

Tangible User Interfaces to Ease the Learning Process of Visually-Impaired Children

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People with visual impairment face significant challenges during their learning process, especially children in the early stages of this process. Different assistive technologies have been developed in last decades to support people with visual impairment when interacting with computers. This kind of technologies assume certain skills and level of maturity in the users. Nevertheless, there is a lack of technologies for children, specifically designed to support their personal development especially in the earliest stages. In this paper we propose a novel system based on Tangible User Interfaces aiming at providing children with visual impairment a new way of learning basic concepts. The system implements an audio-based game through which children are guided and motivated with different activities designed to learn basic concepts by identifying objects physically available that children must grasp with their hands to interact with the system. We have also performed a preliminary evaluation of the system with real users obtaining positive results.

Tangible User Interfaces, Accessibility, User Interface Design, Visual Impairment

1. INTRODUCTION

The use of technology in education has led to the development of many applications and Web-based solutions aimed at supporting learning in a creative and amusing environment. Many applications have been designed as digital games to encourage and engage students of any age in their learning process. Unfortunately, for students with visual impairments the opportunities are very limited, because there still exists a significant gap in the accessibility of serious games and applications for learning. In the literature some specific educational games or applications suitable for visually-impaired children have been proposed, such as BraillePlay [8], a suite to teach the braille code. However, a visually-impaired student has a very limited number of potential applications to consider, and they are for very specific topics. Accessibility guidelines have been proposed in the literature for several years [12] to require the design of applications suitable for all users and not specific for a certain disability. Nevertheless, this field still requires further studies and research to overcome that gap.

The interaction modality with a learning system is particularly crucial to make technology invisible to learners so that they can focus on the study rather than being distracted by the technology itself, which could even become an obstacle or distracting factor. This is especially true for pre-schoolers or

early schoolchildren, who need to interact as much as possible in a natural and simple way, just as if technology were not present. Most interaction modalities used for educational games heavily exploits the visual channel to introduce and show the educational contents in order to allow the students to learn them by imitation. Unfortunately, such an approach is not suitable for children who have a visual impairment. Therefore, alternative but equivalent solutions more accessible and suitable for those who cannot see need to be proposed.

In this paper we present an interactive application to teach some concepts about textures, shapes and geometry to children who have a vision impairment. More specifically, we focused particularly on blind children who can have more difficulties in learning shapes and details. The application has been designed to be simple and intuitive, and at the same time structured as a game. A blind child can thus interact with the game simply through their voice and grasping the different objects. The approach was aimed at making technology “invisible” so that the child can interact and play with the system in a simple and natural way. The interaction is therefore mainly based on speech recognition, touch and sound.

The rest of the paper is organized as follows: Section 2 presents some background concepts and related works. Section 3 describes the system

developed. Section 4 presents the outcomes of the preliminary evaluation performed on the system and finally, section 5 presents the conclusions and future works.

2. BACKGROUND AND RELATED WORKS

2.1 Tangible User Interfaces as Learning Tools

A tangible user interface (TUI) can be defined as one in which the user is provided with a physical representation of the digital information, allowing the user to literally grasp the data with their hands. This is possible thanks to the fact that the data is matched with the physical representations. A TUI must provide feedback to the user, either through the touch itself, through the digitized objects we refer to, or in aural or visual way when the interaction with that object has ended [15].

With a TUI we can transcend the common human-computer interaction, which is usually performed with a screen and images in two dimensions. This interaction can move on to the three-dimensional plane, making the user interact with something closer to reality.

Interest in tangible interfaces has been growing since the early nineties. One of the pioneers in the world of tangible interfaces is Hiroshi Ishii, head of the Tangible Media Group at MIT, who began to investigate with this type of person-to-person interaction in the mid-nineties. The new idea of Tangible Bits arose with the aim of joining the physical world with the digital one. The first tangible interfaces were created where objects, surfaces and spaces were used to materialize digital data [16].

Since the emergence of Tangible User Interfaces (TUI), numerous applications with different functionalities have been created, but hardly any of them has been applied in educational settings. Several reasons why TUI can improve the learning framework [17] are the following:

- Use of physical materials. Keeping in mind that perception and knowledge are linked together, then manipulating physical objects will make it much easier to assimilate their nature. For example, three-dimensional objects can be understood more easily if presented physically than in a digital form.
- Possibility of engaging the user. Interacting with TUI is much more natural than any other method of interaction, therefore it can be more engaging and accessible for children with disabilities.
- Very useful for collaborative learning. Applications with a tangible interface can be designed to be collaborative, enabling several users to interact with the same

objects at a time, in contrast to conventional software applications in which a single user interacts with a single screen.

- It has a greater potential as a learning method when dealing with certain topics. As for example when studying the structure of molecules in chemistry or in biology. It has been shown that relying on 3D figures is more useful than relying on drawings or illustrations.

For all these reasons TUI are a promising technique when it comes to educating any child, but for blind children in particular, they contribute with even more benefits. Only the fact of enhancing their tactile capacity is already a giant step, since, as mentioned, this is essential for their further development. In addition, through an application based on TUI they could get to know the aspect and shape of very large objects by recognizing them in a tactile way, as we can put these objects to scale to be manipulated.

2.2 Games in the education of blind people

Several entertaining and serious games have been proposed in the literature. Unfortunately, they are not suitable for people with a vision impairment since they are mainly visually-oriented [1] and do not offer an alternative perception. So, people with a vision impairment, especially those who are totally blind, are excluded from the opportunity to choose any type of game offered by the market. Some works have researched on how video games requiring different input and output can be developed for people with different disabilities [6, 12]. In this perspective, some design suggestions and frameworks have been proposed [4, 11]. Shoukry et al. [9] propose a framework for mobile educational games, but students with vision impairment are not considered.

Audio is a predominant channel used in games accessible to blind people. So, many auditory games are developed, such as those proposed by [2] and [5]. Song et al. [10] developed two audio-based learning games on TeacherMate, an inexpensive mobile device designed for people in developing countries. Although audio games certainly improve abilities and special skills (e.g. orientation in the space, etc.), they are not designed to teach general topics, such as maths and geometry. This means that a visually-impaired student cannot have access to a set of games and applications available as it occurs for the rest of people. Although our approach is mainly intended to support non-sighted children, it can also be useful for sighted children when learning common topics (like geometry) while interacting in a natural way with a tangible and voice-based game. In [3] the authors propose a mobile application to investigate how to teach to blind children geometric

shapes. However, the mobile prototype was designed for drawing plane figures. Through our application we would like to exploit new technology to explain more complex geometric shapes and other important concepts.

3. "TOUCH&LEARN" SYSTEM

In this section we describe the system developed, called "Touch&Learn", as a first prototype aimed at supporting the learning process of basic concepts for visually-impaired children. Concretely, we have implemented a set of activities to learn the numbers in Braille, geometric shapes (square, rectangle, triangle, sphere, pyramid, pentagon, octagon, cylinder, cone, etc.) and different textures (such as hard, soft, rough, smooth, sticky, sharp, even, uneven, etc.) by touching and identifying objects with these shapes and textures.

As the system is addressed to visually-impaired children, it has no visual interface and the interaction mechanisms are exclusively based on touch, sound and speech recognition. To this end, we use physical objects, as tangible user interfaces, that the user has to grasp to interact with the system, according to the instructions given by recorded audios. Depending on the user's actions or spoken answers, the system reproduces different audios to guide the user through the game with instructions of the different activities or giving feedback to the user according to their actions.

As the system contains many and different loose objects, it is very important to keep things organized in separate compartments where the

user can always find what they need to interact with the system. For this reason, we have designed the system as a big box composed of different compartments to store the objects the user needs to handle.

We have used NFC technology to enable users to interact with the physical objects. Objects are identified with NFC tags placed within them in a user-transparent way. The application is implemented in a mobile device with NFC reader to recognize the objects and react accordingly.

Figure 1 shows a picture of the system in which we can see the compartments the box is composed of to store the different objects. Picture (a) shows a general view of the box in which we can see the objects stored within the different compartments (Numbers in Braille at the bottom, geometric shapes on the left hand side and textures on the right hand side). Compartment (e) contains the Bluetooth speaker as the interaction with the system is guided through audio. Compartment (f) has a thin lid with embossed marks for the user to know where they have to put the object when interacting with the system, as the mobile phone with NFC reader running the application is placed below the lid to read the NFC tag contained in each object so as to identify it and react accordingly. Picture (b) shows some of the numbers and textures included in the box. Picture (c) shows the front side of the box with numbers stuck with Velcro on the upper side and holes on the lower side for the Bluetooth speaker placed below the mobile phone in a hand-made structure to place one underneath the other. Picture (d) shows some of the geometric shapes with NFC tags inside.

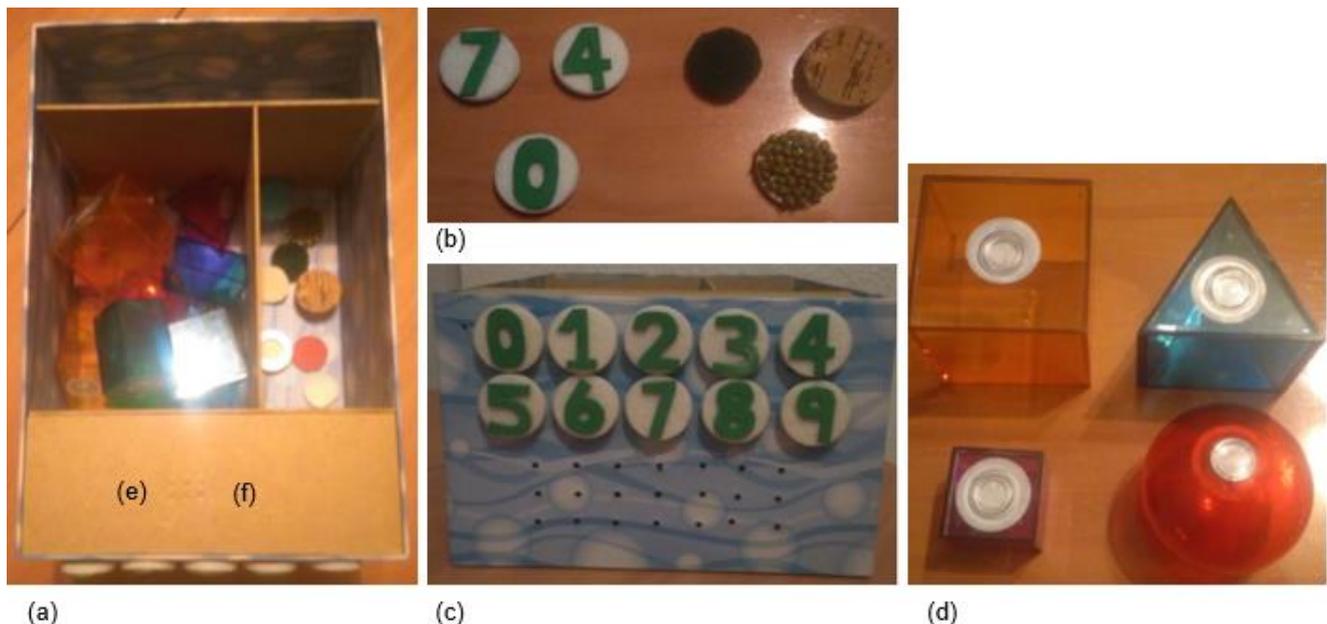


Figure 1: "Touch&Learn" System: (a) General view of compartments, (b) Numbers and textures, (c) Front side with numbers and holes for the speaker inside, (d) Some geometric shapes with NFC tags inside, (e) Compartment for the Speaker, (f) compartment with embossed marks on the lid for the mobile phone with NFC reader

The interaction with the system is quite simple as children only has to literally grasp the object required by the application, depending on the activity, and put it on the lid with the embossed marks (Fig 1- f). The mobile phone with NFC reader will identify the object and, if it is the right one, the system will reproduce the affirmative feedback audio; otherwise the feedback reproduced by the system will be positive and supportive encouraging the child to try it again.

4. PRELIMINARY SYSTEM ASSESSMENT

We performed a preliminary evaluation of the usability of the system by applying the international standard ISO/IEC 25062 [14]. We applied the following method.

4.1 Participants and Context

We could only recruit four participants between 10 and 13 years old. The evaluation was conducted in an informal setting. They were asked to play with the system performing two of the three activities: the identification of geometric shapes and different textures required by the system. Besides, they had to navigate through the different options and select the games. At the beginning of the evaluation session, we explained the details of the system and the way of playing with it to all the children at the same time. Then, they played with the system one by one.

4.2 Usability Metrics

We measured the system usability considering three types of metrics: effectiveness, efficiency and satisfaction, i.e. the users' subjective reactions when using the system. Effectiveness was measured by considering the percent task completion, frequency of errors and frequency of assistance offered to the child. Efficiency was measured by calculating the time needed to complete an activity, specifically, the mean time taken to achieve the activity. These measures are shown in Tables 1 and 2.

Finally, satisfaction was measured with the System Usability Scale (SUS) [13]. This questionnaire is composed of ten statements related to the system usage. In this case, we adapted the questionnaire to the system and type of users. The users had to indicate the degree of agreement or disagreement on a 5-point scale.

Table 1: Performance results: Identifying shapes and textures

Participant	Unassisted completion rate	Assisted completion rate	Task time (min)	Errors	Requests for assistance
1	100	0	3,15	0	0
2	100	0	4,48	1	0
3	100	0	2,36	0	0
4	100	0	3,36	0	0
Mean	100,00	0,0	3,34	0,25	0,00
Min	100	0	2,36	0	0
Max	100	0	4,48	1	0

Table 2: Performance results: Menu navigation and selection of games

Participant	Unassisted completion rate	Assisted completion rate	Task time (min)	Errors	Requests for assistance
1	100	0	3,15	0	0
2	100	0	4,48	0	0
3	80	20	3,52	1	2
4	90	10	3,36	1	1
Mean	92,50	7,5	3,63	0,50	0,75
Min	80	0	3,15	0	0
Max	100	20	4,48	1	2

At the end of the evaluation sessions, the four participants completed the questionnaire proposed by the System Usability Scale (SUS) [1].

Table 3 shows the results of the SUS scores per participant. The final value is between 0 and 100, being 100 the highest degree of user's satisfaction. With a mean score of 79,375, we can conclude that the level of satisfaction was quite high.

Table 3: Satisfaction results per participant

Participant	SUS Score
1	77,5
2	87,5
3	72,5
4	80,0
Mean	79,375

5. CONCLUSIONS AND FUTURE WORK

The teaching and learning process of visually-impaired children is a challenge and current technology can help to make this process funnier and more engaging. In this paper we have presented a system which incorporates novel interaction mechanisms, such as tangible user interfaces, speech recognition and audio reproduction to guide users throughout the application and the different options and games. In this first prototype we have implemented three kinds of activities to learn the numbers in Braille, geometric shapes and textures. We have performed a preliminary evaluation of the system with a limited number of children to assess the usability and convenience of the system, obtaining

quite positive results. As future work we plan to improve the system by adding new activities and games and performing a more exhaustive evaluation involving more children to get more feedback and results.

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