluating an already accepted solution for the genre, the memory game in Audio Game Hub², *Animal Farm*, was tested. The game was designed for desktop (Windows), Android and iOS. In the desktop version, the menu can be navigated using keyboard and mouse, however the memory game itself can only be played with the mouse. As it was also intended to verify how the experience of a visually impaired player using the mouse would be, the user testing was conducted using the desktop version. The participant has severe low vision which requires him to use screen readers in order to make use of computers. He has experience in games - electronic and analog ones - though he had no previous contact with the Audio Game Hub.

The user testing was conducted using a Think Aloud (TA) approach, in which the participant was asked to describe his thoughts and feelings as he plays the game. The participant was asked to play the first phase (six boxes, distributed on a 3x2 grid). The instructions given in the beginning of the game were translated for the player simultaneously. The participant was uncomfortable about being asked to use the mouse. After completing the first phase, he failed his first attempt on the second phase due to the time limit. On his second try, the second phase was also completed.

In the test it was noticed how energy consuming it is for a visually impaired person to work with a mouse. The player himself said that the solution would work better on a touch screen device as it would be possible to have the spatial notion of the boxes' distribution on the screen, while the use of mouse does not permit the same sensation. Although the participant was able to complete two phases of the game, the lack of feedback from the empty spaces that are left after the match of a pair harmed his ability to navigate the board.

When asked to give feedback about the game, the participant main complaint was about the navigation. He could locate and associate the boxes using the 3D audio, but to find the elements on the screen was his main difficulty. The time limit was also detrimental to his experience.

² AudioGameHub is one of 5 applications nominated in Best Accessibility Experience nomination at Google Play Awards 2018

6. Proposed solution

The following section describes the proposed solution for an accessible, customizable and multiplatform educational memory game, as well as the process of developing and testing a low fidelity prototype based on that. The description of the design covers each of the game's elements. The user testing is described, and the results are presented together with a discussion on how to further increment the prototype.

6.1. Design of an accessible memory game

The Mechanics of the game are the same as the classic memory game. A definite number of elements are randomly distributed on a board (in this case the elements are cards). The content of the cards is hidden from the player, and each card has another card that matches its content. The game goal is to find all matching pairs. For this, the player must choose a card, so its content will be revealed. The player then chooses a second card, and if the content of both cards does not match, both cards are flipped down again. If the content of cards matches, the cards are "removed" from the board. The removed pairs stay in the board but are shown as open cards, and their selection auditory feedback is different from the closed ones. The necessity of keeping found pairs on the board was a point brought by Raisamo (2007) and observed during the *Animal Farm* user testing (the lack of feedback from the empty spaces harmed the user ability to navigate the board).

As observed in the test made with *Animal Farm*, for a desktop game to be accessible to visually impaired people, it should be fully played through keyboard. For this reason, the elements on the board can be navigated using the Arrow keys, in which one card is selected at a time. In addition to the discrete one-by-one navigation, each card can also be bound to a key on the keyboard what allows the player to directly select a card, as suggested by Pucher *et al.* (2017). Other actions are bound to different keys of the keyboard, while still taking in consideration standard uses attributed to those keys. For this, both the Space Bar and the Enter key (Return) can be used to open a selected card and reveal its content. The Escape key is used to access and exit the in-game menu. All menus should be designed to be navigated using arrow keys.

As the proposed design is also intended for players with no visual impairment, the game should also offer mouse support. The pointer is used to select cards via a continuous navigation of the board. A selected card would be chosen when clicked upon, revealing its content. The use of the mouse can also be easily transcribed to mobile platforms inputs, as the pointer can be associated to a finger navigating the screen, and the mouse click to a touch.

For the game to be completely accessible, an auditory feedback should be associated with every event of the game (ATKINSON *et al.*, 2006). In this case, the main events are: selection of an element, revealing of an element's content, correct pairs, wrong pairs, attempt to open an invalid card (a card that was already open or that was "removed" from the game) and knocking the edge of the board. For content of the cards, they should be spoken out loud. As this study's game intends to allow customizable content in the cards, the integration with a speech synthesizer seems to be the best option.

To represent the two dimension of the board, the selection auditory feedback changes according to a card's position on the board. The stereo variation (pan) can be used to represents a card's horizontal position, while a variation on the sound's pitch can be used to represent the vertical position (RAISAMO et al., 2007),(USUI et al, 2010),(DELIĆ et al. 2010). Thus, to represent the rows of the board, different notes of the musical scale can be used – the lowest note being associated to the lowest row –, and the pan of the note is adjusted according to which column the card is located.

Graphical feedback should also be given for the game. The selected card can be represented by a bounding box around it. An open card's content displayed in written form. The game elements should be presented with high-contrast, and the texts with big enough font size. A removed pair can be represented as an open card but with lower opacity values. The colour scheme should be the ones that can be fully discerned by all types of colour blindness.

6.2. Development of prototype

With the intention of validating the design proposal, a low fidelity prototype of the desktop version was developed. The prototype was developed using the game engine *Unity*³. The engine was chosen as it offers an extensive audio application programming interface (API). As *Unity* was primarily built for 3D games, its API offers support for 3D audio in which developers can easily control the values of sound assets, like pitch and pan. Moreover, *Unity* offers an in-built Event System that already implements input recognition from keyboard, mouse, touch-screen and game pads, as well as the possibility to create builds for desktop and mobile platforms.

The prototype was created to validate the input controls and the feedback proposed in the design. For this, the game board shown in figure 2 was developed. The sprites and sound effects used were taken from previous projects developed at LOA⁴, all available as open educational resources in the Digital Repository Live Saber⁵. The selected theme for the cards' content was names of countries and their capitals (but this content will be customizable). The audios for the content were created using a free online text-to-speech tool⁶, and used to simulate an in-game speech synthesizer.

The pan values used for the localized selection feedback were, from left to right, -0.75, 0.0 and +0.75, so all three columns would have very distinguishable stereo effects. For the rows, the pitch values were 1.0 and 2.0, for the lower and higher rows respectively.

³ <https://unity3d.com/>

⁴ <http://www.loa.sead.ufscar.br/>

⁵ <http://livresaber.sead.ufscar.br>

⁶ <http://www.fromtexttospeech.com/>



Figure 2 – The visual interface of the memory game prototype

6.3. User testing

In order to validate the developed prototype and to verify the possibility of a column in the complete middle of the board, a user testing was conducted. The test was made with the same participant that had tested the *Audio Game Hub* with a mouse. Apart from the phase in which the cards were distributed in a 3x2 manner, a second phase presenting a 2x3 board was created. The participant was asked to play both phases of the prototype game and share his thoughts on what he was intending to do.

At the beginning of each phase, it was explained to the participant how the cards were distributed. This was very valued by the player, as he was able to have a better overview of the game board. The player still asked us to explain what each sound represented, and every time a sound effect was played he would give us feedback on how that felt and how clear the information was.

The participant finished the first phase but preferred to just give us feedback about the differences between the 3x2 and 2x3 layouts, as the game would not offer a difference in challenge between those two. According to him, the auditory feedback was effective in both layouts as it was possible to navigate through the board in the same way. The participant also described that the knowledge on how the cards were arranged made the navigation easier, something that was also observed by Raisamo (2007). On the other hand, the participant pointed out how the highest pitch could be misunderstood with the edge knocking sound effect, so that more variance in pan might be better for larger quantities of cards.

Feedback on the “already flipped card” sound effect was also given, as the participant found insufficient to have the same “hovering effect” but with lower volume. For him, a sound representing “emptiness” would be optimal. He also asked for a better “end of phase” sound and that when finished some feedback on his performance could be presented.

Regarding the inputs, the participant preferred using the arrow keys as he is “used to navigate through tables, but other players might prefer to use the direct access”. Other feedbacks given was that he liked how the game was played, and that the customizable content will make it more challenging as a pair could have different values for each card, like a word in Portuguese and its translation to English.

6.4. Refinements and new tests

Based on the feedback received from the test, a new version of the prototype was developed. The sound effects used to indicate a card's position were changed to notes of a piano, and a new sound to represent the flipped cards was added. The volume of the sound effects was also adjusted for them to be in the same level.

With the intention of offering a better challenge to the players and test the game with more cards, the new version presents three phases with progressive difficulty: 6 pairs distributed on a 2x3 layout; 8 pairs on a 2x4 board; and 12 pairs configuring a 3x4 distribution.

Further tests were conducted with five users. The new sound effects promoted better experiences and a clearer distinction between each event. However, the tests confirmed the need for an in-game initial explanation or a tutorial level, at the beginning of the game, introducing the mechanics, inputs, feedbacks and the distribution of cards. Two users did not receive this information and had initial difficulties in mapping the card positions, navigating and understanding some sounds feedbacks. Three users received an initial guidance and were able to execute the test safely and smoothly. In the 3x4 phase, some users had difficulties in keeping awareness of their current position in the board. A new function may be implemented to provide the current position (line and column) on demand.

7. Conclusion

In this study, the proposal and evaluation of a design solution for a multiplatform memory game that is accessible for visually impaired people were presented. The design was based on solutions for the genre found in literature through a systematic review, as well as recommendations from a redesign proposal and of guidelines of accessibility and playability. Based on the presented proposal, a prototype was built and tested by vision impaired players in two development iterations, proving it to be functional and accessible.

Through the analysis of the results, it was possible to conclude what are the main features that a memory game (or similar genres) should present in order to be accessible. To offer full keyboard support, together with an extensive auditory feedback that represents each action the player can take, allows visually impaired players to successfully interact with the game. The use of different notes of an octave scale and the stereo variation of those notes can be used to localize the cards on the board.

The interface should be appropriate to enable every player to navigate through it without getting lost. That means offering an auditory feedback for each button and element, including a sound that represents the end of the board (or of the options in the menu). The effects of inputs should be clear, what can be achieved with an in-game explanation about the inputs, feedbacks and the distribution of cards and elements at the beginning of every screen.

Although the test was successful, the game should still be improved with the feedback that was gotten from it. A final version of the game should be developed using sound effects designed specifically for this application, thus creating an auditory identity to the game and enhancing the player's experience. Also, the final version of the game should be built for mobile platforms in order to validate the design on touch-screen interfaces.

As a following study, different input types of the game could be analysed in mobile and desktop versions. As the final version of the game should offer a variety of input types and devices, different tests may be conducted with people with and without visual impairments to analyse the best input type for each group of players.

In addition, the game may be integrated to the REMAR platform, making it possible to customize the contents of the cards and, in this way, the creation of new instances of accessible memory games, according to the teachers' educational goals.

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