An approach to Inclusive Education in Electronic Engineering Through Serious Games

Angel Jaramillo-Alcázar
Facultad de Ingenierías y Ciencias Aplicadas, Universidad de Las Américas, Quito, Ecuador
angel.jaramillo@udla.edu.ec

Carlos Guaita
Facultad de Ingenierías y Ciencias Aplicadas, Universidad de Las Américas, Quito, Ecuador
carlos.guaita@udla.edu.ec

Jorge L. Rosero
Facultad de Ingenierías y Ciencias Aplicadas, Universidad de Las Américas, Quito, Ecuador
jorge.rosero@udla.edu.ec

Sergio Luján-Mora
Department of Software and Computing Systems, University of Alicante, Alicante, Spain
sergio.lujan@ua.es

***Abstract*—The development of video games has had a great growth in recent years. Also, serious games have positioned themselves as a tool that support the learning process of students. Students from electronic engineering are not the exception. However, video games of this type do not usually consider accessibility parameters in their design and those for electronic engineering are not the exception. On the other hand, several educational institutions use mobile devices in their classrooms for a more didactic learning and to achieve better learning outcomes. This article proposes a mobile serious game that addresses some basic principles of electrical circuits. Also, it incorporates accessibility features for students who have hearing or visual disabilities. Experiments were carried out with people with these types of disabilities to validate their accessibility and they were evaluated to verify their level of learning. Finally, the results obtained were analyzed in order to improve the video game.**

***Keywords*—Electronic engineering education, serious games, impairments, disabilities, mobile devices, accessibility, inclusive education.**

I. Introduction

People with disabilities have grown in number around the world. Approximately one billion people live with some type of disability, it is about 15 % of the world population [1]. In addition, in 2010 around 360 million people had disabling hearing loss [2] and 285 million people had some kind of visual impairment [3]. All of them need equal conditions in their lives. Hearing and visual impairments are the two main disabilities related to the senses and this affects the perception and reception of information during learning. Hearing loss in learning may affect the students' speech and language skills and also their vocabulary development [4].

The number of people with disabilities has led to initiatives that promote accessibility as a key feature in the world around us. In serious games, accessibility is also an important feature. This is a category of video games designed with the purpose of supporting the educational process [5].

Serious games are being applied in different knowledge areas: medicine [6], engineering [7], training and education [8], programming [9], business and industry [10], nursing education [11], among others.

Accessibility is the ability of an object to be used in spite of the condition or disability of a person [12]. In video games, accessibility is a factor that is beginning to be considered by software developers. Nevertheless, there are several players with disabilities. It is the case of Chris Robinson [13], Sven Van de Wege [14] and Ben Breen [15], better known as Phoenix, Blind Warrior and Sightless Kombat respectively. All of them are fighting game players. Chris is deaf and Sven and Ben are blind. These cases exist because some video games are accessible to people with different disabilities. However, these are only exceptions.

According to [16], there are four grades of hearing impairment based on a decibel scale representing hearing loss:

- Slight/mild hearing loss (26 - 40 dB).
- Moderate hearing loss (41 - 60 dB).
- Severe hearing loss (61 - 80 dB).
- Profound hearing loss (over 81 dB).

People with mild, moderate and severe hearing loss are grouped under the term *hard of hearing*; whereas people with profound hearing loss are *deaf*. Both, hard of hearing and deaf together represents the total number of cases of hearing impairments [2].

Also, in [17], the visual function is divided into four levels:

- Normal vision.
- Moderate visual impairment.
- Severe visual impairment.
- Blindness.

Both, moderate visual impairment and severe visual impairment, are grouped under the term *low vision*; low vision and blindness together represents the total number of cases of visual impairments related to vision loss [3]. Another vision alteration is *color blindness* which is defined as inability to detect certain colors or not perceive clear differences between red and green or yellow and blue correctly [18]. The person perceives the world as shades of gray.

People with Intellectual Disabilities (ID) have troubles and barriers to get a job. Some tools based in serious games for reeducation and diagnostic of cognitively impaired persons, have been developed [19]. Also, in [20] explains the design and evaluation of 10 games that supports people with learning disabilities and additional sensory impairments to prepare themselves to deal with situation at work, such as money

management, traveling independently, etc. The games were tested in collaboration with three countries: UK, Lithuania and Hungary. Some aspects that this project take into account in the Game is a 3D virtual reality environment using an avatar and a Britain Sign Language (BSL).

Nevertheless, a normal range intellectual quotient (IQ) can be found in children with learning disabilities, however they need that teachers and parents are concerned about their capabilities to help them with new and modern didactic material to improve their skills. A web based system tool that help children from kindergarten and early primary with learning disabilities, to know and improve their IQ, is presented in [21]. Based in a IQ test, the systems identify which disability category the child falls and assigns special games to play to overcome his disability. Then, the child is asked to do the test again to check if there is a learning improvement.

On the other hand, during Goal Net Project the use of serious games with three different classrooms of students with intellectual disability was carry out. Topics such as time and stress management, preparation before the first day at a new job, personal hygiene, job related quizzes, etc, were introduced [22]. Furthermore, the EPINOSI Project with tests for a period of two years, educators supported students with mild intellectual disability on the subject of serious games and new technologies. A specialized training program for primary, secondary and special education, with more than 400 teaching hours, was realized. The authors identified that the educator act as a researcher, as an facilitator and as a fellow-gamer.

In the field of serious games applied to engineering education, a practical example and case study of using Learning Mechanics - Game Mechanics (LM-GM) to evaluate the student retention is presented in [23]. A game, with a competitive leader board element, analytics and a level of user engagement and re-playability, is designed using a commercial game engine (Unity3D) to prototype simulations. This project seeks to increase student engagement through the compelling, engaging, immerse and competitive environment to teach advanced electronic/electrical circuit theory. They motivate to students to apply their knowledge and understanding of circuit theory of electronic circuits successfully to complete the game. The game include seven difficult levels, based in fundamental electronic and electrical circuits learned in the first year undergraduate engineering courses. Additionally, it is a deployment on mobile devices with touch capabilities using a first person perspective and viewpoint. The results obtained reveal that core analytics allow the measurement of student engagement/retention levels, based in the number and time of levels passed by the player (student). Educator can use this game like a tool to quantify the effectiveness of the learning activities.

Furthermore, this work focus on teaching digital electronic systems to students of the second year of electronics engineering, using serious games. A game designed by cases and difficult levels was used. Social networks like Google, were used to test the mini games that consist in little study cases related to specific topics like units system conversion, logic gates simbology and operation, simple logic gates connection and true tables [24].

In spite of efforts that has been made in create and develop serious games, still exist a gap in the accessibility field [25]. The gap can be reduced through the application of serious games in mobile devices and focused to education on people with some disability [26], for example people with visual impairments [25].

The Ohm's law is a basic principle that every student of electronic engineering must understand. Considering this, it is important to apply a different teaching mechanism, through a serious game, to teach the concepts related to this law. This paper proposes a serious game to teach the elemental concepts of electricity: current, voltage and resistance for students of electronic engineering. Also, some features of accessibility for people with hearing and visual impairments are presented.

The rest of this article is organized as follows. In section II, we design GameOhm app with accessible features. Next, in section III, we describe the game evaluation with electronic engineering students. In section IV, we analyze the results of the evaluation. Finally, in section V we conclude the research and we outline our future works.

II. GameOhm Application Design

In this section we describe the video game design and the guidelines considered for people with hearing and visual impairments. There are many authors that propose accessibility guidelines. This authors, in most part, belong to video games development groups. They focus their research on define features that provide the opportunity for people with disabilities to enjoy video games. This contribution is focused in improve the accessibility and offers the possibility of learning through serious games.

In previous works, we have studied some methods that assess the the accessibility of mobile video games for people with motor [27] and cognitive [28] impairments. Also, in [29] and [30] we described and consolidated some guidelines for people with hearing and visual impairments. We defined a guidelines categorization too. Now, we had considered some of that guidelines for the development of this version of GameOhm video game: simple language, customize font type, customize font size, high contrast colors, subtitles and sign language. The latter is an important feature that is beginning to be used. In [31], for example, the video game protagonist is a mouse that uses sign language.

One of the principal aspects in designing any technological solution is the definition of the different actors that will interact with the system. Thus, the actor identified for GameOhm is *Engineering student*. This actor is the electronic engineering student that will use the mobile application to learn basic concepts about Ohm's law: voltage, current and resistance. The functional and no functional requirements that were defined are shown in Table I and Table II, respectively.

All these requirements will be used to define the video game functionalities. Customize font type and size allows the player with hearing or visual impairment a readability,

Table I
FUNCTIONAL REQUIREMENTS

Requirements	Description
Learn electric voltage	The video game should support the user to learn the concept related to voltage.
Learn electric current	The video game should support the user to learn the concept related to current.
Learn electric resistance	The video game should support the user to learn the concept related to resistance.
Accessibility settings	The video game should support the user to customize font type and size and change colors of the games.
Sign Language	The video game should support the user to receive the instructions with sign language.

Table II
NO FUNCTIONAL REQUIREMENTS

Requirements	Description
Android Platform	The app should run over a device with Android 4.0 or later.
Usability	The mobile application should be intuitive, easy to use and understan and implement accessibility strategies for people with hearing and/or visual impairments.
Reliability and robustness	The system must be reliable and robust to user errors.

reduce eye strain, and help keep the gamer informed of the environment. On the other hand, sign language allows to a player with auditory impairments to understand the video game instructions.

The mobile video game was designed with Unified Software Development Process or Unified Process (UP) methodology [32]. It is based on use cases to obtain a reliable and scalable system architecture. UP uses Unified Modeling Language (UML) [33] for the representation of several architectural aspects of the application. In the design of the GameOhm video game, we have considered some artifacts like: use case diagrams, sequence diagrams, logical architecture and navigability diagrams using UML.

1) Use Cases: The use cases identification is the first step in the video game design. Use cases will capture the functional requirements and their relationships with the video game users. Figure 1 shows the use cases and their association with the video game user.

2) Sequence Diagrams: Furthermore, the sequence diagrams describe in detail the steps that the user must follow to execute the different use cases. Figure 2 shows the sequence diagram for the accessibility features configuration. It explains the process to be followed by the user to change the font type, the font size or if the high-contrast version is desired.

3) App Architecture: The definition of the architecture should be able to support the execution of all the processes described in the sequence diagrams. This will allow the development of all previously defined use cases. Thus, the Model View Controller (MVC) design pattern will be taken into account. This design pattern will facilitate the implementation of the resulting design code and provide a high degree of scalability to the application.

Figure 3 shows the architecture of the mobile app. Each

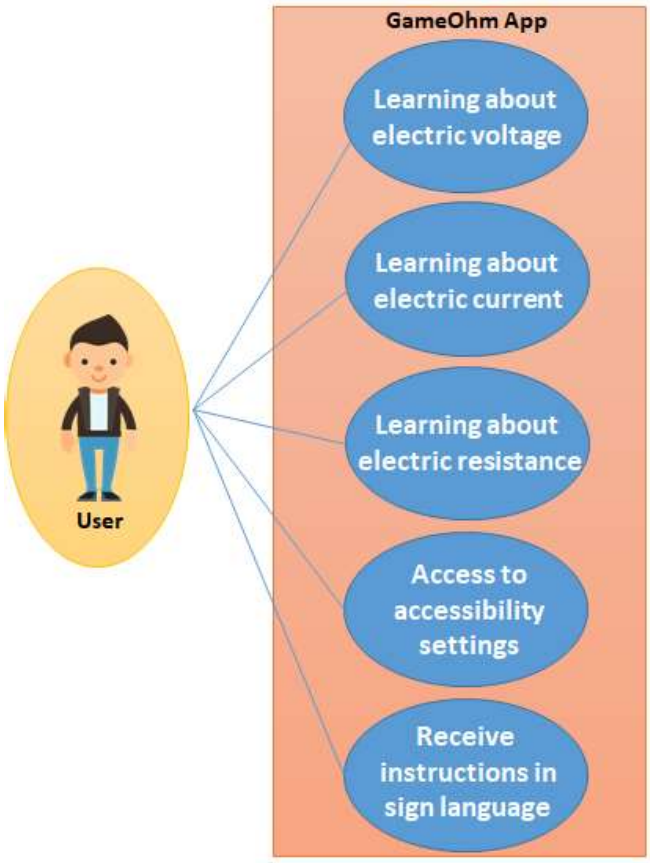

Figure 1. GameOhm Use Cases

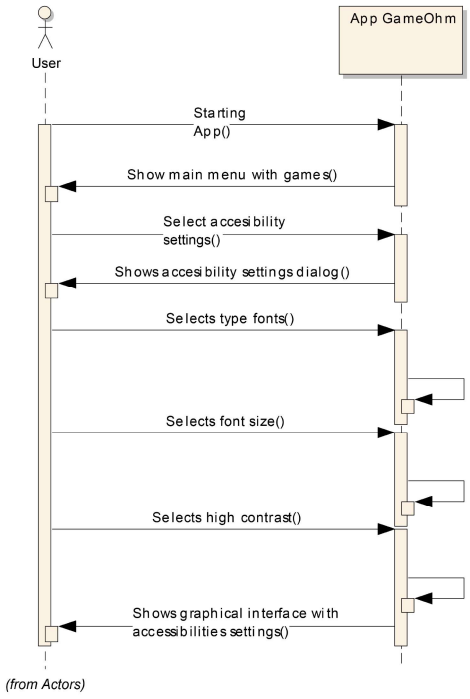

Figure 2. Accessibility Features Sequence Diagram

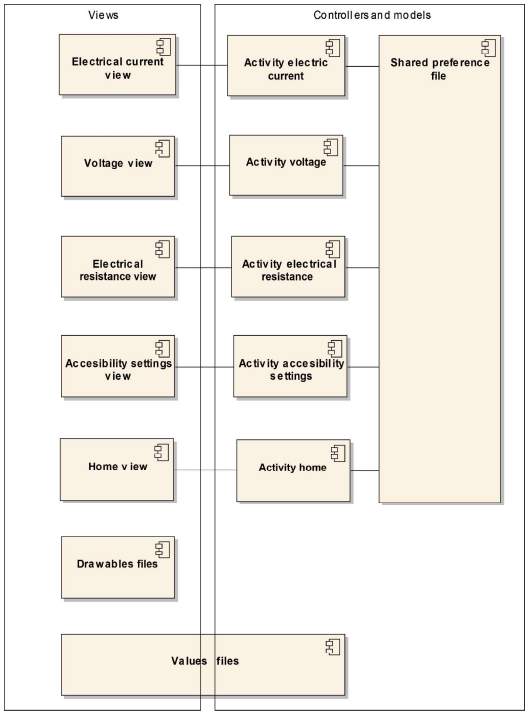

Figure 3. MVC Architecture

block represents a programming system component and also we can see the relationship between each one. Also, it shows the transversability of some of them when it is used by more than one component in the application.

4) App Navigation: The navigability that the application will have between the different modules is presented in Figure 4. Each module can access the others except the accessibility module, which will be accessed only through the main menu screen.

III. GameOhm Review and Students Assessment

Once the mobile video game was developed, some tests were carried out with first semester students of electronic engineering.

Likewise, GameOhm app was installed on six Samsung Galaxy Tab S2 with Android Marshmallow 6.0.1. They were used by twenty-two students in a sixty-minute evaluation session. In Figure 5, we present some screen captures of the final version used by the students. The upper left capture corresponds to the initial screen of the game where a selection menu of the three games is presented.

In the lower left capture, we present the game of electric current. In red circles are the electrons that should be placed on the conductor in yellow. The formula for calculating the current is presented, where q is the number of electrons and t is the unit of time. Depending on the number of electrons and the set time, the current that circulates on that conductor varies.

The upper right capture corresponds to the voltage game. The game explains the difference in potential measured in two

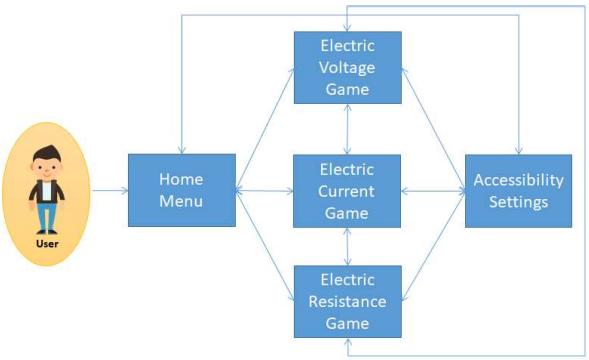

Figure 4. App Navigation

points. The student can set the potential value at each point and observe how the total voltage value varies based on this.

At the bottom right we present the resistance game. This set allows to vary the characteristics of the conductor cable as its length or thickness. The value of the resistance obtained in ohms is calculated through the formula.

In all games, a video with the description and the instructions of the corresponding game in sign language is presented. Also, at the bottom of each game, the subtitles are displayed in a simple language understandable to the students. In the right top of all screens there is the button for configuring the accessibility parameters as we can see in Figure 6.

Once the students played GameOhm after a general explanation of the video game, we proceeded to perform a knowledge assessment with three questions about the basic principles

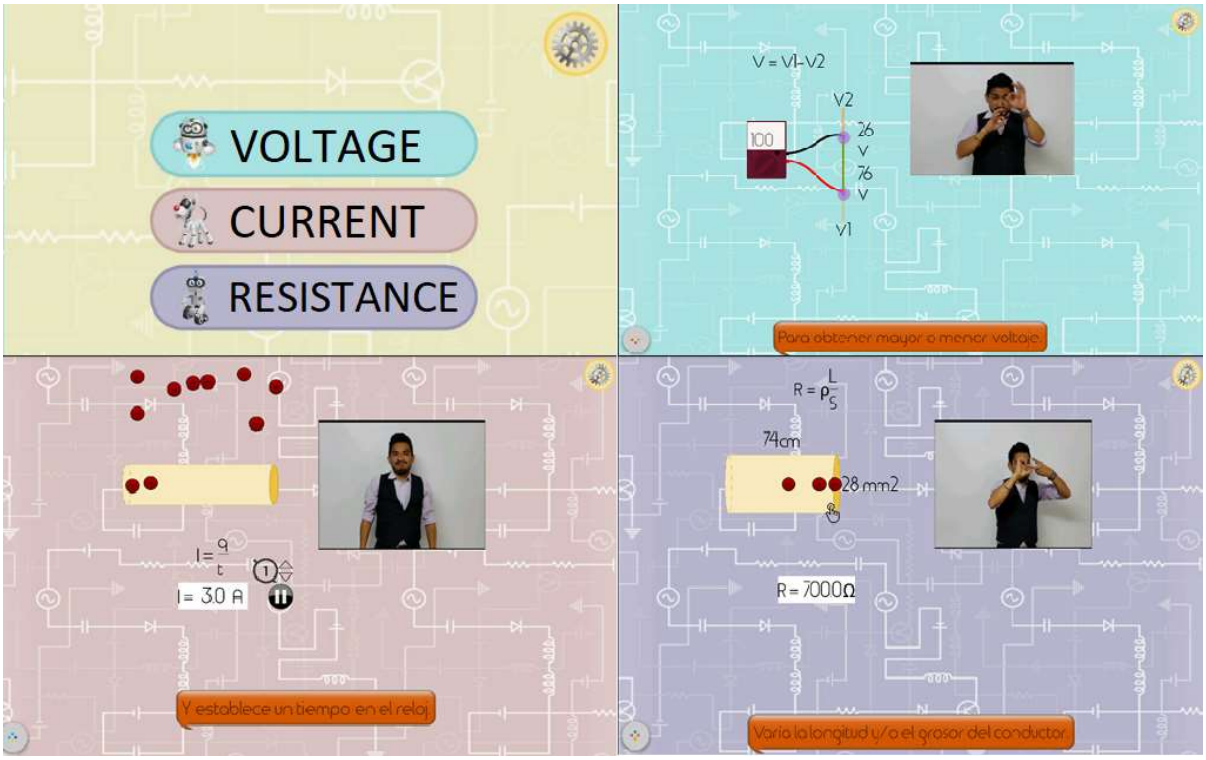

Figure 5. GameOhm Screen Captures

Figure 6. GameOhm Accessibility Features

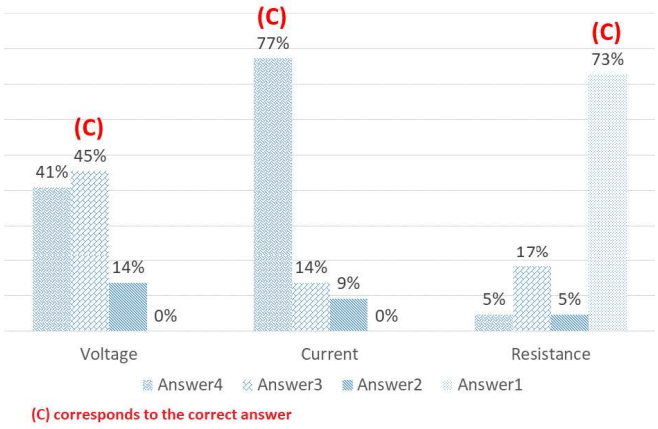

Figure 7. Students Assessment Results

of electronics such as: Voltage, Current and Resistance. The results obtained by the students can be seen in Figure 7. In red is showed the correct answer of each question (C).

IV. Discussion of Results

This mobile video game is aimed at reinforcing the basic knowledge of electronics engineering, in this case Ohm's law. We have some considerations about the learning assessment about the three main topics covered in the game: resistance, voltage and current.

In the first question, related to the concept of Resistance, the 73 % of responses are correct. Also, in the question about Current, the 77 % of the students answered correctly. In both cases, this result could be represent that the two concepts were assimilated correctly.

On the other hand, in the third question about voltage, just the 45 % of responses are correct. It could mean that more than the half of students did not understand the concept related to voltage and maybe it is needed to improve the content presented. Another alternative could be to consider a different logic for the voltage game, taking into account an example that clarifies the concept in question.

The mobile video game also presents accessibility features

for people with hearing and visual impairments as we can see in Figure 6. This is a relevant characteristic for those people that have troubles in their vocabulary development due to their hearing loss. In Figure 8, for example, we can appreciate the high contrast configuration and subtitles of the resistance game.

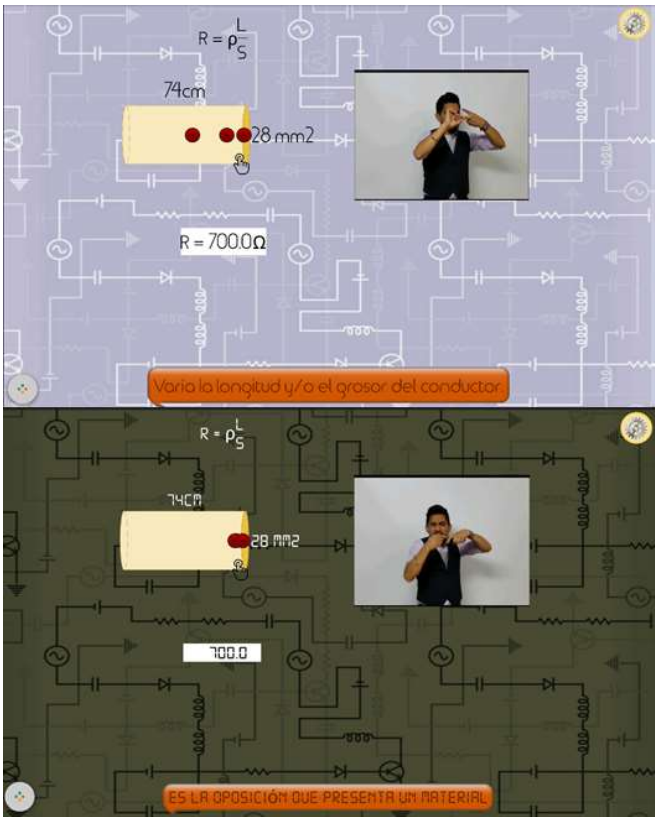

Figure 8. High Contrast Configuration

V. Conclusions and Future Work

This research tries to support the learning process in engineering students, specially from the electronic area and for people with hearing and visual impairments. Serious games development has growth and is important to consider accessibility parameters in their design and implementation. The use of non-accessible serious games goes against the Article 24 - Education of the United Nations Convention on the Rights of Persons with Disabilities [34], considering that avoids people with impairments having access to education on equal terms with a person without disabilities.

Every area related to engineering education has his own particularities and they need to beef up some specific topics that are essential in their knowledge area. Ohm's Law is a basic principle that every student of electronic engineering must understand and dominate. The results obtained in the evaluations show evidence that there was learning by the students. However, it is necessary to apply more specific evaluations to have more accurate results.

The use of mobile devices has increased in recent years. This has given way to the development of applications for teaching purpose. The proposed mobile video game tries to support the learning process in students of elemental electronic. Also, it incorporates accessibility features that could be set by students with hearing or visual impairments. It is important to consider that, as with oral language, there is not necessarily a unique sign language for everyone, and even less is a universal language. There are different sign languages in the world, located regionally.

In the development of the application and while the translations to sign language were done, the application was slightly tested by a couple of deaf students generating a high interest and acceptance in them. However, the next step in our research will be to conduct usability tests with students with hearing or visual disabilities. This will allow us to assess the effectiveness of the features incorporated in the video game. There are other features that could be included in a new version of GameOhm. The long-term objective is to propose a mobile video game totally accessible for people with hearing and visual impairments and/or other disabilities.

Acknowledgment

We thank the faculty of the *Instituto Nacional de Audición y Lenguaje* for their support in the translation into sign language of the different descriptions of the video game presented.

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