Interaction Techniques in Three-Dimensional Virtual Environments Based on Games to Support Chronic Diseases Treatment: A Systematic Review

Eunice P. dos Santos Nunes[1(✉)], Gabriel A. Gutierrez[1], Dayany A. C. Santos[1], José Viterbo[2], Daniela Trevisan[2], Cristiano Maciel[1], and Luciana C. Lima de Faria Borges[1]

[1] Institute of Computing, Federal University of Mato Grosso (UFMT), Cuiabá, MT, Brazil
eunice@ufmt.br, gabrieldeavilagutierrez@gmail.com, daya.anaile@gmail.com, crismac@gmail.com, lucianafariaborges@gmail.com

[2] Institute of Computing, Fluminense Federal University (UFF), Niterói, Rio de Janeiro, Brazil
{viterbo,daniela}@ic.uff.br

Abstract. Games have quickly risen in culture, as well as serious games, which in addition to providing entertainment, also play the role of teaching resources. At the same time, the lack of information in children in relation to Diabetes has caused this disease to be treated with neglect. This paper presents the results of a Systematic Review on interaction and immersion strategies applied in Virtual Environments based on games or Virtual Reality proposed for children and adolescents in the context of the treatment of chronic diseases such as Diabetes. From the results obtained with the SR, it was possible to identify the main techniques that were applied to design the user-centered design project, including the experience of the stakeholders and their needs.

Keywords: Serious game · Diabetes · Chronic diseases · Virtual Reality

1 Introduction

Digital games have become popular in recent years and have become part of the popular culture, going beyond entertainment. Several areas of knowledge have applied digital games as an interaction strategy to aggregate knowledge and motivate training and teaching. The term "serious games" has been used to refer to games where entertainment is not the main objective [23]. Alvarez and Damien [1] define serious games as games aimed at combining serious aspects such as teaching, learning, communication or information with fun elements that are found in digital games.

Within the healthcare area, studies can be found that develop serious games with different purposes such as teaching and training [3], rehabilitation [3], physiotherapy [25], anxiety treatment [10, 20], as well as syndromes and phobias [10, 20]. In this

X. Fang (Ed.): HCII 2019, LNCS 11595, pp. 333–350, 2019.
https://doi.org/10.1007/978-3-030-22602-2_25

context, we realized that the games area may contribute to the treatment of chronic diseases by means of involving, interactive and immersive Three-dimensional Virtual Environments (3D VE). Among the various chronic diseases that affect adults and children indiscriminately, Diabetes heads the list.

According to the International Diabetes Federation (IDF) [18], in 2017 approximately 425 million adults (20–79 y.o.) lived with Diabetes and by 2045 this number, representing world data, is likely to reach 629 million. In Brazil, estimates indicate that more than 12.5 million Brazilians live with the disease [2], which is responsible for the increase of blood glucose, and can cause complications such as visual impairment, renal failure and amputation of members.

Data from the IDF [19] also point out that about 1 million Brazilians suffering from diabetics develop ulcers and 200,000 will need to undergo amputations, out of which nearly 20% lead to death. Some of these patients, about 10%, may suffer lower limb amputations, such as feet due to the destruction of their tissues. One of the disease's microvascular complications is nerve damage, which can lead to loss of feeling and worsen existing wounds in the feet, kidneys and eyes, as the disease can progress to kidney failure and blindness. Therefore, it is important to make the population aware of the adequate treatment of the disease, using different means of communication and interaction.

It should be noted that the greatest challenge lies in the lack of an early diagnosis and an adequate diet. The lack of information on best practices in the treatment of Diabetes, especially children and adolescents, has contributed to the progression of the disease.

In this context, this paper presents the results of a Systematic Review (SR), aiming to answer the following research question, "which interaction and immersion in 3D VE techniques based on Games and Virtual Reality (VR) are applied in contexts of chronic disease treatment, especially Diabetes?".

2 Methodology

The investigation methodology applied in this study started from a Systematic Review of the literature that followed the PRISMA model (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [11]. Three phases were followed: planning, conducting and results extraction.

In the planning phase, the SR protocol was established by guidelines that were followed throughout the review. In the conducting phase, primary studies from the last five years (2012–2017) were sought to find new approaches that could answer the research question of this study *"Which interaction and immersion in 3D VE techniques based on Games and Virtual Reality (VR) are applied in contexts of chronic disease treatment, especially Diabetes?"*. The search for studies was based on the combination of search strings applied in the IEEE and ACM databases.

The SR conducting phase considers two important steps: (i) preliminary selection, which consists of the analysis of the titles and summaries of each work and (ii) final selection, which consists of the analysis of the full texts of the articles included in the preliminary selection stage. The selection of the works of interest was performed according to the inclusion and exclusion criteria defined in the protocol.

In this study, we considered as **inclusion criteria** the papers that present:

- applications that address the treatment of Diabetes through 3D or 2D Virtual Environments, based on Games and Virtual Reality;
- applications that address the treatment of chronic diseases through 3D or 2D Virtual Environments, based on Games and Virtual Reality;
- interaction and immersion techniques in 3D VEs, specially aimed at children and adolescents.

Regarding the **criteria for the exclusion** of papers, those studies whose focus did not correspond to the research question raised or that did not meet the established inclusion criteria were excluded from the SR.

In the results extraction phase, the answers to the research question were included in the SR final selection and the results were summarized. Figure 1 shows a distribution of the included and excluded works of the SR, as well as the search strings adopted in the research.

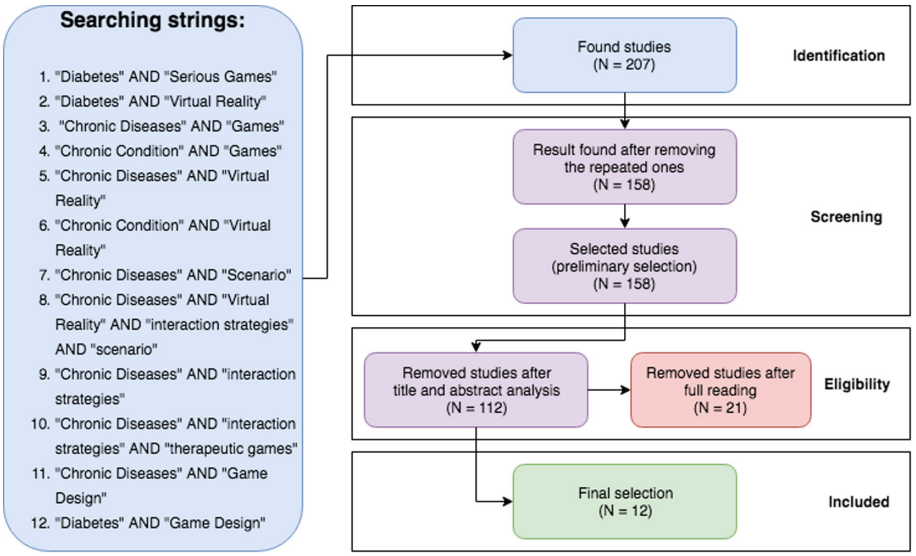

Fig. 1. Number of articles included and excluded in the RS steps

A total of 207 studies were found during the SR phase, 34 studies selected in the preliminary selection and 12 articles included in the final selection phase, which present answers to the research question.

From the SR results, some relevant aspects were identified, such as: the type of Virtual Environment (VE) in which the work (2D or 3D) was developed; the interaction strategies applied; the VE study context; Participatory Design (PD) techniques applied; the challenges explored in the VE scenarios; the available computational interaction and/or immersion devices; whether or not experiments were carried out and the target audience of the works. SR results are presented in Sect. 3.

In sequence, the results of the SR were used to support a 3D serious game project to aid Diabetes Treatment, especially for children and adolescents. The serious game project is presented in Sect. 4.

3 Systematic Review Results

This section presents the SR results, showing studies that use Virtual Environments in the context of Diabetes and also those related to other Chronic Diseases. Table 1 summarizes the main aspects observed in the studies in the SR, and then presents a synopsis of each work, aiming at a better understanding of the contributions from this bibliographic survey to the larger objective of the research project, which is the design of a 3D VE to support the treatment of Diabetes.

3.1 Works Related to Diabetes

The work of Fernandez et al. [12] presents a design proposal containing illustrative images for the design of a game, which uses VR techniques to simulate a supermarket and a person shopping. The game's goal is to present an attractive environment of food products for the player to interact with, and through the interactions during the exploration in the VE, to verify the behavior of people suffering from Diabetes, in order to guide them on how to overcome the food consumption challenges and adopt healthy eating habits. It is an educational tool, the objects of which were modeled using Maya[1] and 3D Studio Max[2] softwares to recreate the scenario in a 3D environment. In addition, Eye Tracking (EG) and Electroencephalography (EEG) techniques were applied to compare measurements such as the gaze pattern and cognitive load. The results are incipient, since the tool is still being designed and has not been tested with potential users.

Borsboom [6] presents a "proof of concept" study which demonstrates the feasibility of creating a serious game for the purpose of teaching people how to manage Diabetes symptoms. The game prototype was developed on the Unity 3D game engine and features a set of gaming techniques that can be applied to represent different symptoms of Type 1 Diabetes through a video game. The research methodology included the selection of participants from different age and gender groups suffering from Type 1 Diabetes in order to play the video game for a short period of time. Data were collected on how much participants knew about managing Diabetes symptoms before and after playing the video game. Data collection was related to the content depicted in the video game, specifically about glycemic control, calorie count, meal portions, and types/levels of physical exercises. Different instruments were used in the data collection, such as checking participants' hemoglobin level, questionnaires and interviews. Results showed that it is possible to adapt the Minecraft game or The Elder Scrolls: Skyrim to train people on the best way to manage of Type 1 Diabetes, and this is part of future research of Borsboom's study.

[1] https://www.autodesk.com.br/products/maya/overview.

[2] https://www.autodesk.com.br/products/3ds-max/overview.

Table 1. Main aspects of the studies selected in the SR

Font	Environment	Interaction Strategy	Approach	Participatory Design	Challenges	Interaction Devices	Experiments	Target Audience
Hatzigiannakoglou. [15]	2D VE	Game, Avatar, First person shooting (FPS), Explanatory Audios	Down Syndrome	Uninformed	Choice	Mouse and Wii-Remote	✓	Children, Teen and Parents
Stach and Schlindwein [26]	2D VE	Game Based Learning, Avatar, Google Maps	Diabetes	Interviews	Defense	Touch screen		Children with Diabetes
Oikonomou and Day [27]	3D VE	Breath Exercise, Game, Avatar	Cystic Fibrosis	Usablity feedback	Breath	Positive Expiratory Pressure (PEP) connected by USB	✓	Children and Parents
Fernandez et al. [12]	3D VE	Game, First person shooting (FPS), hands-on food choice training	Diabetes	Uninformed	Exploratory learning	HMD VR Wrap 1200VR, joystick		Patients Uninformed Age
Orji, Vassileva and Mandryk [28]	2D, cross platform application	Game Based Learning, slow-casual game	Health Care, Diabetes	Profile Questionnaire	Nutrition knowledge	Touch screen	✓	General

(continued)

Table 1. *(continued)*

Font	Environment	Interaction Strategy	Approach	Participatory Design	Challenges	Interaction Devices	Experiments	Target Audience
Borsboom [6]	3D VE	Game, First person shooting (FPS), Avatar	Diabetes	Uninformed	Management of Diabetes	Touch screen	✓	Patients with Diabetes Tipo 1
Bomark [4]	2D VE	Social learning Game, Virtual community, Avatar	Diabetes	Feedback Questionnaire	Mini-Games with several challenges, missions, competition	Touch screen	✓	Children and Parents
Brox et al. [7]	2D VE	Social learning Game, Virtual community, Avatar	Diabetes	Feedback Questionnaire	Mini-Games with several challenges, missions, competition	Touch screen	✓	Children and Parents
Bomfim and Wallace [5]	2D VE	Game Based Learning, Creating of Character	Health Care	Uninformed	Nutrition knowledge	Touch screen		Young Adults
Chen et al. [9]	2D VE	Game Based Learning, Avatar	Diabetes	Feedback Questionnaire	Best choices	Touch screen	✓	Adults

(continued)

Table 1. *(continued)*

Font	Environment	Interaction Strategy	Approach	Participatory Design	Challenges	Interaction Devices	Experiments	Target Audience
Harris, Duresi and Tuceryan [14]	2D VE	Game Based Learning, Gamification	Diabetes, Obesity	Uninformed	Mini-Games with Several Challenges	Touch screen, accelerometers, camera and voice recognition		Children and Teen
Kyfonidis and Lennon [21]	2D VE	Game Based Learning, Interface Tangível with multiple feedback channels	Diabetes	Uninformed	Exploratory learning	Touch screen		Children and Parents

The works of Brox et al. [7] and Bomark et al. [4] discuss the design process of a game based on the concept of social learning games, which are both engaging and fun for diabetic children. The methodology applied in the research included, in addition to a bibliographical research, search in discussion forums related to Diabetes chronic disease, interviews with Diabetic children (aged 8 – 12), their families and health professionals. The authors found several educational games related to Diabetes, especially dealing with nutritional aspects and healthy eating habits, but no social games were found. Thus, the authors proposed a game that explores most of the social aspects through a social learning platform, in which avatars, leader boards, achievements and communication, among other issues, are part of the game. This allows strategies, such the use of sections of pre-recorded games by opponents, to be contested by other players, making an asynchronous game seem to be synchronous, or strategies that require players to ask their friends for help in some tasks. Another feature is the ability to "push" missions onto players by asking them to help on behalf of one of their friends or by challenging them to overcome a high score set by one of their friends. In addition, rewards encourage participants to continue playing and to try other minigames on the platform. The authors realized that offering several minigames introduces variety and helps integrate learning tasks.

To test the concept, Brox et al. [7] developed the Glucose Race minigame, in which the player uses different types of transport (airplane, car, motorcycle, walking). The minigame challenges players by using their own knowledge about insulin (fuel is food, oil/air is insulin, and speed is level of exercise). Once the player realizes that the game's strategies match the mechanisms of insulin and blood sugar, they can use their knowledge to perform better. The player must plan the race before starting; speed, fuel and oil must be balanced. The competition takes place with races pre-recorded by friends, giving the impression of live interaction. Friends' help can be provided by pre-recorded comments and tips from previous game sessions. The game also explores aspects of persuasive games, as it seeks to persuade users to modify their behavior.

The authors concluded that it is not easy to get feedback from children about issues they are unfamiliar with. It should be noted that the children who participated in the experiments were not familiar with intrinsic learning games, social games and persuasive games, which may have somehow hampered the performance of the players [4, 7].

Another study on Diabetes, with an educational purpose, is presented by Chen et al. [9]. The game design was applied to an existing open source 2D game (Mario Brothers). The study led to the identification of three strategies to enable education through games: (1) Structure Enhancement (SE); (2) Feedback Enhancement (FE); (3) Challenge Enhancement (CE). Driven by the three design strategies, the authors implemented game modifications to incorporate educational resources. The main character in the game, named Mario, has Type 1 Diabetes. Health-related choices, which must be faced by Mario, become the challenges of the game.

Examples of challenges are managing Mario's health, especially about blood sugar; making choices about food intake or insulin injection when Mario's blood sugar level diverges from the appropriate level; keeping adequate blood sugar levels as they increase when children progress through the different phases of the game. The final goal is to save a princess who is locked in a castle and beat the guards of evil. To achieve this goal, Mario needs to manage his Diabetes and keep himself healthy. What is expected is that as Mario advances through the phases of the game, he will gradually learn the skills to remain well by making appropriate food choices; taking regular exercise and injecting adequate amounts of insulin when needed.

A pilot study on usability issues was conducted using a version of the Mario Brothers game adapted to the purpose of the research. Forty-six people participated (25 women, 21 men, 18+) playing for 20 min and answering a feedback questionnaire at the end of the game. The results of this pilot study showed that participants enjoyed playing the game and found it valuable for educating diabetic patients [9].

Harris et al. [14] present a 2D VE conception that seeks to motivate children and adolescents, prone to or diagnosed with chronic diseases such as Diabetes and Obesity, to use technology to develop healthy habits for the purpose of prevention and treatment. The system is based on gamification techniques, mobile platforms and cloud computing. In smartphones, the accelerometer, camera and voice recognition are used to capture lifestyle data such as eating habits and exercise. The cloud is responsible for processing the data collected by the smartphone, since its battery and processing power are limited. Gamification is represented by trophies (achievements) or penalties (failures).

The project developed the Architecture of the Integrated and Personalized Diabetes Coach for Children, based on the lifestyle intervention proposed by one of the authors' Medical Clinic, including the following five themes: (1) think about your drink – choose water, leave out sweet beverages; (2) make your plate colorful – include more fruit and vegetables; (3) snack attack – choose healthy snacks; (4) pay attention to portions – portion control; (5) eat at home – eating out trouble shooting [14].

The VE is based on minigames to encourage children's participation. All minigames follow a 2D interface, with play mechanics similar to "Angry Birds", "Pokemon" and "Bubble Pop." Each minigame is meant to teach about a specific topic. No experiments were conducted with the project's target audience, but the authors are confident that the VE will have a great impact on the treatment of Diabetes in children [14].

The work of Kyfonidis and Lennon [21] proposes a tangible interface game for the learning of concepts on Type 1 Diabetes for 3–8-year-old children. The design and evaluation phases include multi-stakeholder collaboration (diabetes advisors, nurses, parents and children). Based on requirements elicited by an initial qualitative research and literature review, the game will promote exploration, collaborative learning, learning through reflection and will follow the concepts the constructivism theory of developmental psychology. The creation of a tangible interface game for interactive learning with multiple feedback channels will, potentially, empower children with Diabetes, providing a more effective, engaging, fun and age appropriate education. This work resulted in the conception of a more accessible game design for 3–8-year-old children with Type 1 Diabetes, within a clinical setting.

Stach and Schlindwein [26] present web-based health game for children suffering from Diabetes to help them check their blood sugar level (BSL). The game design proposes that the player build bases in different locations using the Google Maps locator and the data of his glucose meter. Google Maps is used to locate the player through the user's login to their Google account. When the player starts the game, he can see his location on the map. The game attaches the player's diabetes data to real life locations. Players build their castle with a protective wall around it by entering the value of a BSL measurement for the first time. From then on, the location of each measurement will become a tower point to give more scoring points and more protection against mysterious Dark Forces. The game's objective is to protect the castle and earn points. Thereby, the player is forced to walk around and measure the BSL regularly. The measuring and the BSL data transfer need to be done manually, as there is no glucose meter which can be connected to the smartphone – thus, especially young children are tempted to cheat in order to reach good values and game scores.

3.2 Works Related to Other Chronic Diseases or Health Care

Hatzigiannakoglou [15] proposes a 2D serious game of First-Person Shooting (FPS) aiming to help children and adolescents with Down Syndrome to understand healthy eating and change their habits when necessary. The game uses explanatory audios throughout the story, in order to make children's understanding and engagement easier. The game uses a mouse or Wii Remote as interaction devices. The article does not provide details on the game development methods and techniques. The results of the study highlight that it was possible to develop the game design, which consists of four

minigames (Breakfast, Snack, Lunch, Beverages), from the interviews conducted with the children's parents and/or caregivers. Initially, the VE presents a story that addresses the healthy food and beverage groups in contrast to the unhealthy groups.

Oikonomou and Day [27] present a breath-controlled serious game that encourages the user to engage more frequently, and effectively, in the cleansing physiotherapy of the vital mucus. They present a game that uses software that controls the heart rate and an air pressure sensor connected to the computer via a USB port. Four minigames were developed (Cave Flight Game, Flower Garden Game, Pirates Game, Whirlpool) based on existing physiotherapy guidelines for Cystic Fibrosis patients. The game was tested by a young patient along two weeks. Preliminary results showed that minigames need to be improved in some aspects of usability, which were pointed out by the experiment participant and their parents. No hardware errors were reported.

Orji et al. [28] present a slow-casual style game (slow, simple, easy to learn, easy to play) that addresses the need for intervention in order to teach patients (with Diabetes or potential risk of Diabetes) how to make healthy choices while eating out. This approach includes patients with different health goals in order to promote learning and reflection. LunchTime is a cross-platform application, based on a client-server system implemented using Java Enterprise technology. Participants played the game for a period of 10 days. The evaluation consisted of pre (baseline) and post (exit) surveys, used to identify behavioral changes before and after playing LunchTime for a period of time. The pre and post surveys included the same questions on nutritional knowledge (attitude towards healthy eating and health concern), but some other (different) questions were added to the post survey. The results of the evaluation showed that the LunchTime game made learning easier by increasing participants' nutritional knowledge and led the authors to a reflection both during the exploration in the game and then out of the VE. Thus, LunchTime met the goals, which were to teach people about healthy eating according to their health goals. A positive attitude change regarding healthy eating was noticed in the research participants group. As future work, the authors intend to evaluate LunchTime with a diverse audience and for a longer period of time in order to identify the positive and/or negative impacts on patients' lives.

Bomfim and Wallace [5] propose a game design that uses the Self-Determination Theory (SDT) to build up players' competence, autonomy and relatedness as consumers, encouraging them to develop an understanding of the nutritional benefits of healthy food. The game's reward is achieving balanced sugar, sodium, fats and fibers in their purchases. The design of the game is based on the Food Literacy (FL) approach which combines knowledge, skills, and behavior required to plan, select, manage, prepare, and consume foods that meet nutritional recommendations. FL is also associated with confidence, autonomy and empowerment towards food. The game's Artwork (design) was downloaded from icons8, vecteezy, pixabay, and clipart. The game was developed using Android Studio, which is compatible with Android 4.0 or higher versions. This study addresses an important gap in the literature that focused primarily on weight loss and calorie control to improve health conditions. The proposed game is an important step in understanding how game design can be used to develop FL skills. The proposal has not yet been validated by potential users, since the authors point out that experiments to validate the proposal will be conducted, in the future, with university students.

3.3 Discussion on the SR Results

Considering the SR results and the research question (which interaction and 3D VE immersion techniques based on Games and Virtual Reality are applied in contexts of chronic disease treatment, especially Diabetes?), we identified that the main strategy of interaction applied in VEs developed in the context of chronic diseases is Game Based Learning, combined with other interaction strategies, such as: First Person Shooting, use of avatar, hands-on food choice training, social learning game, virtual community, slow-casual game, explanatory audios, google maps and tangible interface with multiple feedback channels.

It is important to note that 25% of the selected studies propose 3D VEs, while 75% present 2D VE proposals. The main interaction device implemented in VEs is still the touchscreen feature, which may be justified by the ease of interaction and the fact that it is available on smartphones and tablets making the VE more reachable for users who do not have access to web devices, knowing that approximately 65% of the world's population have access to some kind of mobile device, according to the GSMA [29].

Other interaction devices were found in the studies, such as the use of HMD in the work of Fernandez et al. [12] in addition to features available on the smartphones themselves that were found in the work of Harris, Durresi and Tuceryan [14], such as accelerometer, camera and voice recognition. Therefore, in relation to the immersion techniques raised in the research question, we only found these two studies that make use of immersive virtual environments.

Considering chronic diseases, it is important to highlight that most studies (75%) were developed to support the treatment of Diabetes in order to seek the balance of blood glucose level through healthy eating habits, learn to make the best choices and improve nutritional knowledge on foods.

Regarding VE design supported by Participatory Design techniques, we did not find this approach in the selected studies. We noticed that approximately 50% of the works included users' participation through the application of Profile and/or Feedback Questionnaires and interviews. However, we did not identify the application of a PD methodology, seeking to guarantee the "willingness and capability" of potential users of the proposed technologies. When we do not use the PD techniques, we do not feel confident enough of the public acceptance considering the different user groups, and if, in fact, the VE attends the citizens' need, who in this case, are people with some chronic illness, their caregivers/parents and health professionals who accompany them.

Given these results, we noticed that there is a gap in the literature regarding the design of 3D VEs available in mobile devices and designed with the co-participation of users from the beginning of the development cycle.

Taking this into consideration, Sect. 4 presents the ABCDiabetes serious game proposal designed with the users' co-participation and including some of the interaction techniques identified in the SR.

4 The Serious Game "ABCDiabetes"

The ABCDiabetes game was designed in partnership with Júlio Muller University Hospital - Federal University of Mato Grosso, Brazil. The first phase of the game aims to raise awareness among Diabetic children and adolescents for them to make the best food choice.

The results of the Systematic Review were used to support the serious game project considering some of the successful strategies found in the SR. Considering that the works selected in the SR did not address PD techniques in the conception and evaluation of VEs, this study proposes a serious game constructed in a collaborative way, with the participation of stakeholders and potential users of the system, in order to offer a product that meets the real needs and desires of end users. Thus, the Contextual Inquiry and Mockups techniques were adopted.

4.1 Participatory Design Sessions

In the first stage of the PD sessions, the Contextual Inquiry technique [16] was applied involving the multidisciplinary team (nurses, pediatricians, psychologists, nutritionists, developers, children, adolescents and caregivers). In the second stage, we presented the Mockups [7] to potential users and their caregivers in order to conduct experiments to evaluate the user experience. The stages are described below:

Stage 1. Contextual Inquiry

The Contextual Inquiry technique consists of field interviews and brainstorming meetings with HUJM health professionals, four children with Diabetes and their parents or caregivers (indicated by the physician in charge of the Pediatric ward of the Hospital), as well as the project development team [14].

Initially, a meeting was held at the Julio Müller University Hospital, where the pediatrician and the multidisciplinary team nutritionist explained, by means of a therapeutic toy (Fig. 2), what Diabetes is, how the disease acts on the body, and how to

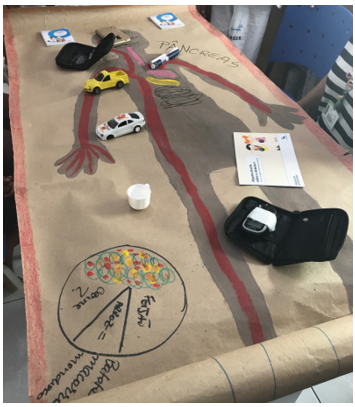

Fig. 2. Therapeutic toy used by the HUJM team (teaching about Diabetes).

choose good food items by making healthy food replacements. The Contextual Inquiry technique also included the application of questionnaires with the users, to specify the system requirements. According to Kumar et al. [12], the adoption of this type of technique makes the collected information more reliable. From the results of the meetings and aspects identified in the SR, we defined that the first phase would address the choice of food for a healthy meal. Thus, we determined the game scenario, the narrative, 3D objects, virtual characters and strategies of interaction and gameplay.

Stage 2. Mockups

The Mockups technique basically consists of creating prototypes of the object to be developed, in order to obtain samples of its artifacts, as well as to test and evaluate with potential users [22]. Generally, the prototype presents all the components that will be part of the final product, in a clear and objective way, seeking to avoid double interpretations. The Mockups technique is the result of the application of the Contextual Inquiry technique, considering that the final product must meet the needs of the end users.

From the results of the PD sessions with the multidisciplinary team in the first design stage, it was possible to plan the ABCDiabetes game interfaces, starting with the "Food Choice" phase. This phase was defined by the multidisciplinary team, considering that the meals directly influence the glucose level of the patients, being a complex stage, especially for school children.

After the meetings held at the hospital, the prototype was built and PD sessions were conducted with health professionals and some children selected by the Pediatric team in order to validate the game's proposal.

4.2 Serious Game Interface Project

The game is divided into phases, the first phase being "Food Choice", which aims to educate the player in the choice of the best food for diabetic people. When starting the serious game, the player can select his avatar and explore the "Joy Square" virtual scene. In the square, the player finds nutritional information about the food available in the environment.

When the player gets near the non-playable character, represented by the nutritionist (Fig. 3), she interacts with the player offering three daily meals (breakfast, lunch/dinner and snack) for the player to assemble. The player then chooses which meal he wants and starts the "Food Choices" phase. It should be noted that the player must consider the nutritional information while choosing food items.

Thus, it is recommended that before the player chooses the food he will include in his meal, he should navigate through Joy Square exploring the food stalls and observing the nutritional information of each food, as shown in Fig. 4. Food stalls are separated by types: Fruit, starchy foods and Bread, Beans and Peas (legumes) and Meat.

Soon after the player chooses the meal (breakfast, lunch/dinner, snack), the avatar is taken to Joy Square where healthy and unhealthy foods from the upper part of the scene (Fig. 5) begin to fall, randomly, and the player chooses the food to assemble the meal according to the nutritional information of each food, previously presented in the stalls.

Fig. 3. ABCDiabetes "Food Choice" - Interaction with the Nutritionist to select the meal

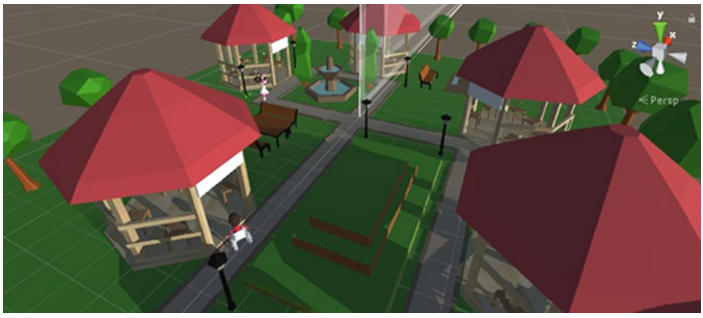

Fig. 4. Joy Square interface with food stalls

It should be emphasized that the navigation system allows movements in three dimensions (3D). As for the interaction techniques, these were implemented by virtual control - touchscreen, Bluetooth VR control, accelerometer/gyro sensor and Playstation 2 (PS2) control model [17].

The first-phase interface includes a glucose meter bar, which indicates the amount of glucose ingested from the food collected and displays the player's score. The player should pay attention to the glucose level displayed on the meter as he is advised to keep the meter bar on the green level. If the player collects more foods with a high glucose content, the bar turn red, indicating a high level of glucose in the blood. However, if the player stops collecting food, the bar will also turn red indicating low blood glucose.

Fig. 5. First phase interface - "Food Choice"

4.3 Used Technologies

The ABCDiabetes game was implemented using the Unity 3D[3] game engine, which has a good rendering graphics engine, easily portable to other platforms and it allows the developer to use C# and JavaScript programming languages.

For the development of the 3D virtual world scenario and the virtual characters, the Blender[4] tool was adopted, which is a free and open source 3D modeling tool. The scenario was assembled also using some 3D models acquired in the Unity Assets store, in addition to models developed in the LAVI[5] research group.

For the animation of the virtual characters and 3D objects, the Mixamo[6] tool was used. In addition, other animation features available in Unity itself and even the implementation of specific animation algorithms that are under development in the LAVI research group were adopted.

Each scene in the game has a 3D audio soundtrack. In the square scene, where the game begins, the sounds of birds singing are distributed near the trees of the VE, and the sound intensifies according to the proximity of the avatar that represents the player in the scene.

5 Conclusions

Based on the results obtained from the SR, interaction strategies and game challenges were satisfactorily identified and applied in the ABCDiabetes proposal.

[3] https://unity3d.com/pt.

[4] https://www.blender.org/.

[5] http://lavi.ic.ufmt.br/.

[6] https://www.mixamo.com/.

The design and evaluation phases of ABCDiabetes were conducted in a collaborative way, with the participation of the multidisciplinary team and end users. We emphasize the importance of Participatory Design techniques in the success of this construction. The 3D VE was developed following the game-based learning strategy, using avatar, virtual characters, 3D virtual objects, challenges the player will have to face and hands-on food choice training, in order to control the level of blood glucose through a healthy diet. The technologies used in the implementation of the project were satisfactory.

Future work will consist of using the ABCDiabetes game with diabetic children and adolescents to verify the game's contribution towards the treatment of Diabetes, and consequently, its contribution to the Healthcare area. It is still necessary to improve the serious game in relation to aspects of movement and interaction with the virtual objects.

Finally, this study represents a relevant social contribution to the areas of Health and Education that use 3D VE for different issues. For the Computing area, this study represents a reflection on the best practices in designing 3D VE interfaces, as well as the need to propose methodologies based on PD approaches for the design and evaluation of 3D VEs based on games.

Acknowledgments. This research was supported by the Institutional Program of Scholarships for Scientific Initiation of Federal University of Mato Grosso (UFMT-Brazil), National Council for Scientific and Technological Development (CNPq) and by Hospital Universitário Julio Müller (HUJM).

References

1. Alvarez, J., Djaouti, D.: An introduction to Serious game - definitions and concepts. Serious Games Simul. Risks Manag. **11**, 11–15 (2011)
2. Atlas IDF 2017 - Diabetes no Brasil. https://www.diabetes.org.br/profissionais/images/2018/poster-atlas-idf-2017.pdf. Accessed 12 July 2018
3. Bertrand, J., et al.: Serious games for training, rehabilitation and workforce development. In: IEEE Virtual Reality (VR), pp. 195–196. IEEE, Lake Buena Vista (2013) https://doi.org/10.1109/vr.2013.6549427
4. Bomark, P.: User centric social diabetes game design for children. In: Proceeding of the 16th International Academic MindTrek Conference (MindTrek 2012), pp. 291–293. ACM, New York (2012)
5. Bomfim, M.C.C., Wallace, J.R.: Pirate Bri's grocery adventure: teaching food literacy through shopping. In: Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA 2018), Paper LBW068, 6 p. ACM, New York 2018
6. Borsboom, A.S.: Investigating the potential of interactive media to encourage engagement with type 1 diabetes management. In: Warren, J., Gray, K. (eds.) Proceedings of the Seventh Australasian Workshop on Health Informatics and Knowledge Management - Volume 153 (HIKM 2014), vol. 153, pp. 13–19. Australian Computer Society, Inc., Darlinghurst (2014)
7. Brox, E., Hirche, J., Evertsen, G., Yliräisänen-Seppänen, P., Brum, M.R., Rieder, R.: Virtual reality applications for smart cities in health: a systematic review. In: XVII Symposium on Virtual and Augmented Reality (SVR), pp. 154–159. IEEE(2015)

8. Charlier, N., Zupancic, N., Fieuws, S., Denhaerynck, K., Zaman, B., Moons, P.: Serious games for improving knowledge and self-management in young with chronic conditions: a systematic review and meta-analysis. J. Am. Med. Inform. People Assoc. **23**(1), 230–239 (2015)
9. Chen, G., Baghaei, N., Sarrafzadeh, A., Manford, C., Marshall, S., Court, G.: Designing games to educate diabetic children. In: Proceedings of the 23rd Australian Computer-Human Interaction Conference (OzCHI 2011), pp. 72–75. ACM, New York (2011)
10. Gonzalez, C.S., Collazos, C., Gonzalez, J.L., Toledo, P., Blanco, F.: The importance of human factors to enhance the user experience in videogames. In: 2012 International Symposium on Computers in Education (SIIE 2012), Andorra la Vella, pp. 1–4 (2013)
11. Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G.: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement (Reprinted from Annals of Internal Medicine). Phys. Ther. **89**(9), 873–880 (2009). https://doi.org/10.7326/0003-4819151-4-200908180-00135
12. Fernandez, J.R., Murphy, M.D., Mahajan, P.A., Fidopiastis, C.M.: The Virtual Supermarket: Interactive Educational Tools for Reducing Diabetes Risks (2013)
13. McCarthy, G.M., Rodriguez Ramírez, E.R., Robinson, B.J.: Participatory design to address stigma with adolescents with type 1 diabetes. In: Proceedings of the 2017 Conference on Designing Interactive Systems (DIS 2017), pp. 83–94. ACM, New York (2017). https://doi.org/10.1145/3064663.3064740
14. Harris, A., Durresi, A., Tuceryan, M.: In: proceedings of the 29th International Conference on Advanced Information Networking and Applications Workshops (2015)
15. Hatzigiannakoglou, P.D.: Junk-food destroyer: helping adolescents with down syndrome to understand healthy eating through serious game. In: Proceedings - 7th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games) (2015)
16. Holtzblatt, K., Jones, S.: Contextual inquiry: a participatory technique for system design, pp. 177–210. Lawrence Erlbaum Associates, Hillsdale (1993)
17. Junior, V.A.C.: Desenvolvimento de Jogos Sérios para Dispositivos Móveis Acessíveis às Pessoas com Deficiência na Coordenação Motora: um Experimento na Área de Saúde. 72f. Monografia – Universidade Federal de Mato Grosso, Cuiabá, (2018)
18. IDF Diabetes Atlas 8th Edition 2017 Global fact. https://www.idf.org/aboutdiabetes/what-is-diabetes/facts-figures.html
19. Kayali, F., et al.: A participatory game design approach for children after cancer treatment. In: Proceedings of the 2014 Workshops on Advances in Computer Entertainment Conference (ACE 2014 Workshops). Article 16, 6 p. ACM, New York (2014). https://doi.org/10.1145/2693787.2693801
20. Kumar, S., et al.: Leveraging contextual inquiry methods to empower patients in a learning health system. In: 48th Hawaii International Conference on System Sciences (HICSS), pp. 3141–3147 (2015)
21. Kyfonidis, C., Lennon, M.: Mummy, why do I have diabetes?: a tangible interface for educating children with type-1 diabetes. In: Proceedings of the the 15th International Conference on Interaction Design and Children (IDC 2016), pp. 524–528. ACM, New York (2016)
22. Melo, A.M., Baranauskas, M.C., Soares, S.C.M.: Design com Crianças: da prática a um modelo de processo. Braz. J. Comput. Educ. **16**(01) (2008)
23. Moraes, R.M., Machado, L.S., Nunes, F.L., S., Costa, R.M.E.M.: Serious games and virtual reality for education, training and health. In: Maria Manuela Cruz-Cunha (Org.) Handbook of Research on Serious Games as Educational, Business and Research Tools, 1 edn, vol. 1, p. 315–336. IGI Global, Pennsylvania (2012)

24. Nunes, E.P.S.: Uma Revisão de Literatura sobre Recomendações de Design de Jogos Digitais 3D para Pessoas como Deficiência. In: Workshop de Iniciação Científica, vol. 1 (2017). ISBN: 978-85-7669-431-1
25. Sadaf, S., Abdullah, A.H., Muhammad, S., Sajjad, M.: Psychotherapy through video game to target illness related problematic behaviors of children with brain tumor. Curr. Med. Imaging Rev. **10**(1), 62–72 (2014)
26. Stach, C., Schlindwein, L.F.M.: Candy castle: a prototype for pervasive health games. In: Proceedings - IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops) (2012)
27. Oikonomou, A., Day, D.: Using serious games to motivate children with cystic fibrosis to engage with mucus clearance physiotherapy. In: Proceedings - 6th International Conference on Complex, Intelligent, and Software Intensive Systems (2012)
28. Orji, R., Vassileva, J., Regan, L.M.: LunchTime: a slow-casual game for long-term dietary behavior change. Pers. Ubiquit. Comput. **17**(6), 1211–1221 (2013)
29. Number of Mobile Subscribers Worldwide Hits 5 Billion, 13 June 2017. Press Release. https://www.gsma.com/newsroom/press-release/number-mobile-subscribers-worldwide-hits-5-billion/