The use of 3D printing for the development of a learning tool for the visually impaired

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Abstract

3D printing is a technology that allows manufacturing objects from a virtual model. The field of education has appropriated its use due to its potential to contribute to the teaching-learning process, especially for the education of the visually impaired. Visually impaired people develop their skills through alternative means, mainly using auditory and tactile landmarks as a way of obtaining information. Within the innovative perspectives for education, this study aims to propose a learning tool using 3D printing technology to build a board game employed for the use of unplugged programming language in the education of children visually impaired for their development of logical thinking skills. The learning tool production started in its modeling performed using specific software that generated 3D virtual models. Later, these files were sent to a 3D printer for printing, using the fused filament fabrication, originating physical copies of modeled objects. Then, the objects, now printed, went through a finishing process for their completion. Part of the game components received braille indications accordingly to the proposed in this study. As a result, we obtained a game prototype adapted for the visually impaired, made through 3D printing, with the potential to assist in the teaching-learning process.

Keywords: 3D printing; visual impairment; learning; education; serious games

1. Introduction

The 3D printing technology is a tool that makes it possible to manufacture three-dimensional objects from a virtual model (Aguiar, 2016). 3D printing is a type of additive manufacturing, as its production process involves successively addition of materials deposited layer by layer. In the fused filament fabrication (FFF), a thermoplastic filament is heated, melts and is deposited on a base, layer by layer, until it forms the desired object (Aguiar, 2016; Buehler, 2016).

3D printers have been identified as responsible for a new revolution, being compared to personal computers that, between the 70s and 80s, were fundamental for the revolution of information and communication technologies (ICTs) (Dalmazo, 2010). The current spread of 3D printing it is also because of the digital manufacturing laboratories and the growing expansion of the Maker Movement that propagates a philosophy of creator culture, in which people or groups develop diverse projects using specific software and equipment that can be shared and recreated by any individual (Papavlasopoulou et al., 2017; Fonda & Canessa, 2016).

Digital manufacturing laboratories are spaces open to the community with infrastructure and personnel available for creativity and innovation, such places may or may not have a relationship with schools and universities (Fonda & Canessa, 2016)

3D printing has quickly become a widely used tool in the educational field due to its potential to contribute to the teaching-learning process and because it is a versatile technology that stimulates creativity and motivation. It is one more resource that presents itself to education and with which students can get involved during the process of knowledge development, in addition to the possibility of exploring playful and multidisciplinary aspects (Augusto, 2016; Buehler, 2016).

In this context, 3D printing presents itself as an instrument for active methodologies, where students actively participate in the teaching-learning process, thus becoming protagonists in the knowledge construction (Jorge et al., 2018).

The three-dimensional object, in a printed stage, assumes the role of complementary didactic teaching material, helping the teacher to illustrate the proposed content and expanding the possibility of creating new teaching materials that will serve students in their entirety and, especially, the visually impaired.

Visual impairment is a type of sensory impairment in which the main character is limited or impaired vision, one of the most important sensory pathways to obtain information from the external environment. There are two types of visual impairment, blindness, and low vision (Nunes & Lomonaco, 2010; Ochaita & Rosa, 1995).

3D printing technology is another resource to be used in the educational environment, capable of expanding the learning possibilities of visually impaired students. The difficulties encountered by the visually impaired to study various themes can be reduced by making specific didactic material available with the aid of 3D printing. Such material contains tactile resources, such as models, embossed images and elements in braille (Jo et al., 2016).

The perception of the reality of a visually impaired person is quite different from individuals who see normally, as a result of the important reduction or loss of the acquisition of information through the visual sensory system. Therefore, it is essential to implement ways of teaching that favor the apprehension of knowledge by people who cannot achieve it through vision adopting alternative means (Nunes & Lomonaco, 2010; Ochaita & Rosa, 1995).

Recently, teaching programming logic in elementary education has been suggested, within the innovative perspectives for education. The main objective of this application is to assist the development of logical thinking skills, and for that reason, schools have incorporated initiatives in the area of game development, educational robotics, and programming logic (Bottino et al., 2007; Atmatizidou et al., 2018). The Brazilian Computer Society (BCS) recommends that computer content should be offered for Basic Education, calling attention to the axes where it is recommended to present these contents without using a computer (Sociedade Brasileira de Computação, 2017).

Despite the significant growth in the use of technologies and active methodologies in the school environment, there is little use of 3D printing associated with the development of logical reasoning through unplugged activities (without the use of a computer) for elementary and high school students. Even rarer are the applications of this relationship between 3D printing and programming logic for visually impaired students.

There are educational initiatives for the teaching of visually impaired students, such as those presented by Sarmento and Alves who prepared a bibliographic review describing a history of 46 (forty-six) initiatives, created between 1987 and 2015, planned for the teaching and learning of visually impaired students using mathematical games. The study demonstrated the lack of techniques and tools for learning programming logic, through unplugged activities in these initiatives (Sarmento & Alves, 2017).

Therefore, the goal of this work was to propose a teaching resource aiming to improve the teaching-learning relationship of visually impaired children, based on the use of 3D printing technology.

2. Material and methods

The research groups of UNEB (Bahia State University), Education, Health and Technologies (EDUSAUT) and Nucleus of Applied Research and Innovation (NPAI), approached their experiences about 3D printing technology, making it possible to dialogue with MandacaruLab, an open laboratory designed by NPAI, from where the Bahian startup Mini Maker Lab (MML) came from.

MML is a startup that disseminates the maker culture by stimulating learning through playful activities and developing solutions for educational robotics and logical reasoning using 3D printing. Among its products, there is the MML Code Table, composed of a generic board game made of canvas (Figure 1), characters, obstacles and pieces of visual programming language (which fit together). This set of structures allows players to move their characters to complete missions, aiming to develop logical/analytical reasoning through an unplugged programming language.

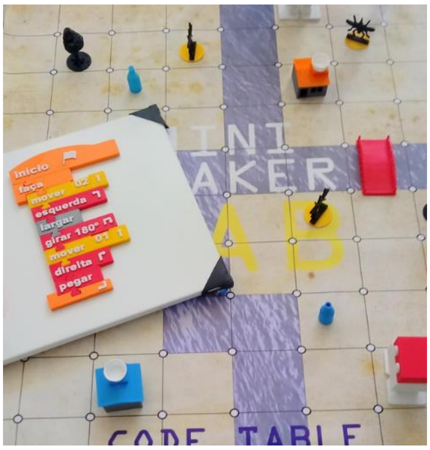

Figure 1. MML Code Table, Salvador, 2018.

The visual programming language pieces (Figure 2) are made using 3D printing and inspired by Scratch. Scratch is a software designed by Mitchel Resnick and projected by the Lifelong Kindergarten group at the Massachusetts Institute of Technology (MIT) Media Lab. It is a graphic programming language that uses logic blocks, sound and image items, so the user can create their own stories, animations, and games. It was developed for children and young people from 8 to 16 years old, but individuals of all ages use it. It is free for the main operating systems and the user can share their productions online (Scratch Brasil, 2014).

Figure 2. Pieces to make the visual programming language (3D printing in portuguese). MML, Salvador, 2018.

The idea of using the MML Code Table for teaching visually impaired individuals emerged as an innovation from the need to produce a generic tactile board and different pieces for the game using 3D printing. Thus, the referred board is three-dimensional, has relief and color contrast, in addition to alphanumeric coordinates to facilitate the location of other pieces and characters on the board. The pieces to overcome obstacles, the obstacles, the pieces to be removed or placed according to the mission, the pieces that represent homes, cards with explanation, and the characters, were all made through 3D printing and adapted to the generic tactile board. The insertion of Braille language was necessary for the pieces used to form the lines of visual programming, the cards with explanation, and the alphanumeric coordinates on the board. The different pieces, cards, and characters were designed according to a pre-determined theme for this study, although several topics can be studied according to other areas of interest.

The process starts from a virtual 3D model, exported in STL format (specific extension for the 3D printer), later, this file is sliced in layers using specific software. Then, the sliced 3D model file must be transferred to the 3D printer to finally be printed (Chad, 2015; Katara & Doss, 2015).

All virtual models, including miscellaneous pieces, characters, and tactile board, were developed using AutoCAD 2018 software (Autodesk, inc.), besides cards that were modeled using SketchUp Pro 2017 (Trimble) software. So, in this work the virtual models were modeled integrally, not requiring the use of

3D model repositories. After being exported, the files went through the slicing process using the Repetier Host 2.0.5 software (Hot-World GmbH & Co. KG), resulting in sliced 3D models whose files were saved on an SD memory card and finally taken to the 3D printer for printing.

The process used was the fused filament fabrication (FFF) using the GTMax3D Core A1 printer. The printed parts went through the finishing process, refining the product to favor its usability. The filament used was the 1.75mm PLA Premium Filament, PLA (polylactic acid) type, from a renewable and biodegradable source. Filaments in red, yellow, orange, blue, black, green, white, gray and pink were used. Each color was printed separately and joined (when necessary), later, through the adhesive bonding, since the printer prints with only one filament roll at a time. For bonding, it was used instant adhesive based on medium viscosity cyanoacrylate.

3. Results

3.1 Game prototype adapted for the visually impaired

The game prototype adapted for the visually impaired consists of cards, pieces of visual programming language, a dice, other pieces of the game that fit the board and the tactile table board itself. The latter is divided into squares with holes in their center which represent the houses of the game and work to fit the other pieces. The inspiration came from chess for the visually impaired. It is also worth mentioning the contrast of colors that appears as a facilitator for gameplay, the alphanumeric coordinates in braille for the location of other pieces and characters on the board, and the cards with explanations, also in braille, to define the order of the missions to be carried out.

The visual programming language pieces (Figure 2) comprise:

- 1 piece START
- 1 piece DO
- 3 pieces MOVE
- 2 pieces 01, 02, and 03
- 1 piece 04, 05, 06
- 2 pieces RIGHT
- 2 pieces LEFT
- 1 piece SPIN 180º
- 1 piece TAKE
- 1 piece DROP
- 1 piece END

Figure 3 presents the model with the chosen topic arboviruses, Dengue, Zika, and Chikungunya, seeking to allow discussions in the area of health education. The game itself revolves around a city infested by the Aedes aegypti mosquitoes and actions to combat it.

Figure 3. MML Code Table board game adapted for the visually impaired. MML, Salvador, 2018.

The characters missions are to collect the garbage scattered around the city (bottles and tires) and cover the water tank of the player's house, located on the other side of the river. For this, players must use the visual programming language to "program" the characters (robots) to move around the board and carry out their missions.

The tactile elements of the board can be seen in Figure 4 and the *Cards* with explanations in Figure 5. The game also has an audible timer and a dice (Figure 2).

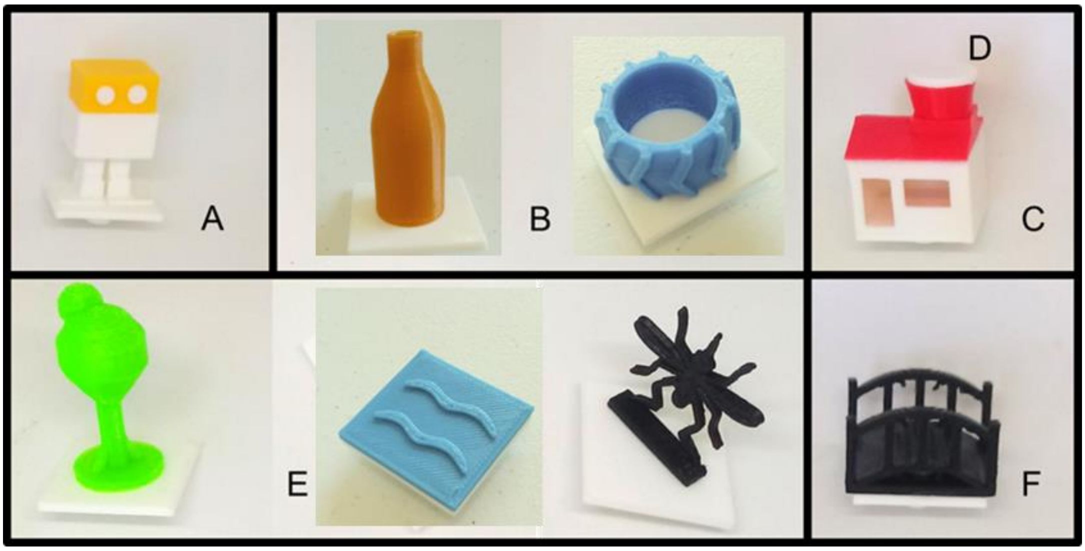

Figure 4. Tactile elements of the board. A. Characters who are the actions agents orchestrated by the players, B. Pieces that must be collected as garbage (bottles and tires), C. Pieces representing the residences (houses), D. Pieces for action “to cover the water tank ”(lids of water tanks in homes); E. Pieces that are obstacles (trees, river, and Aedes aegypti), F. Pieces to cross the river (bridges). MML, Salvador, 2019.

Figure 5. Cards with an explanation of the game's missions (3D printing in portuguese). MML, Salvador, 2019.

Purpose of the game: Players must complete each mission drawn among the cards;

Game Rules:

- The game can only be played by a maximum of two players;
- The character must be positioned facing the object that will undergo the action;
- The dice roller indicates who starts the game by the highest number obtained;
- Each round the dice is rolled to indicate the maximum number of squares on the board that the character can go through;
- Every action of the character is established by programming lines defined by each player;
- Each player determines his strategy and has 3 minutes set on the timer to assemble the pieces of the programming lines and finalize the code;
- The player should only move the character on the board after completing the code, which takes place through a specific piece (see Figure 1: orange piece at the bottom of the figure);
- If there is an error in the programming lines, the code will only work until the last correct line, interrupting the play;
- If it is not finished in 3 minutes, the code will not work, so the character will not move on the board;
- The bridge must be used to cross the river and the other parts are obstacles that must be circumvented.

Result of the game:

- The first to complete the missions wins.

Note that:

- We always start the programming lines with the START piece and then the DO piece, which will give the character the action command;
- The number of houses covered corresponds to the number determined by the dice. Remembering that the number designated by the dice is the **maximum** number of houses that can be crossed, it is not mandatory to reach this number;
- The last, END piece must be placed to indicate that the programming lines have been completed;
- The TAKE piece must be used to collect the garbage (bottles and tires);

- The DROP piece should be used to cover (DROP) the water tank.

4. Discussion

According to Freire, teaching is not a mere transfer of knowledge and content, but the promotion of elements for its production, so everyone must assume the role of agent producer of knowledge. Thus, it becomes evident the importance and the need for active participation of the subjects involved, something can be perceived during the stages of a game (Freire, 2016).

A research conducted by Huang and Lin show preliminary results that point out that different teaching materials assist the development of different skills and learning results (Huang & Lin, 2016). It is well known the importance of using new teaching resources, capable of influencing learning in the most diverse situations, including in visual impairment, with a relevant impact on the understanding of knowledge. Visually impaired children face important difficulties in the educational process, especially to follow the content, for which only verbal description is not enough to promote the understanding of the above. In a study carried out in China, researchers used texts in braille about oral health to children with different degrees of visual loss, seeking to evaluate the improvement of oral hygiene through the guidance provided. The results showed that there was a significant improvement in oral health when compared before and after this intervention (Khurana, 2019) reinforcing the role of didactic resources in the teaching-learning relationship, regardless of their format.

Therefore, prototypes of games adapted for the visually impaired can, at least in part, help to meet the need for new teaching resources in a universe demanding of these, especially in education for the visually impaired, since it provides the development of skills using other senses besides of vision. In line with our work, a previous study demonstrated that the development of a specific design on mobile devices focused on braille application (mobile phone-based Braille application, "mBRAILLE"), allowed individuals with vision loss to learn English and, in the pilot study, users approved this technology (Nahar, et al., 2015).

The serious games deserve to be highlighted in the educational scenario, which are instructive games introduced in the educational setting. These games enable attractive and interactive educational practices, capturing the attention of the student/player who can learn in an active and motivating way, reinforcing playfulness and proving that students can expand their learning using technologies to their advantage. Thus, games can be relevant collaborators for the teaching and learning process (Read, 2015).

The time that children and young people dedicated to playing games is an important determinant that concepts and educational issues can be increasingly introduced into games (Rothman, 2011). However, games should only be used for education if they have clear and accurate learning purposes. Based on games it would be possible to teach content, as well as enhance capacities and aptitudes, however, these must be truly attractive and motivational, presenting something pleasurable amongst the playfulness, without making the pedagogical character evident and, thus, not running the risk of becoming dull and tedious (Gros, 2003; Guillén-Nieto & Aleson-Carbonell, 2012).

The game prototype adapted for the visually impaired presented in this study is a game that involves participants, promotes competition between players and brings, in a playful and motivating way, new content to be addressed while the player develops logical reasoning skills.

As the perception of the visually impaired is altered because of the loss or reduction of the acquisition of information through the visual sensory system, when using this learning tool, the player makes use of means to acquire knowledge that goes beyond the vision. In the perception of the world, two of the senses stand out, hearing and touch (haptic system). Hearing achieves very important teleceptive purposes for the blind. The haptic system or active touch (when on purpose the person actively seeks information when handling something) is the most powerful sensory system that a blind person has to understand the world around. Because active touch, skin receptors, and underlying tissues promote excitation from muscle and tendon receptors, thus assimilating joint data and balance. Through touch, different characteristics of objects or beings are perceived, such as texture, temperature, shape, and spatial relations. The blind moves the hands intentionally, slowly and successively, investigating particularities of the form to then achieve a mental image (Ochaita & Rosa, 1995).

For the person with low vision, the size of the pieces and color contrast is essential, and for the blind, the promotion of tactile, auditory and kinesthetic experiences using other sensory routes to perceive and represent the world around is crucial. Therefore, we believe that the prototype presented here holds great potential as an auxiliary tool for teaching, impacting learning.

The act of playing with other subjects promotes communication and social interaction, a fact that, according to Ochaita and Rosa, provides psychological/cognitive development (Ochaita & Rosa, 1995). When communication is associated with the action of the visually impaired on the environment, they can command the mental skills that provide an understanding of reality. Then, the visually impaired when using the game prototype is socially interacting with another player and with the teacher in the role of mediator. Also, the game provides actions on the environment, since during the game it works on concepts of movement in space and laterality. These elements help the visually impaired to understand and apprehend the reality that surrounds them.

It should be noted that the game prototype adapted for the visually impaired has details regarding the students/players' perception capacity, since its excess may hamper perception. Therefore, the models are simplified, always highlighting the main information. Another important point to emphasize is its components, being produced through 3D printing, and have the flexibility of customization which allows the insertion of new modeled objects, being, in this way, adaptable to different contents.

This study sought tools and techniques to support the learning of the visually impaired in a context in which 3D printing can be a differentiator. 3D printing technology can create personalized instruments suitable for different degrees of visual impairment and acuity, favoring the development of cognitive skills and abilities (Jo, 2016).

The didactic material made in the 3D printer offers a learning opportunity to the visually impaired, which should be offered to any student, with or without disabilities. The visually impaired person has the same capacity for abstraction as people who normally see, but only develops it with the help of some adaptations and through alternative routes, such as hearing and touch (Nuernberg, 2008). In Brazil, only preliminary studies have been carried out with this focus, therefore, more research is needed to analyze and consolidate the results obtained.

5. Conclusion

This study reveals that 3D printing has great potential to produce teaching materials from the most diverse areas of knowledge, with wide possibilities for practical application, including in schools, favoring the development of multidisciplinary tools. Finally, this innovative approach can increase the use of 3D printing technology, aiming for the improvement of learning in different age groups and especially regarding visually impaired children.

6. Acknowledgement

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