FRAMEWORK FOR THE DESIGN OF INTERACTIVE COLLABORATIVE TOOLS TO SUPPORT LITERACY TEACHING TO DEAF CHILDREN THROUGH STORYTELLING

LEANDRO FLÓREZ ARISTIZÁBAL

Tesis presentada para obtener el grado de
Doctor en Ciencias de la Electrónica

Dirigido por:
Ph.D. Sandra P. Cano Mazuera

Universidad del Cauca
Facultad de Ingeniería Electrónica y Telecomunicaciones
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Codirigido por:
Ph.D. César A. Collazos – Universidad del Cauca
Ph.D. Andrés F. Solano – Universidad Autónoma de Occidente

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Resumen Estructurado

Antecedentes

Los principales temas que inicialmente se consideraron para comenzar esta investigación surgieron al tratar de comprender cómo las personas sordas aprenden a leer y escribir, esto condujo a hacer una investigación previa sobre estrategias de enseñanza de lectura/escritura y observar a los niños sordos en un aula mientras realizaban actividades diseñadas y llevadas a cabo por el profesor. Se estudiaron en profundidad dos estrategias de enseñanza, la primera fue la llave Fitzgerald y la segunda fue Logogenia. Del trabajo realizado durante las sesiones de observación, dos estrategias más que indirectamente estaban siendo utilizadas por el maestro llamaron nuestra atención, estas son la narración de historias y el aprendizaje colaborativo. Finalmente, no se estaba utilizando tecnología en el aula debido a la falta de herramientas educativas disponibles diseñadas para niños sordos y más específicamente para la enseñanza de la lectura/escritura en español, lo que llevó a descubrir si había algún framework/metodología para el diseño de tales herramientas.

Objetivos

El objetivo principal de esta investigación fue establecer un framework para el diseño de herramientas colaborativas interactivas que apoyen la enseñanza de la lectura/escritura de niños sordos a través de la narración de cuentos. Los objetivos específicos que llevaron al cumplimiento de este objetivo general son:

- Analizar métodos de enseñanza de lectura/escritura para niños sordos de 5 a 11 años.
- Definir estrategias de aprendizaje colaborativo que puedan integrarse en un enfoque de enseñanza de lectura/escritura.
- Diseñar un framework para el diseño de herramientas colaborativas interactivas para apoyar la enseñanza de lectura/escritura de niños sordos.
- Desarrollar un prototipo de sistema colaborativo interactivo para apoyar el framework propuesto.
- Evaluar el framework propuesto a través de un caso de estudio utilizando el prototipo desarrollado.

Métodos

Se llevó a cabo una investigación de métodos mixtos, donde se recopilaron datos cualitativos y cuantitativos. Se llevaron a cabo revisiones sistemáticas de la literatura para descubrir cómo se usaban la narración de cuentos y el aprendizaje colaborativo como estrategias educativas para la educación de los niños sordos. También se llevaron a cabo varios estudios de caso con niños sordos y educadores durante los 4 años de investigación para obtener realimentación valiosa de aquellos que se beneficiarán de esta investigación. Se utilizaron y adaptaron diferentes técnicas como encuestas, entrevistas, observación directa y smileyometer para recopilar datos de estos usuarios.

Resultados

Las revisiones sistemáticas de la literatura arrojaron los primeros resultados de esta investigación donde se identificó una brecha, y esto condujo al diseño del framework propuesto en este estudio. Este framework se evaluó durante toda la investigación y se desarrolló un prototipo funcional de alta fidelidad siguiendo cada etapa del framework. Los resultados de los casos de estudio y las pruebas de usabilidad

realizadas muestran que la contribución de esta investigación impacta positivamente el trabajo realizado por diseñadores y desarrolladores de herramientas educativas que tienen como objetivo desarrollar tales herramientas para apoyar la enseñanza de la lectura/escritura a niños sordos. Los resultados también demuestran cuán útiles son la narración de historias y el aprendizaje colaborativo como estrategias atractivas para motivar a los niños a aprender a leer y escribir.

Conclusiones

El marco propuesto facilita desglosar las actividades de cada etapa y adaptarlo a un conjunto particular de objetivos/estrategias de aprendizaje para desarrollar habilidades de lectura/escritura en niños con diferentes capacidades, como los niños sordos. La adaptación realizada en esta investigación muestra que el framework propuesto no es un framework de propósito general, sino que es un enfoque modular que se puede transformar de acuerdo con las necesidades de los usuarios finales. El nuevo framework propuesto en esta investigación, y su adaptación para la lectura y escritura, contribuye al diseño de tecnología educativa/interactiva para personas sordas al tiempo que los hace parte del proceso de diseño y teniendo en cuenta sus necesidades particulares. Esto permite una mejor aplicación de la tecnología a la educación y, en consecuencia, una mejor experiencia de aprendizaje.

Palabras clave: Lectoescritura, Aprendizaje Colaborativo, Narración de Cuentos, Niños Sordos, Diseño, Accesibilidad.

Structured Abstract

Background

The main topics that were initially considered to start this research came from trying to understand how deaf people learn to read and write, this lead to do some previous research on literacy teaching strategies and observing deaf children in a classroom while doing activities designed and carried out by the teacher. Two main teaching strategies were studied in depth, the first one was the Fitzgerald Key and the second one was Logogenia. From the work carried out during the observation sessions, two more strategies that were indirectly being used by the teacher caught our attention, these are storytelling and collaborative learning. Finally, no technology was being used in the classroom due to the lack of available educational tools designed for deaf children and more specifically for Spanish literacy teaching, which led to find out if there were any framework/methodology for the design of such tools.

Objectives

The main objective of this research was to establish a framework for the design of interactive collaborative tools to support literacy teaching to deaf children through storytelling. The specific objectives that led to the fulfillment of this general objective are:

- To analyze literacy teaching methods for deaf children from 5 to 11 years old.
- To define collaborative learning (CL) strategies that can be integrated in a literacy teaching approach.
- To design a framework for the design of interactive collaborative tools to support literacy teaching to deaf children
- To develop a prototype of interactive collaborative system to support the proposed framework.
- To evaluate the proposed framework through a case study using the developed prototype.

Methods

A mixed methods research was carried out, where qualitative and quantitative data were collected. Systematic literature reviews were carried out to find out how storytelling and collaborative learning were being used as educational strategies for deaf children education. Several case studies with deaf children and educators were also carried out during the 4 years of research in order to have valuable feedback from those who will benefit from this research. Different techniques such as surveys, interviews, direct observation and smileyometer were used and adapted to collect data from these users.

Results

The systematic literature reviews delivered the first results of this research where a gap was identified, and this led to the design of the framework proposed in this study. This framework was evaluated during the whole research and a functional high-fidelity prototype was developed by following each stage of the framework. The results of the case studies and usability tests carried out show that the contribution of this research impacts positively the work done by designers and developers of educational tools who

aim to develop such tools to support literacy teaching to deaf children. Results also demonstrate how useful storytelling and collaborative learning are as engaging strategies to motivate children into literacy learning.

Conclusions

The proposed framework makes it easy to break down the activities of every stage and adapt it to a particular set of learning goals/strategies to develop literacy skills for children with different abilities such as deaf children. The adaptation made in this research shows that the DesignABILITY framework is not a general-purpose framework, instead, it is a modular approach that can be transformed according to the final users' needs. The new framework proposed in this research, and its adaptation for literacy, contributes to the design of educational/interactive technology for deaf people while making them part of the design process and taking into account their particular needs. This enables a better application of technology to education and consequently a better learning experience.

Keywords: Literacy, Collaborative Learning, Storytelling, Deaf Children, Design, Accessibility.

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Chapter 1

Introduction

Information and Communications Technologies (ICT) have changed the way people manage information and the way we communicate with others. From computers to mobile devices, technology is at our fingerprints and can be used as a resource for educational purposes [1]. Organizations, experts and practitioners in the education sector are increasingly recognizing the importance of ICT in supporting educational improvement and reform [2].

Designing and developing technological tools aimed to support the education of children with disabilities can become a very difficult challenge because traditional methods for creating such tools (i.e. Software Development Methodologies) generally overlook particular needs of end-users like children with some kind of impairment [3]. Disabilities affect the way students learn and that is why most of them require assistive or adaptive technology depending on the kind of abilities they have [4].

From an HCI perspective, some methodologies and models have been proposed to improve accessibility and usability of interactive systems [3][5] while others involve children in the design/development process through a User-Centered Design (UCD) approach [6][7].

These kinds of approaches may not be suitable for all developments because on one hand they are not specifically designed to develop educational tools, so they lack of information regarding teaching/learning strategies, didactics or learning goals [8]. On the other hand, evaluation methods that are usually proposed in traditional and the

aforementioned approaches are not adapted to be used with children with some kinds of disabilities [9][10]. Finally, some of these methodologies that are aimed to improve accessibility usually provide general accessibility guidelines and not the necessary ones for designing tools that can be used by children with a particular disability. These issues make designing and development processes take longer than expected.

Focusing on one particular disability (deafness), research shows that deaf children face communication challenges due to the late acquisition of a first language at home, as 90% of these children have hearing parents [11][12] who do not know Sign Language (SL). SL is seen as the mother tongue of deaf community [13][14] and many countries legally recognize it as such [14][15]. Learning a first language (SL for deaf people) during the first five years of age [13] is necessary to acquire other skills such as a second language in a written form or knowledge in other areas like math and sciences [16]. According to this, bilingual education should be adopted [17] in order to prepare deaf children for a more inclusive environment where they should not be at disadvantage with their hearing classmates. This is how literacy teaching becomes a major challenge for educators and technology may support this process if it is designed taking into account teachers and deaf children's needs.

In pedagogical and learning aspects it has been found that there is a need and desire for deaf children to work with their classmates in a collaborative way [18]. In this case, the use of Collaborative Learning (CL), a method in which students work with one another to achieve a common goal [19], could promote learning and communication skills among classmates. Unfortunately, there is not much information about the use of CL in the education of Deaf children [20]. It has also been identified that developing reading and writing skills is a major challenge for these children because the strategies used with them must differ from those used with hearing children, for instance some deaf children communicate only through sign language (SL) and they are mainly visual learners [21]. Teachers must find adequate methods and tools to support their teaching process and make learning meaningful and engaging for deaf students and one way to do so is through storytelling or interactive storytelling (IS) and the inclusion of Information and Communications Technologies (ICT) [22].

To the best of our knowledge, there is not a clear way to involve these strategies (CL and IS) in existing methodologies for the development of educational tools aimed at Deaf children.

Based on these findings, the following research question arises:

¿How can collaborative learning activities be designed to be part of an educational interactive tool to support literacy teaching to Deaf children?

¿How can interactive storytelling strategies be integrated during the design of an educational tool to support literacy teaching to Deaf children?

1.1 Objectives

1.1.1 General

- To establish a framework for the design of interactive collaborative tools to support literacy teaching to deaf children from 5 to 11 years old through storytelling.

1.1.2 Specific

- To analyze literacy teaching methods for deaf children from 5 to 11 years old.
- To define collaborative learning (CL) strategies that can be integrated in a literacy teaching approach.
- To design a framework for the design of interactive collaborative tools to support literacy teaching to deaf children
- To develop a prototype of interactive collaborative system to support the proposed framework.
- To evaluate the proposed framework through a case study using the developed prototype.

1.2 Hypothesis

Integrating collaborative learning and interactive storytelling strategies as part of the design process of a system to support literacy teaching to Deaf children will allow the development of educational tools that enable a better and engaging learning experience by allowing children to learn along with their peers and thus make the learning process meaningful.

1.3 Methodology

This thesis was developed using a mixed methods research where qualitative and quantitative data were gathered in order to evaluate the work done during the design of every stage of the framework proposed. To achieve every specific objective, a 4-phase methodology was proposed (Identify, Analyze, Design, Evaluate).

Identify. In this stage the need was identified through observation of the educational context of deaf children in two institutions located in Popayán and Cali (Colombia).

Analyze. This stage is about understanding what challenges these children are facing and how they could benefit from storytelling and collaborative learning in their learning process.

Design. The framework is designed in this stage as well as the prototype of a collaborative interactive system following each stage of the framework.

Evaluate. This stage consists in evaluating not just the prototype but also the framework through the collection of qualitative and quantitative data.

1.3.1 Systematic Literature Reviews

Two systematic literature reviews (SLR) were carried out by following the Kitchenham and Charters guidelines for performing literature reviews in software engineering [23]. The purpose was to find out what has been done and how it could be integrated in this proposal. The first SLR was about how storytelling has been used to support the education of deaf children. The second SLR was about finding information on how collaborative learning has been used as an educational strategy for deaf people. Both SLR were published and presented in international conferences [24][20] and were fundamental for fulfillment of the first two specific objectives.

1.3.2 Ethical Considerations

This research is governed by ethical, scientific, technical and administrative standards for health research defined primarily by the Ministry of Health of the Colombian government in its resolution No. 8430 of 1993 [25]. The ethical code from the Association of Deaf People from Valle (ASORVAL by its acronym in Spanish) was also applied in every case study carried out (Appendix A).

Consent forms were signed by educational institutions and parent or legal representatives of deaf children who participated in the case studies carried out in the institutions (Appendix A).

1.4 Contributions

A framework is proposed for the design of accessible interactive tools aimed to support literacy teaching to deaf children. The core of the framework could be adapted for different impairments, teaching strategies and learning goals. In this study, we focused on one particular disability (deafness) and taking into account that hearing problems affect the development of communication skills like reading and writing, our proposal focuses specifically on literacy teaching. We have been working with deaf children in co-design sessions and through case studies aiming to understand their particular

needs and support the development of literacy skills through technology. In the pedagogical and learning aspects, it has been found that there is a need and desire for children to work with their classmates in a collaborative way. In this case, the use of Collaborative Learning (CL), a method in which students work with one another to achieve a common goal [19], could promote learning and communication skills among classmates. Unfortunately, there was not much information about the use of CL in the education of Deaf children [20] but this research has started to change this situation.

It has also been identified that developing reading and writing skills is a major challenge for these children because the strategies used with them must differ from those used with hearing children, for instance some deaf children communicate only through sign language (SL) and they access information visually [21]. Teachers must find adequate methods and tools to support their teaching process and make learning meaningful and engaging for deaf students and one way to do so is through storytelling or interactive storytelling (IS) and the inclusion of Information and Communications Technologies (ICT) [22] as this research proposes.

Existing methodologies do not provide guidance for the development of tools aimed at deaf children. To close this gap, the proposed framework has been designed to focus on one particular (but extensive) learning goal and by engaging two well-known strategies in literacy learning: Interactive Storytelling [26][27][24] and Collaborative Learning [28][29]. Since gathering a group of children to work together in a common task does not guarantee an effective collaborative work [30], it is necessary to structure activities that lead to true team work. The use of storytelling and ICT could help not just to make learning a written language meaningful and thus motivate children, but also it can be a way to promote collaboration among deaf students.

By providing this framework, designers and developers have a guide through the design process of a software-based technological tool targeting at helping to support the development of reading and writing skills for deaf children. A prototype was developed following the stages of the framework and was evaluated by teachers from different institutions for Deaf children in Colombia.

1.5 Origins of the Material

Material presented in this thesis has appeared in several conference papers and journals throughout the duration of the author's PhD programme, from January 2016 to December 2019. In this section, we provide a list of papers that have been published in various journals and international conferences that led to the contributions of this thesis.

1. **Flórez-Aristizábal, L.** and Collazos, C. *Metodología para el desarrollo de aplicaciones interactivas móviles desde un enfoque de diseño centrado en el usuario para la enseñanza de la lectura a niños sordos*. XI Congreso Colombiano de Computación, Popayán, Colombia, 2016.

2. Cano, S; Collazos C.; **Flórez-Aristizábal, L.** and Moreira F. *Augmentative and alternative communication in the literacy teaching for deaf children.* 19th International Conference of Human-Computer Interaction, Vancouver, Canada, 2017.

3. **Flórez-Aristizábal, L.**; Cano, S. and Collazos, C. *Using storytelling to support the education of deaf children: A systematic literature review*. 19th International Conference of Human-Computer Interaction, Vancouver, Canada, 2017.

4. Cano, S; Collazos, C.; **Flórez-Aristizábal, L.**; González, C.; and Moreira, F. *Assessing user experience for serious games in auditory-verbal therapy for children with cochlear implant*. 5th World Conference on Information Systems and Technologies, Madeira, Portugal, 2017.

5. **Flórez-Aristizábal, L.**; Cano, S.; Vesga, L. and Collazos, C. *Towards the design of interactive storytelling to support literacy teaching for deaf children*. In HCI for children with disabilities, Human-Computer Interaction Systems, Springer, 2017.

6. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Solano A. and Slegers, K. *Collaborative learning as educational strategy for deaf children: a systematic*

literature review. XVIII International Conference on Human Computer Interaction, Cancún, México, 2017.

7. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Moreira, F.; Alghazzawi, D. and Fardoun, H. *Tools and methods applied in interactive systems to evaluate the user experience with deaf/hard of hearing children*. 5th International Conference on Technological Ecosystems for Enhancing Multiculturality, Cádiz, Spain, 2017.

8. Cano, S.; Collazos, C.; **Flórez-Aristizábal, L.**; González, C. and Moreira, F. *Towards a methodology for user experience assessment of serious games with children with cochlear implants*. Telematics and Informatics, Vol. 35, No. 4, pp. 993-1004, 2018.

9. Cano, S.; Collazos, C.; **Flórez-Aristizábal, L.**; Moreira, F.; Peñeñory, V. and Agredo V. *Designing collaborative strategies supporting literacy skills in children with cochlear implants using serious games*. World Conference on Information Systems and Technologies, Nápoles, Italia, 2018.

10. Enríquez, L.; Noguera, E.; **Flórez-Aristizábal, L.**; Collazos, C.; Daza, G.; Cano, S.; Alghazzawi, D. and Fardoun, H. *Graphical user interface design guide for mobile applications aimed at deaf children*. International Conference on Learning and Collaboration Technologies, Las Vegas, United States, 2018.

11. **Flórez-Aristizábal, L.**; Cano, S.; Manresa, C. and Collazos, C. *Towards a computer-supported collaborative learning approach for deaf children*. Second International Conference on Accessibility, Inclusion and Rehabilitation using Information Technologies, Palma de Mallorca, Spain, 2018.

12. Cano, S.; **Flórez-Aristizábal, L.**; Collazos, C.; Fardoun, H. and Alghazzawi, D. *Designing interactive experiences for children with cochlear implant*. Sensors, Vol. 18, No. 7, 2018.

13. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Benavides, F.; Moreira, F. and Fardoun, H. *Digital transformation to support literacy teaching to deaf Children:*

From storytelling to digital interactive storytelling. Telematics & Informatics, Vol. 38, pp. 87-99, 2019.

14. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Solano, A. and Brewster S. *DesignABILITY: Framework for the design of accessible interactive tools to support teaching to children with disabilities*. CHI Conference on Human Factors in Computing Systems, Glasgow, United Kingdom, 2019.

1.6 Thesis Outline

Chapter 2 presents a background about literacy in deaf children's education and the information collected in two systematic literature reviews about storytelling and collaborative learning as supportive strategies in the education of the deaf.

Chapter 3 presents related work on the design of educational tools and how these can be designed for people with disabilities. Different strategies and methodologies/frameworks are explained in this section.

In chapter 4, the proposed framework is presented. First, the core of the framework is explained and how it was adapted for literacy teaching to deaf children. Each sub-stage of this adaptation is also explained in detail.

Chapter 5 shows how the framework was evaluated by experts. The results are shown and subsequently discussed.

In chapter 6, the procedure of the development of a prototype is presented. This prototype was designed by following all the stages proposed in the DesignABILITY framework.

Finally, chapter 7 presents the conclusions of this research and future work to be done.

Chapter 2

Background

2.1 Literacy in Deaf Children's Education

One of the main reasons Deaf people do not finish higher education is due to poor literacy skills [31]. The development of reading and writing skills is a challenge for most Deaf children especially because 90% of these children are born from non-Deaf parents [11][12]; this could become in the first issue these children face (communication with parents) and it may derive in a late acquisition of a first language (L1) which should be a Sign Language (SL) that parents probably do not use. Learning a first language during the first five years is critical to acquire a second language (L2) in a written form (for instance, English or Spanish) [13] which will allow them to communicate with hearing people who do not know a SL. Literacy skills are also important to have access to information and thus create and construct new knowledge in other areas like math or sciences [16][32][33].

In order to achieve literacy learning goals with deaf children, the strategies used by teachers must differ from those used with hearing children, taking into account that they learn by mapping the language they speak (e.g. English or Spanish) with text on a board or page [34], while deaf children cannot do the same with sign language as it has a completely different structure from a written language, for instance, American Sign Language (ASL) which is the language used by deaf community in United States, is not English, they are two completely different languages [16][34].

2.2 Strategies for the Development of Literacy Skills with Deaf Children

2.2.1 Storytelling

Storytelling is known as a social and cultural activity of creating or sharing stories and it has lately being a topic of interest in fields like HCI and Artificial Intelligence (AI) [35][36]. Storytelling is pervasive in different aspects of children's life such as the development of skills in communication or to enforce the relationships with peers and adults [37]. In the field of education, storytelling has demonstrated to be a great resource to work in different areas like natural sciences [5], foreign language teaching [38], sign language [39][40], programming [41] and literacy [42][27][26][43][44].

According to the National Storytelling Network (NSN) high-quality storytelling must be interactive [45] and nowadays technology provides new opportunities for children not just to have fun but also to learn. Interactive storytelling is an interdisciplinary field in which the humanities meet artificial intelligence [46] where stories are told by combining personal narratives with technology and this is essential to engage the new generation of digital natives [47]. Therefore, Human-Computer Interaction (HCI) plays a key role in the design and development of interactive environments for children, especially for those with disabilities who present specific problems and incorporate unusual forms of interaction [48].

Strategies like storytelling are used to engage children into learning a written language, due to stories make the literacy learning process meaningful as they can relate printed words with stories they enjoy. The text that is part of the stories used, is the first contact children have with literacy learning, that is why the selection of the material must be adequate for their age, not just the story that is being told but also the text that is going to be part of the learning process [18].

A systematic literature review (SLR) was carried out to find out how this strategy has supported the education of deaf children.

Using Storytelling to Support the Education of Deaf Children: A Systematic Literature Review

Introduction

Deaf children learn at different paces compared to their hearing peers [31] and this has aroused interest among researchers and teachers who are constantly looking for new and different ways to improve education processes of these children. As technology advances and teaching strategies changes, new tools can be implemented to support the education of people with disabilities. In this SLR, it was important to know how a teaching strategy like storytelling has helped deaf children in their education and how the inclusion of ICT could improve these teaching and learning processes through interactive storytelling.

Background

In this section, a short overview of storytelling is presented, and how it can be enriched by means of technology and HCI. Moreover, education of deaf children is also introduced in this section.

Education of Deaf Children

The Salamanca statement [49] is a document that is informed by the principle of inclusion and proposes that education systems should be designed in order to consider the wide diversity of children and their unique characteristics, interest, abilities and learning needs [50]. Unfortunately, deaf children are facing difficulties in different areas of knowledge mainly due to the late acquisition of a first language which should be a sign language (SL). Some SL are legally recognized in national laws or constitutions or are mentioned in the laws of different countries [15]. Children must be exposed to an accessible language during the first five years of age [13] and for deaf children it should be the SL used or accepted in their countries but unfortunately for some of them this language is not acquired properly at home due to 90% of them are born to non-deaf parents [12][13] who do not use this language.

It is then clear that in order to acquire any kind of knowledge, it's necessary to have a proper communication channel and that's why a bilingual education should be adopted [17] where SL is seen as primary language in order to start developing skills in a second language (written language) and other areas like math. One of the main reasons deaf

children don't finish higher education is poor literacy skills according to [51]. Literacy problems may affect the development of other skills and learning of other areas such as math and science [16] and this leaves deaf people in a disadvantage compared to their hearing peers. Taking into account that sign language is the primary communication channel of deaf children, different educational strategies must be implemented in order guarantee the fundamental right to education for these children as stated in [49].

Research Method

This study was carried out by following Kitchenham and Charters [23] guidelines to perform a systematic literature review in software engineering. These guidelines define the procedures to be followed in order to identify and summarize existing data about a particular subject. In subsequent sections, the steps followed to perform the review are presented.

Research Questions

The main objective of this study is to answer the following research questions.

RQ1: How is storytelling being used to support education of deaf children?
RQ2: How could interactive storytelling support education of deaf children?

Data Sources and Search Strategies

The search included papers that are written in English and Spanish. The search was made in electronic databases with very specific keywords and filtering criteria. The following electronic databases were used.

English search:

- IEEE Xplore (http://ieeexplore.ieee.org)
- ACM Digital library (http://dl.acm.org)
- SCOPUS (https://www.scopus.com/home.uri)
- Springer (http://link.springer.com)
- ProQuest (http://search.proquest.com)

Spanish search:

- ProQuest (http://search.proquest.com)
- Dialnet (https://dialnet.unirioja.es)
- Redalyc (http://www.redalyc.org)

The keywords to address the search in order to find relevant studies in English and answer the research question were: *Storytelling, deaf, children, learning or education, sign language*. The same words were used in Spanish: *Cuentos, niños, sordos, aprendizaje o educación, lengua de señas o lenguaje de señas*.

From this group of keywords, it is mandatory that the words storytelling (*cuentos*), deaf (*sordos*) and at least one of the other ones are included in all the results, that is how the following search queries came up in each of the databases:

IEEE Xplore. It has an advanced search that allows to find articles where the keywords are found just in the title and abstract. After applying a search query with all the words, more than 80000 articles irrelevant for the search were obtained, that is why it was decided to perform individual searches were the words storytelling and deaf were combined with each one of the others, getting as a result that only three words (storytelling, deaf and children) were necessary to get the only relevant paper this database offers to help answer the research questions.

(“Document Title”:storytelling AND “Document Title”:deaf AND “Document Title”:children OR “Abstract”:storytelling AND “Abstract”:deaf AND “Abstract”:children)

ACM Digital Library. It also has an advanced search where keywords can be found only in the title and abstract. The structure of the string is the same used in IEEE Xplore but with all the keywords included.

acmdlTitle:(+ “storytelling” +deaf +(learning children education “sign language”)) OR recordAbstract:(+ “storytelling” +deaf +(learning children education “sign language”))

SCOPUS. It lets perform a search where the words can be found not just in the title and abstract but also in the keywords of the document. In this database all the words were included.

(TITLE-ABS-KEY (storytelling AND deaf) AND TITLE-ABS-KEY (learn OR child* OR education* OR “sign language”))*

Springer. It does not allow to find the keywords just in the title and abstract, instead, it performs the search finding the words in the whole document. Since Springer could offer relevant results in chapters of books, these ones were also included in the search. storytelling AND deaf AND (learning OR children OR education OR “sign OR language”)

ProQuest (English and Spanish). ProQuest was used to find papers in English and Spanish. The same structure of the string used in the previous databases was used for both searches.

(storytelling deaf) AND (children OR “sign language” OR education OR learning)
(cuentos sordos) AND (niños OR “lenguaje de señas” OR “lengua de señas” OR educación OR aprendizaje)

Dialnet. It does not have an advanced search where operators like AND/OR can be used. This is why the search had to be done using the 2 most important keywords in order to find enough results to be filtered.

Redalyc. It has a poor engine to perform searches, even though it is one of the most relevant databases for literature in Spanish, so it was decided to perform the search using Google where a search can be filtered by site and filetype. All the words could be used here.

cuentos sordos niños OR “lengua de señas” OR “lenguaje de señas” OR educación OR aprendizaje site:redalyc.org filetype:pdf

Management of Studies and Inclusion/Exclusion Criteria

The exclusion criteria (EC) are all the reasons why some studies found are not included into the systematic review.

- EC 1: Document not available to download
- EC 2: Document not in English or Spanish
- EC 3: Document not related to storytelling and deaf people

On the other hand, the inclusion criteria (IC) show the factors to consider a paper as relevant to answer the research questions. In this case, there is only one reason to include a paper in the systematic review.

- IC: Document related to the use of storytelling with deaf people.

Data Extraction

A template was developed to register all the results given by each database. On this template, relevant information was recorded from every paper such as: (a) Name of database, (b) String used, (c) Inclusion or exclusion criteria, (d) ID of paper, (e) Authors, (f) Paper Title, (g) Keywords, (h) DOI, (i) Year of publication, (j) Name of conference or journal where the study was published, (k) Type of publication. The search of this systematic review was performed in September 2016. 623 studies were obtained from all databases. Once the inclusion and exclusion criteria were applied, only 24 studies were selected for the review process. Table 1 shows detailed data about the number papers found on each database and relevant studies selected from them.

Database name	Search results	Duplicated papers	Relevant papers
IEEE Xplore	1	-	1
ACM	3	-	3
SCOPUS	14	5	6
Springer	269	9	1
ProQuest (English)	233	26	9
ProQuest (Spanish)	11	-	0
Dialnet	18	-	1
Redalyc	74	-	3
TOTAL	**623**	**40**	**24**

Table 1. Summary of search results.

Data Analysis and Results

In order to determine how storytelling is being used to support the education of deaf children, the selected papers were classified into different categories:

Skill. Research that clearly shows the support to a specific skill to be developed.

ICT. Research that makes use of any kind of technology to support learning.

Development. Research that proposes the development of a tool, app or platform to support learning.

Strategies/Activities. Research focused on presenting strategies or activities developed to support learning with or without ICT.

Figure 1 shows the number of papers that fitted in each category.

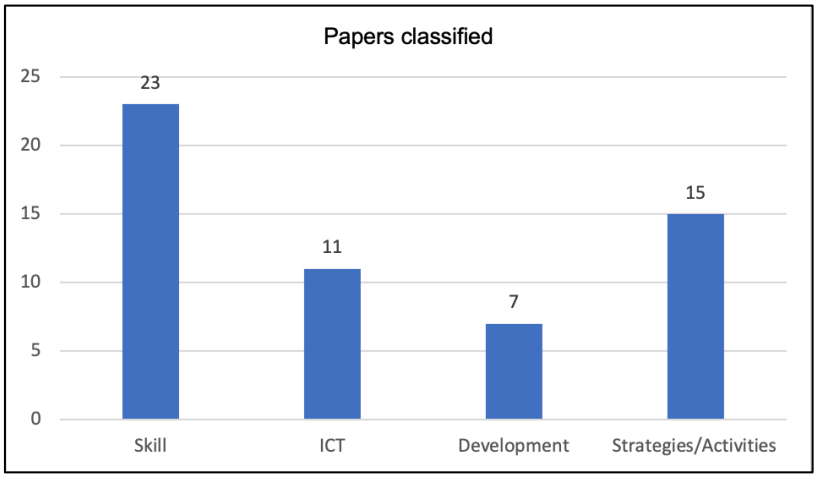


Figure 1. Classification of papers.

96% of the papers aimed to develop or strengthen a particular skill [S1-S20, S22-S24], 46% showed the use of ICT as a resource [S1-S5, S11, S18, S19, S21, S23, S24], 29% had an app, tool or platform as a result to support teaching/learning [S1-S5, S18, S21] and 62,5% presented activities or strategies as part of the educational process [S5, S6, S8-S17, S20, S22, S23]. Some papers matched more than 1 category. The category *skill* was divided into 3 subcategories identified in the papers in order to know what the target areas of knowledge are.

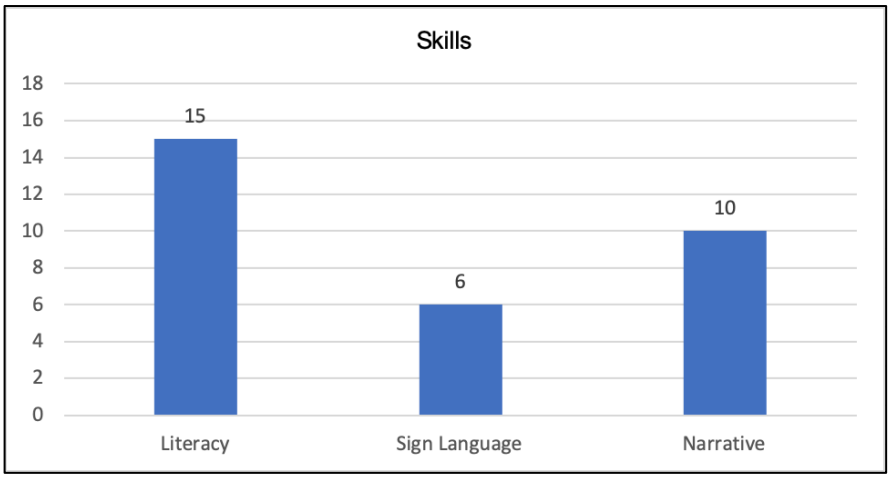


Figure 2. Skills aimed to be developed or strengthened.

Figure 2 shows that 65% of the researches aim to support literacy in deaf children skill [S1-S3, S5-S8, S10, S11, S14, S15, S17, S18, S22, S24], 26% sign language [S4, S5, S8, S11, S14, S19] and 43% narrative [S4, S9, S10, S12-S14, S16, S17, S20, S23].

From the strategies/activities category, It was identified that 33% of the papers involved a collaborative work of children with peers [S5, S6, S8, S10, S15].

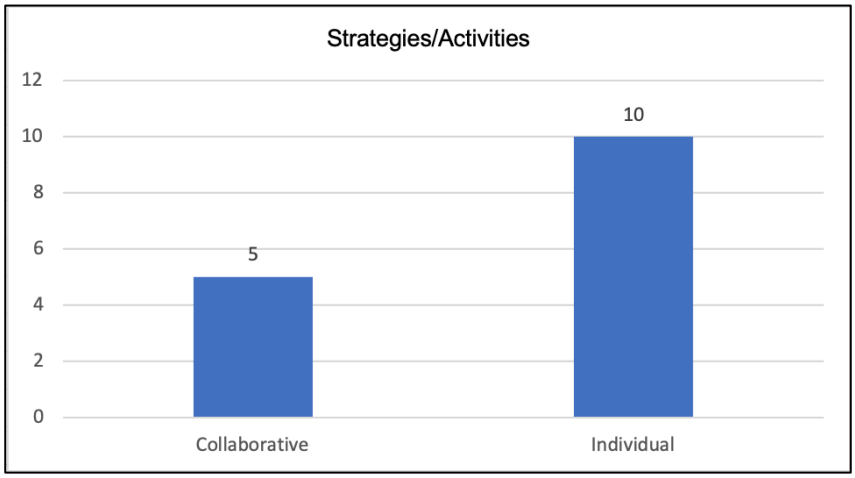


Figure 3. Papers with collaborative or individual strategies/activities.

Finally, it was relevant to know which sign languages were used by users in the different researches in order to identify if these were used as primary communication channel.

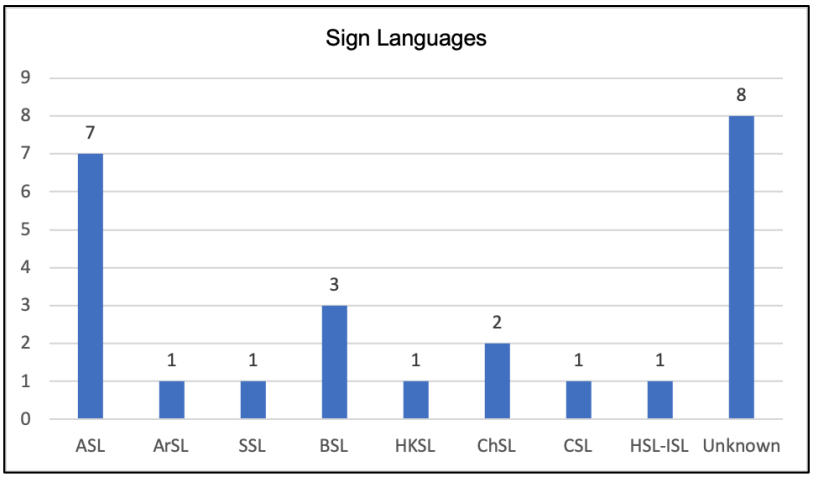


Figure 4. Sign languages used as primary communication channel in researches.

From all the papers, 33% of them did not mention the use of any sign language [S3, S6, S7, S10, S13, S18, S20, S21], while 29% made use of American Sign Language (ASL) [S1, S8, S9, S11, S14, S19, S22], 12,5% made use of Brazilian Sign Language (BSL) [S5, S8, S24] and 8% used Chilean Sign Language (ChSL) [S15, S16]. Arabian Sign Language (ArSL) [S2], Spanish Sign Language (SSL) [S4], Hong Kong Sign Language (HKSL) [S12], Colombian Sign Language (CSL) [S17], Hebrew and Israeli Sign Language (HSL-ISL) [S23] were each mentioned in one different paper. In some researches, more than one sign language was used.

Findings about Research Questions

In this section, it was discussed how the data extracted from reviewed papers address the two research questions.

RQ1. *How is storytelling being used to support education of deaf children?*

Results showed that there is not much information from the last five years about the use of storytelling in order to support the education of deaf children, but the 24 studies reviewed showed the great impact that storytelling has on deaf children, mainly in the development of skills related to communication and language such as literacy, narrative and the use of sign languages. It was also found that different strategies are being implemented in the classroom in order to address these issues related to communication and that almost half of the studies showed the implementation of

technology not just to be used in the classroom, but also at home. Finally, some studies show the use of collaborative strategies with great results.

RQ2. *How could interactive storytelling support education of deaf children?*

The studies reviewed showed that the inclusion of ICT engages children and allow them to take the education process outside the classroom. Through interactive storytelling, children will not be restricted to a fixed story, instead, they will be direct authors of it and this could improve not just skills like sign language, literacy and narrative but also imagination. Unfortunately, there is even less efforts made in order to use interactive storytelling, since just a small part of the reviewed papers show the inclusion of interactive stories, but this is also an opportunity to propose a methodology that could motivate researchers to start working towards the inclusion of deaf children in society through education.

Conclusions of the SLR

A systematic review was conducted where 24 out of 623 papers were selected to answer the research questions. After data extraction and analysis, it is possible to determine that skills related to language and communication are the most common among researches that involve the use of storytelling as an educational resource for deaf children. Storytelling has been used for a long time with this community but according to the last five years there is not much research around the use of this strategy to educate deaf people and there should be made more efforts taking into account that new technologies such as smartphones and tablets open a new set of opportunities to impact positively in the lives of these children through a well-known strategy such as storytelling.

Nowadays, deaf children are also considered digital natives, and this could make interactive storytelling an even more effective strategy for them, but unfortunately, there is not an established methodology to make use of interactive storytelling through the use of ICT.

According to the results of this study, a great opportunity is identified to propose an approach to design interactive storytelling where researchers can integrate technology

and education in order to remove barriers in the way of deaf children by letting them tell their own stories.

2.2.2 Collaborative Learning

Collaborative Learning (CL) is a learning strategy in which two or more people learn or attempt to learn something together by interacting with each other and taking advantage of one another's knowledge or skills [52][53]. CL has been shown to benefit students at social, academic and psychological levels [54]. This approach showed to be very effective as seen in [53][55][56] where students have perceived they have more control over their learning processes and the effects of this teaching strategy have a lasting effect on them. To achieve positive outcomes from CL, it must be applied in carefully crafted environments, not just technical but also social [52].

Integrating collaborative learning strategies in literacy learning may therefore be very favorable for children's learning, much more if they suffer from a disability such as hearing impairment. Jenkins et al. [57] analyze how CL favors special education since it offers a more dynamic environment with less coercion. It should be kept in mind however that it works better for some than for others. As a result, they note that the first mechanism through which teachers see that CL affects learning relates to the children's ability to speak or communicate to one another in special ways. Antil et al. [58] report the same from different teachers: "*They seem to have their own language. They are able to express their thoughts and ideas for each one in a way that I can't"* while another teacher states *I use teacher language and kids explain in a kid language, and as much as I try to do that, I'm still their teacher. I'm not a kid".* This means that students can actually take advantage of their peers' knowledge to construct their own, as the information received from other students can be easier to understand.

Another SLR was carried out to find out how collaborative learning has been used in the education of deaf people.

Collaborative Learning as Educational Strategy for Deaf Children: A Systematic Literature Review

Introduction

According to the World Health Organization, about 15% of the world's population are estimated to live with some form of disability which affects disproportionally vulnerable populations, mainly in lower-income countries [59]. People with deafness must use visual ways to communicate, that's why they have a special language for interaction based on signs which makes use of the body language and lip patterns [60]. These specific ways of communication, make deaf people learn at different paces compared to their hearing peers [31] (especially when sharing the same classroom) and that's why teaching/learning strategies, as well as educational tools, should be inclusive and accessible, where no matter what their abilities are, everyone in the same classroom should be able to use them. In this SLR, it is important to know how Collaborative Learning (CL) has been applied in the education of deaf children and what emerging software-based tools have been used to support CL in order to identify how deaf children could benefit from working and learning in collaborative environments with other deaf/hearing peers.

Background

Collaborative Learning + ICT

CL as an approach where 2 people learn by working together trying to achieve a common goal, could be more effective through the inclusion of ICT, since ICT facilitates student work, gives them independence and grabs their attention which in the end generates motivation according to the results found in [54]. ICT also allows the communication between peers regardless of time or location and this is a clear advantage for virtual education. New technologies like Augmented Reality (AR) have been used to promote CL [61][62][63][64] by engaging students with applications and games that superimpose virtual objects in a real world environment through computers and recent studies have shown how this technology can also be used with deaf children [65][66]. Cadeñanes and González [66] highlight how ICT such as AR avatars increased deaf children's interest in communication and improved in skills such as reading and writing.

Research Method

This study presented in this paper was carried out by following the guidelines to perform a systematic literature review in software engineering proposed by Kitchenham and Charters [23]. These guidelines define the procedures to be followed in order to identify and summarize existing data about a particular subject. In subsequent sections, the steps followed to perform this review are presented.

Research Questions

The main objective of this study was to answer the following research questions:

RQ1: How is Collaborative Learning being applied in the education of deaf children?
RQ2: What kind of technologies have been used in Collaborative Learning environments for deaf children?

Data Sources and Search Strategies

The search involved papers that are written in English and Spanish from the last five years (2012-2017) since it is relevant to know what emerging technologies are being used in CL. The search was made in electronic databases with very specific keywords and filtering criteria. The following electronic databases were used.

English search

- IEEE Xplore (http://ieeexplore.ieee.org)
- ACM Digital library (http://dl.acm.org)
- SCOPUS (https://www.scopus.com/home.uri)
- Springer (http://link.springer.com)
- ProQuest (http://search.proquest.com)
- ERIC (https://eric.ed.gov)

Spanish search

- ProQuest (http://search.proquest.com)
- Dialnet (https://dialnet.unirioja.es)
- Redalyc (http://www.redalyc.org)

A first search in the databases included the words: Collaborative learning, Cooperative learning, deaf, children and education, but the number of papers found was really low

and in some databases there where not one single paper with these terms. The keywords to address the search were reduced in order to widen the span of the search and increase the number of relevant papers found in English/Spanish, for instance, the word “children” was not included from the search because there could be studies where the focus groups are deaf adults with educational strategies that could also be replicated with deaf children. In addition, according to the National Association of the Deaf, over the years, the most commonly accepted terms have come to be “deaf” and “hard of hearing”, so it was decided to use both of them in the search. The keywords in English were: Collaborative learning OR Cooperative learning, deaf, hard of hearing. The same words were used in Spanish without making any translation to “hard of hearing” since its translation does not represent the Deaf community but people with difficulties to hear: Aprendizaje colaborativo OR Aprendizaje cooperativo, sordos. Some of the results are depicted below:

IEEE Xplore. It has an advanced search that allows to find articles where the keywords are found in Metadata and Full Text, it was decided to perform a general search to obtain as many papers as possible. After performing the following search clause, 21 papers were found.

(((“collaborative learning”) OR “cooperative learning”) AND (deaf OR “hard of hearing”))

ACM Digital library. It also has an advanced search where keywords can be found only in the title and abstract but due to the low amount of papers found, the general search was used and 2 papers were found.

+(“collaborative learning” “cooperative learning”) +(deaf “hard of hearing”)

SCOPUS. It allows to perform a search where the words can be found not just in the title and abstract but also in the keywords of the document. In this database, 7 papers were found.

(TITLE-ABS-KEY (“collaborative learning” AND deaf) OR TITLE-ABS-KEY (“cooperative learning” AND deaf) OR TITLE-ABS-KEY (“collaborative learning” AND “hard of hearing”) OR TITLE-ABS-KEY (“cooperative learning” AND “hard of hearing”))

Springer. This database does not allow to perform searches only in the title and abstract, instead, it performs the search finding the words in the whole document. Results from chapters of books were also included since these could be relevant for the research. 82 papers were retrieved from this database.

(“collaborative learning” OR “cooperative learning”) AND (deaf OR “hard of hearing”)

ERIC. This is probably the world's largest source of educational information and is supported by the U.S. Department of Education. With the following search clause, 9 papers were found.

(“collaborative learning” OR “cooperative learning”) AND (deaf OR “hard of hearing”)

ProQuest (English and Spanish). ProQuest was used to find papers in English and Spanish. The same structure of the command used in the previous databases was used for both searches. 80 papers were found in English and just 2 in Spanish.

(“collaborative learning” OR “cooperative learning”) AND (deaf OR “hard of hearing”)
(“aprendizaje colaborativo” “aprendizaje colectivo”) AND sordos

Dialnet. It does not have an advanced search and operators like AND/OR can’t be used. Two searches had to be performed in order to include all the words. Only 5 papers were found in Dialnet.

Aprendizaje colaborativo sordos
Aprendizaje colectivo sordos

Redalyc. Its engine does not allow to perform searches with filter or make use of operators like AND/OR, even though it is one of the most relevant databases for literature in Spanish, so the search was performed using Google where a search can be filtered by site and file type. In this database, 21 papers were found.

“aprendizaje colaborativo” OR "aprendizaje colectivo" sordos site:redalyc.org filetype:pdf

Management of Studies and Inclusion/Exclusion Criteria

The exclusion criteria (EC) are all the reasons why some studies found are not included into the systematic review.

- EC 1: Document not available to download
- EC 2: Document not in English or Spanish
- EC 3: Document not related to collaborative or cooperative learning and deaf people

Studies were selected for the systematic review if they met the following inclusion criteria:

- IC 1: The study was published between 2012 and 2017
- IC 2: The study focused on collaborative or cooperative learning with deaf people

Data Extraction

All the results of each database were registered in a template where all the relevant information of each paper was recorded: (a) Name of database, (b) Search terms, (c) Inclusion or exclusion criteria, (d) ID of paper, (e) Authors, (f) Paper Title, (g) Keywords, (h) DOI, (i) Year of publication, (j) Name of conference proceedings or journal in which the study was published, (k) Type of publication like chapters of books, article for a journal or conference papers. The search of this systematic review was performed in March 2017. 229 studies were obtained from all databases. Once the inclusion and exclusion criteria were applied, only 14 papers were selected for the review process. The remainder papers were excluded since they were not focused on deaf community or collaborative learning, for instance, the words deaf or collaborative/cooperative learning appeared in some papers only in the reference sections. Once these papers were reviewed, it was found that 3 of them [S5, S6, S7] were based on the same study (not the same content); something similar happened with papers [S1, S9] which were also results of a same study, in other words, the 14 different papers did not represent 14 separate studies but just 11 studies that involved Collaborative/Cooperative Learning with Deaf people. Table 2 shows detailed data about the number of papers found on each database and relevant studies selected from them.

Database name	Search results	Duplicated papers	Relevant papers
IEEE Xplore	21	-	3
ACM	2	-	1
SCOPUS	7	3	4
Springer	82	5	2
ERIC	9	3	1
ProQuest (English)	80	11	3
ProQuest (Spanish)	2	-	-
Dialnet	5	-	-
Redalyc	21	-	-
TOTAL	**229**	**22**	**14**

Table 2. Summary of Search Result.

Data Analysis and Results

After reviewing the papers, [S5, S6, S7] were considered as one publication since they were part of the same study, and the same was done with [S1, S9], so in total there were only 11 relevant results for this review.

The different strategies and technologies used in all the studies show the following results:

In [S1, S9] a game was built using a computer and external hardware; allowing students to work collaboratively by making decisions using body movements (jumping) and improved their motivation to learn grammar because it was enjoyable. The game also has a ‘fill in the blanks’ function that obtained good responses from students where most of them agreed that it helped their own learning. The conclusions of the study suggest that both functions of the system support the construction of CL environments for deaf children.

[S2] was the only study where an architecture was developed. It was made to support wireless infrastructures and mobile learning for Deaf and Hard of hearing (DHH) students. The conclusion in this study is that wireless networks and mobile devices

form an attractive and helpful framework for supporting DHH students and foster collaboration in remote environments.

In [S3] the use of video streaming, whiteboards, file and application sharing in combination with sign language to support a bilingual work seems to improve the usability and interactivity between instructors and students according to the conclusions of the researchers.

The results of the study [S4] show that students had an improvement in the understanding of lip movement language after one month of using a system that presents visual animations of a face moving the lips according to the words spoken by the tutor of the class through a microphone. Unfortunately, this study does not present any collaborative strategies used to achieve these results, so it was not possible to identify how children worked in group activities.

In [S5-S7] a model and a tool were developed to support sign language understanding. In this study an AR avatar makes signs on a computer and children learn from it in a logical and sequential way to make signs, read and write, and the results reveal an improvement in all these communication skills. This study showed that by using AR avatars, child interest in learning is increased. This is something that has to be taken into account since this kind of technology is now possible through mobile devices and could be a great opportunity to promote learning of children.

The work done in [S8] is the most inclusive of all because a system was built taking into account different disabilities (visual and auditory), so it is an approach that can be used by deaf and blind people, people with low vision and people with no disabilities. The project was not tested with users since it was still in a construction phase and even though it is presented as interactive and collaborative, the strategies to achieve this are not mentioned.

In [S10] a virtual space for group learning activities was created so every student could interact through Moodle, blogs, wikis, a tool for social networking, hypermedia, video-sign language and lip-reading. The results show that the use of blogs, wikis and hypermedia was not helpful, on the contrary the use of video-sign language and lip reading was an effective strategy. It is important to bear in mind that the target group

in this study was not deaf children but deaf adults, so it cannot be assumed the results would be the same if the strategies are applied with children.

An application for iPads was developed in [S11] which allow students to collaborate by peer-reviewing the artwork of their classmates. According to the authors, after using the app, students thought they acquired knowledge and art skills easier than normal classroom lectures. They also report enjoying collaborative learning using the application. Peer-reviewing could be a great idea to improve communication skills for deaf students through written text. This study was not focused on children, but the strategy could be easily replicated with them.

In [S12] the Google Hangouts platform was chosen for remote tutoring as a one-on-one approach between the tutor and every student. On one hand, results were positive when the student had an active participation during the remote session with the tutor and when educational material were embedded into the session and accessible for both parties (document sharing, online homework programs and whiteboards applications). This allowed students to work directly in course materials without depending entirely on visual communication with the tutor. On the other hand, a passive role was assumed by the students due to the lack of opportunities to collaborate when peripheral material was used in the remote tutoring (Projecting printed lecture notes, office whiteboards). This passive role forced students to depend on the visual communication channel to acquire knowledge. So, synchronous remote tutoring holds great potential when it is used to promote active learning. This was another study that did not involve children, but the strategies are suitable to be worked with them.

Another study that made use of Google platforms was [S13] where a mix of deaf, hard-of-hearing and hearing students used Google Chat and Google Documents to interact and collaborate during a series of lab sessions. Both tools were effective in fostering collaboration and allowed students to complete their work with the assigned requirements. As with previous studies, this one was not focused on children, but the tools and features that these platforms offer could be easily integrated in the education of deaf children.

An approach to facilitate the communication between DHH students and hearing students in an algebra-based statistics course can be found in [S14]. In this study,

students worked in mixed groups by using a whiteboard (“low-tech” strategy) and tablets (“high tech strategy”). The former was easy to implement with no training required and was favored by the hearing and hard of hearing students. It also allowed students of the group to see others work and thus understand how they solved some problems. The latter showed that students liked the novelty of the tablet PC’s and communication provided by these devices. The use of the tablets also helped students understand more clearly the work being done and they felt that the group worked more as a team. The cons of this second approach are that they were difficult to implement, due to access to the proper equipment and software, out-of-class training, and technical support. This study is from 2012 but the activities carried out were performed between 2007 and 2009, which could be the reason of the training required before working with tablets and the technical support, since it was a pretty new technology back then, but nowadays these devices are less expensive and children are more familiar with these devices and their interfaces, so this is something that could support even more the use of mobile devices for learning. In this study, the age of the participants was not mentioned, but due to it was an algebra-based statistics course, it is assumed that students were not children.

As this study focuses on the use of CL in the education of deaf children, we defined different categories in order to know: a) The educational objective of the study, b) what was developed or used (model, tool, platform) or used in order to achieve the educational objective, c) how researchers collected data and how they evaluated the results, d) what kinds of technologies were used during the study and e) what type of activities or strategies were applied to promote collaborative work.

Educational Objectives

2 out of 10 studies aimed to support literacy skills [S1, S5, S6, S7, S9] and 1 of these [S5, S6, S7] also focused on the acquisition of sign language. 6 studies had a different educational purpose: [S4] on developing lip movement learning, [S8] on spatial graphic representation, [S10] on e-commerce, dyscalculia and international accounting standards, [S11] on art and peer-review learning, [S12] on chemistry, [S13] on teaching and [S14] in communication among peers. The remainder studies [S3] and [S2] did not focus on any particular skill or field of knowledge.

What was developed or used?

This category involves the elements developed and/or used in order to achieve the objectives of each study: Tools which are developed as part of the study and used to support the activities carried out, Platforms or Frameworks developed also as part of the study and used to support different services and technologies, Teaching Models developed or proposed as educational support and Existing technologies used (but not developed) to support also the activities carried out.

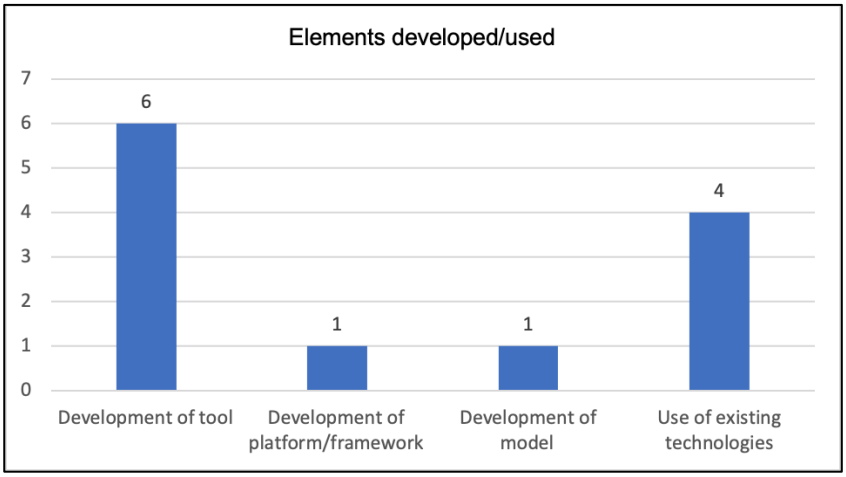


Figure 5. Elements developed or used to achieve the objectives of the study.

Figure 5 shows that 6 studies concerned the development of a tool. In [S1, S9] a Puppet Show System was designed for hearing-impaired children. [S3] shows the development of a system to create a virtual classroom for deaf people. In [S4] a system to learn lip movement language was proposed, while [S5, S6, S7] (papers that report data from the same study), show the development of a desktop Augmented Reality (AR) application and is also the only study where a teaching model was proposed. In [S8] an interface for a Virtual Environment of Education-Learning was developed for deaf and blind people but also for users without disabilities and in [S11] a system was built to allow peer-review for art education using an app developed for iPads and a server. Only 1 study [S2] focused on developing a platform or framework, where an architecture was proposed to support Deaf and Hard of hearing (DHH) students through wireless networks and mobile learning (M-Learning). The remainder 4 studies used the integration of already developed tools like Moodle, Wikis, Blogs, social networks and hypermedia in [S10], while [S12] used Google Hangouts for remote tutoring, [S13]

made use of Google Documents and Google chat for group work and [S14] compared the use of whiteboards and tablets in collaborative work.

Assessment and Data Collection Techniques

This is an important resource for researchers in order to gather information that can be evaluated and thus determine the results of the study or how effective the use of technology is [67]. Just 5 studies mention the assessment or data collection techniques used, and questionnaires or surveys were used in all of them to get data from users through using Likert scale answers [S1, S5-S7, S9, S10, S11, S14]. Two studies mention how the questions of the surveys were created: In [S5-S7] researchers designed the questions of the survey using the most relevant elements of the Principles of learning and Teaching P-12 [68] which is a set of 6 principles that can be used by schools, teams of teachers and individuals to reflect on practice and support professional dialogue to strengthen pedagogical practices. The Danielson's Group Framework for Teaching [69] was also used in [S5-S7] to design the questions; the framework identifies those aspects of a teacher's responsibilities that have been documented through empirical studies and theoretical research as promoting improved student learning. In [S1, S9] the physical/emotional/narrative presence (PENS) scale [70] was used to create the items. Studies [S2, S3, S4, S8, S12, S13] did not show how this kind of information.

Used Technologies

Technology is something that was involved in all the studies, which demonstrates that nowadays CL relies on ICT as an educational resource for deaf people since it has shown to help create more interactive and engaging learning environments [71][72]. The type of technologies used in the studies were divided in: a) The use of sensors and external hardware, b) DVD, TVs and Projectors, c) Desktop Computers d) Mobile Devices.

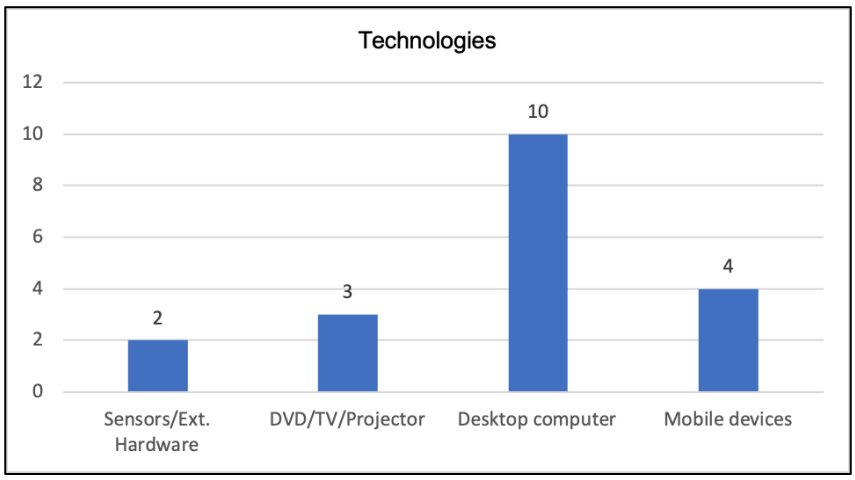


Figure 6. Used Technologies.

As can be seen in Figure 6, 10 out of 11 studies [S1-S13] made use of desktop computers to enrich teaching/learning processes. 2 studies made use of sensors and/or another kind of external hardware besides computers [S1, S2, S9]. 3 studies show the use of DVDs, TVs or Projectors [S1, S5-S7, S9, S14]. Finally, 4 studies made use of tablets or smartphones [S2, S5-S7, S11, S14]. One of these studies [S5-S7] made use of AR, which is a relatively new technology.

Activities or Strategies Applied to Promote CL

In [S1, S9] the system allows children to make decisions in group and answer questions by jumping up and down with their bodies. Filling in the blanks was another way to make collaborative decisions among children. In [S2] the idea is to have parallel classes where students can collaborate through mobile devices remotely. The virtual classroom proposed in [S3] allows people to collaborate through video streaming, application sharing, whiteboards, and file sharing. In [S5, S6, S7] students watch a series of videos in a collaborative learning environment with mixed-reality. In [S10] researchers propose the use of blogs, wikis and social networking to promote collaboration among students. The strategy used in [S11] is peer-reviewing the art work made by students. In this study students upload their work to a server using their mobile phones and the server application assigns the work to another student which will have to review it and annotate their comments using an app developed for iPads. In [S12] they used Google Hangouts as a platform for remote tutoring in chemistry and biochemistry courses. The collaborative work in this study was not an active approach among students but between the tutor and one student at a time. Other Google services were used in [S13],

in this case it was Google Chat and Google Documents. Three lab sessions were carried out and students could collaborate through chat and co-construct a document according to the assignments of every lab session. Finally, in [S14] two different approaches to improve communication in groups where DHH students are mixed with hearing peers. One of the approaches was the use of a whiteboard for 2 groups of 4 students in order to allow all members of each group to see the work-in-progress. The second approach was the use of tablet PCs for working on the problems where students could collaborate, share and contribute through these devices on a wireless network.

Findings about Research Questions

RQ1: How is Collaborative Learning being applied in the education of deaf children?

Unfortunately, collaborative learning (CL) for deaf people is something that has not been documented by the research community in the last five years, but in the reviewed papers, some useful activities and strategies were found that can actually enhance the education of deaf children. Through the reviewed papers, CL can be used in different ways and with different kind of tools (low-tech and high-tech). CL proved to be effective in all the studies and even more when ICT is part of this learning strategy. Finally, to answer this question, CL is being used in peer-reviewing, remote tutoring and video streaming, games (digital and non-digital), through platforms like Google Hangouts, Google Documents and Chat.

RQ2: What kind of technologies have been used in Collaborative Learning environments for deaf children?

It was clear that nowadays the use of technology helps to engage not only deaf children but also deaf adults into learning, since all the studies reviewed show that the use of computers and some other kind of technology like sensors, screens, mobile devices or AR encouraged students to learn and collaborate due to the facilities offered and for the game, it was also enjoyable. In the case of mobile devices, it is intriguing that with the actual use and opportunities that these devices offer, only 4 studies [S2, S5-S7, S11, S14] include this technology. Technology also proved to be useful for remote learning, which is crucial to allow deaf community to enroll in virtual education and with free platforms like Google Hangouts and Google Documents, there are no barriers of time or space to learn and collaborate with peers either from a smartphone, tablet or

desktop computer. Nowadays, technology is not that expensive as it used to be, developers can build systems with open-source software and hardware, which makes them affordable.

Conclusions of SLR

A systematic Literature review was conducted where 14 out of 229 papers were selected as relevant to answer the research questions. These 14 papers were the result of 11 different studies where deaf people were involved in collaborative learning approaches. The fact that only 11 studies were found in 5 years illustrates the lack of research regarding the implementation of Collaborative Learning to support the education of deaf children since only 6 out of the 11 studies were focused on them. After data extraction and analysis, it was found that skills related to communication (literacy, sign language or lip movement) are one of the main objectives for researches that work with the deaf community.

There should be more research aiming to promote the use of CL and ICT in educational environments for deaf children because these could be used as a resource to promote learning inside and outside the classroom as well as improve communication skills with other deaf and hearing children.

The use of ICT is also crucial for allowing people with disabilities to be part of virtual education, but the design of virtual environments should be conceived taking into account the differences of each disability in order to make these spaces inclusive, for instance, the use of sign language or lip-reading is important for deaf community to have access to information.

None of the studies included well-know and effective educational strategies like storytelling [32], especially in those studies where literacy was the educational objective, in fact, they don’t mention any educational strategy for literacy teaching to deaf children like Logogenia [73] or Fitzgerald Key [74], which are the pedagogical base of the major research this study is part of.

Based on the results of this systematic review, an opportunity raises to promote the development of interactive collaborative tools by proposing a framework for the design of such tools to support literacy teaching to deaf children.

Chapter 3

Related Work

3.1 Design of Educational Tools

Reviewing the literature on the design of educational tools, different frameworks, models and methodologies have been proposed to provide a path in the development of such tools.

Annetta [75] proposes a framework for serious educational game design. It is composed of 6 elements that are grounded in theories and research not just in education but also in psychology. The 6 elements of the framework are: (1) Identity, (2) Immersion, (3) Interactivity, (4) Increasing Complexity, (5) Informed Teaching, (6) Instructional. Even though the 6 elements are explained in detail, there is no evidence of tools developed with this approach that can actually support its effectiveness in serious game (SG) design.

A triadic theoretical framework for SG design was proposed by Rooney [76] where he comprises play, pedagogy and fidelity. As a theoretical framework, it outlines underpinning theories that may be the basis for SG design. However, the author highlights that the framework presents difficulties in balancing game design (play/entertainment), simulation design (fidelity) and pedagogy. No tools developed with this framework were found during the literature review, so there is no way to validate it.

A methodology was proposed by Peláez and López in [77] which presents a very large development life-cycle (13 stages) and even so, it lacks relevant pedagogical and technical information, which makes it not appropriate for the development of quality educational software. No prototypes were developed with this methodology.

Abud [8] designed a methodology for educational software engineering. This proposal gives a detailed description of each of the 6 stages that are part of the methodology (conceptual phase, analysis and initial design, iteration plan, computational design, development and deployment). This proposal gives relevant information in the technical aspects and how the pedagogical characteristics can be gathered through artefacts with specific activities to be carried out in each stage. A prototype was developed with good results and acceptance by the development team and teachers.

Costa et al. [78] developed a hybrid methodology based on User-Centred Design (UCD) principles for the development of educational software. It is divided into 4 stages: planning of educational guidelines, storyboard design, implementation and maintenance/operation. This a multidisciplinary methodology that includes experts in sciences didactics, educational technology, project management, graphic design, programming and usability. Just like the previous one, this is a very well-structured methodology where the role of educators is well defined in the life-cycle. Different prototypes have been developed and the methodology was being implemented in small and medium software development companies. It is important to note that authors recognize that the use of this method may not be appropriate for all educational software taking into account the diversity among users, objectives of use or changes in technology.

Even though the aforementioned approaches involve educational aspects in the design of SG or educational software, they do not provide any accessibility features or learning goals as they are general purpose frameworks/methodologies. Evaluation phases are not included either, which makes difficult to know how these tools should be evaluated and tested, especially when children are involved. In the following section, some frameworks/models are presented which address accessibility issues.

3.2 Designing for People with Disabilities

As seen in the previous section, some approaches for the design/development of educational tools do not take into account accessibility as part of the process life-cycle. To address this issue, some proposals include this user experience (UX) facet (accessibility) as part of the core elements in the design process.

A disability-aware software engineering process model was developed by Nganji and Nggada [3] where the process takes into account the needs of people with disabilities from the beginning of the life-cycle. First, the needs of the system are established, then, Personas are created, and then the scope and feasibility of the system are made in order to avoid loss of resources like money or time during the development. The rest of the phases are all about technical aspects (system requirements and analysis, acquire identified technologies, design system architecture, design system components, implement the system, test and deploy, evaluation, improvement, maintenance). Although this process model can be used to develop educational tools, it does not provide any clue about how to approach children in an educational context, which makes the design/development process more complex.

Granollers et al. [5] also developed a process model called Process Model of Usability and Accessibility Engineering (MPIu+a for its acronym in Spanish). This approach adds to the software engineering model a set of well-organized activities: analyze requirements where usability is important from the beginning of the process, support for user interface design and evaluation of usability objectives through iterations. The accessibility components of this model are general-purpose, and it requires more time of research when a particular disability is being addressed. This model can also be used for the development of educational tools but as the previous study it does not provide any information related to involve children in the process with education as the main goal of the tool.

A more narrowed approach was developed by Guimarães et al. [12] to inform the design of learning objects for teaching written Portuguese to deaf children. This framework is specifically created for a particular learning goal (writing) and disability (deafness). It is divided into five stages: Visual contextualization of the text, reading of

the text in Brazilian sign language (LiBras), meaningful linguistic elements, individual reading and re-elaboration. The framework does not include any technical aspects about the development of a tool, it is more a pedagogical approach to be taken into account when designing technology aimed at the development of literacy skills of deaf children.

Newell et al. [79] states that approaches like User-Centered Design, Universal Design or Design for All are not entirely suitable for the development of educational tools, especially aimed at people with special needs. They suggest an approach they call *User Sensitive Inclusive Design* where designers develop real empathy with their user groups (including those with disabilities). Something similar is proposed by Ladner [80] with his *Design for User Empowerment* approach where users develop the project, design the requirements and features, develop the prototypes, test the prototypes, and analyze the results of testing to refine the design. Both studies, show the need of approaches with clear information on how users, with different abilities, may be part of the design of a tool.

An ability-based design concept proposed by Wobbrock et al. [81] shows how designers should focus on the abilities of the users instead of their disabilities in an effort to create systems that leverage the full range of human potential. This is very important when a tool is supposed to help children develop educational skills.

In 2017, Guerrero-García et al. proposed an HCI-Agile methodology to develop interactive systems for children with disabilities [82]. This methodology was based on FlowiXML [83] and spans four phases for the development of a system (initiation, planning, executing and controlling). This is a good starting point for the development of educational tools aimed at children with disabilities, but since this methodology is not focused on one particular disability or educational goal, a lot of research must be done prior to the design of the system, this includes understanding the special needs of children with auditory impairments or the most appropriate teaching/learning strategies, which makes the process takes longer than a designer may expect.

Alsumait and Fasial [84] proposed a roadmap to define an interactive collaborative tool architecture to improve learning outcomes for Arab deaf students. The proposal is based on five pillars:

a) Active learning. This is concerned with the techniques and methods that involve a student in constructive learning rather than being passive and listening to a traditional lecture
b) Student activity space. It is a virtual space with real-time capabilities where deaf members are offered with a self-paced tool to acquire the knowledge, view different resources, get engaged with the content, form groups and assign different roles
c) Technology used. E-learning technology is mostly visual and very interactive, thus fitting the deaf students' learning style perfectly.
d) Communication. Deaf students must be urged to discuss and express their knowledge and acquired experience with their colleagues.
e) Assessment. Designing assessment activities can help deaf students to become lifelong learners and lead to effective interferences.

This architecture includes deaf-related information to take into account when designing CL scenarios, which is very helpful for the purposes of this research.

A methodological approach for the design of serious games aimed at children with cochlear implants was developed by Cano in [85]. This proposal is oriented to a software-engineering process and is called *Methodology for the Conception of Serious Games for Children with Auditory Disability* (MECONESIS by its acronym in Spanish). Four phases are defined in this methodology: (1) Analysis, (2) pre-production, (3) production and (4) post-production. This methodology supports not only the design and development of serious games, but it also provides guidelines about how serious games may be adapted for a particular kind of user and serve as supporting material for the educator or therapist. Something important to highlight about this research is that it aims for the development of specific-purpose tools for children with particular needs, which is also the objective of this research.

Chapter 4

Framework for the Design of Interactive Collaborative Tools to Support Literacy Teaching to Deaf Children

A framework is proposed in this study aiming to address the particular needs and abilities of deaf children. In this chapter, the core of the framework is presented as a modular solution that could be later adapted to other disabilities and educational purposes, that is how the DesignABILITY framework is designed.

4.1 Core of the Framework

The name of this framework (DesignABILITY) turns the word DISABILITY into Design+ABILITY, which means designing for different abilities. The framework proposed in this study was designed bearing in mind that different disabilities require different ways to address the same issues, for instance, literacy skills can be developed by children with cognitive, auditory or visual impairments as long as appropriate educational and learning strategies are implemented during the teaching process. This statement must also be applied to the development of technological tools that aim to support educational processes for people with different abilities.

The proposal is divided into four stages as can be seen in Figure 7:

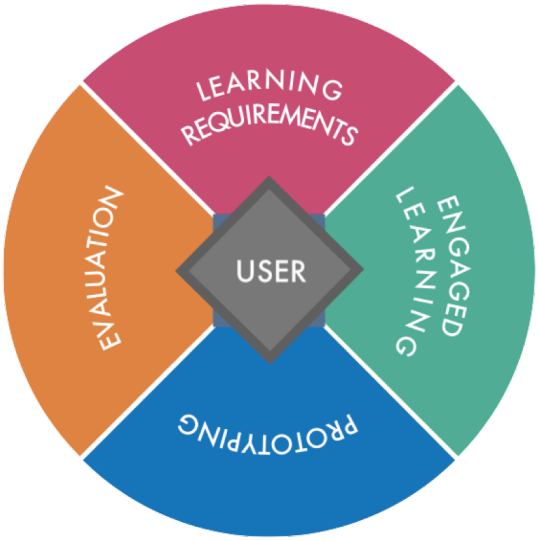


Figure 7. Core of the Framework for the Design of Accessible Interactive Collaborative Tools to Support Teaching.

4.1.1 Learning Requirements

In order to design a specific-purpose educational tool, it is important to know and understand what the learning requirements are. The first stage of the framework is all about finding out the learning goals that should be supported by the technological tool and the strategies used in the teaching process. As mentioned before, these strategies will differ depending on the final users and their diversity. It is very important to have the support of educators and people involved with the target users as these requirements reflect the needs and expectations of teachers that will benefit from the tool be designed to support their teaching process.

4.1.2 Design for Engaged Learning

Once the learning requirements are set, it is time to design how children will be engaged into learning. This stage seeks to find out how learning can be engaging and motivating for children. The work done in this part of the process must be a complement of the

learning strategies defined in the previous stage. The approaches used in this stage may vary depending on the abilities of the final users and the learning goals/strategies of the previous stage. Once again, educators play a key role in this stage since they know better what their students like, their strengths and weaknesses, thus the strategies used here may be adapted to suit children's skills. To test the strategies, children could give the most valuable feedback, so it is important to involve them in this stage prior developing prototypes in order to make the necessary changes to increase motivation and engagement.

4.1.3 Prototyping

The first prototype of interactive tool should be designed in this stage. The prototype must integrate the learning strategies and aspects of the approaches chosen for engaged learning defined in the previous stages in order to be considered as a supportive tool to achieve the learning goals. From low-fidelity to high-fidelity prototypes, it is very important to involve both, educators and children in this stage, once again, to get feedback that can actually give insights on how good and useful the designed system could be and if it actually supports educator's teaching process.

4.1.4 Evaluation

The last stage involves evaluating the prototype (technical aspects) and the user experience using techniques suitable for children with any special need. Elements of the "design for engaged learning" stage should also be evaluated in order to re-design how children may be engaged into learning. This stage may involve evaluating not just the system but also learning outcomes, depending on the complexity of the system and learning goals. Once this stage is over, an iterative process may take place in order to address issues found during the evaluation process of the system.

4.2 DesignABILITY (Deafness + Literacy)

In order to show how the framework can be used, this work was focused on deafness and the development of one particular but extensive skill like literacy. Reading and writing are considered the second language of deaf people who use sign language as their main way of communication [60]. Poor literacy skills affect the development of new knowledge in areas like math and sciences [16]. Based on the results of previous researches, storytelling is a great way to engage deaf children into learning a second language in a written form [22][39]. A collaborative learning approach could enhance the construction of new knowledge by working with peers [53].

4.2.1 Methodology to Adapt the Framework

Each stage of the DesignABILITY framework was complemented with the necessary elements that may guarantee a life-cycle that meets both educational and technical needs during the design of an interactive/collaborative tool to support literacy teaching to deaf children. To achieve this new version of the framework, a multidisciplinary work was done with teachers and experts who have experience working with deaf children as well as engineers and designers with an HCI background.

For the first two stages (learning requirements and design for engaged learning), teachers from Colombia (Popayán), Spain (Madrid) and Scotland (Gourock and Glasgow) were interviewed in order to identify the learning requirements for literacy development of Spanish or English with deaf children. This work was complemented by reviewing the curricula from different institutions in Colombia and Scotland and the official curriculum of Madrid (Spain) and England. For the “design for engaged learning” stage, different case studies were carried out in Colombia with deaf children and their teachers in order to find out how children learn and how this process may be improved with technology.

For the prototyping and evaluation stages, HCI experts are part of this study. The complementary elements of these two stages are based on the work done in our previous studies with deaf children [9][86][24].

The resulting framework complements the four stages of the original core of the DesignABILITY framework.

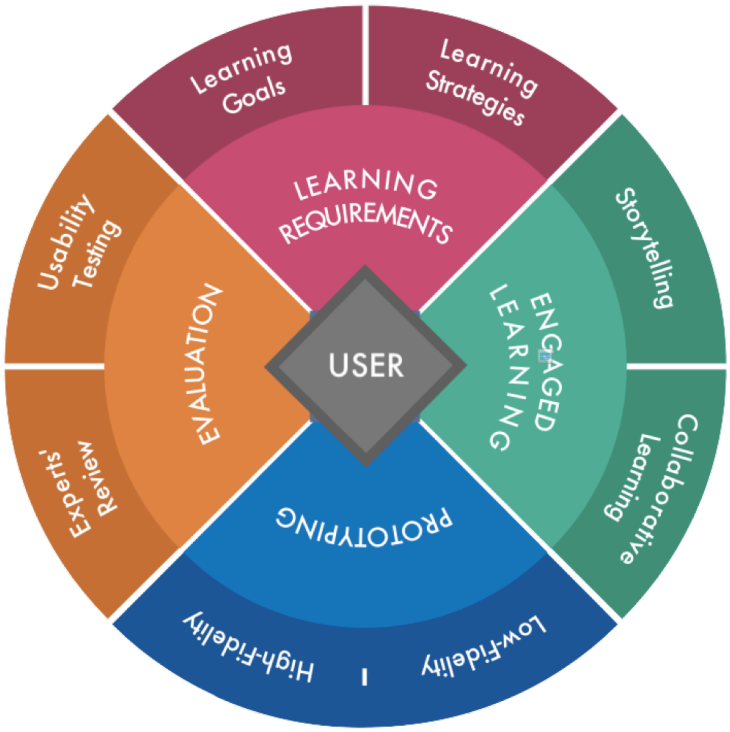


Figure 8. Framework for the Design of Interactive Collaborative Tools to Support Literacy Teaching to Deaf Children.

4.2.2 Learning Goals.

This is the first stage of the framework where the Learning Goals (LG) must be set. During this stage, an interdisciplinary work must be done between the designer of the tool and the educator in charge of the teaching process. The framework provides a set of goals that have been analyzed from curricula in literacy for Spanish and English. Three curricula are from three educational institutions (EI) in Colombia (La Pamba, Simón Bolívar, Teodoro Gutiérrez Calderón), another one is from Madrid in Spain and the national curriculum in England provides the learning goals for English literacy. It is important to note that all this information is aligned with official documents provided by the respective countries to assure quality in education.

The LG for the first year of education of all five curricula were mapped and similarities in all of them were found, especially in the Colombian and Spanish ones as the language is the same. The LG were divided into five categories: Reading, Writing, Grammar, Orthography and Vocabulary. Some LG had to be adapted to suit Deaf children's needs.

1. Reading

- Identify and recognize the alphabet letters and its correspondent sign.
- Know the correspondence between uppercase and lowercase letters.
- Describe and give information (either written or using sign language) about elements of a story previously read.
- Associate information given by images with the content of the text in a story.
- Identify nouns and adjectives.
- Associate written words with their respective signs.

2. Writing

- Produce texts sequencing sentences to form short narratives.
- Write basic subject+verb+object sentences
- Write from memory simple sentences dictated by the teacher.
- Produce texts accompanied with appropriate images.
- Identify errors in their texts by comparing with a model text.
- Use color coded marking to correct errors in text

3. Grammar

- Join words and clauses using and/or.
- Use pronouns correctly as subjects in sentences.
- Write nouns with the appropriate gender (male/female for Spanish) and number (singular/plural).
- Write adjectives with the appropriate gender (male/female for Spanish) and number (singular/plural for Spanish).
- Distinguish and use verb tenses (past, present, future)
- Use of articles.
- Identify sentences in a text by the punctuation and capital letters.

4. Orthography

- Separate sentences with periods.
- Separate words with spaces and full stops.
- Use uppercase and lowercase letters correctly.
- Use punctuation marks correctly (period, question marks)

5. Vocabulary

- Match initial vocabulary with the appropriate signs (depending on the sign language used).
- Know the letters of the alphabet in order.
- Order alphabetically a series of written words.
- Classify names by category (people, animals, objects).
- Find particular names from a given category.
- Learn words with similar and opposite meaning (synonyms and antonyms).

4.2.3 Learning Strategies

Different literacy teaching strategies or methods can be used to achieve these goals. During this research, two particular strategies designed for Deaf children's literacy are being studied: the Fitzgerald Key [74] and Logogenia [73]. The former helps to understand the structure of grammar by assigning a different color to the different kinds of words, for instance, pronouns (subject) can be yellow, nouns (objects) can be orange, while verbs may be represented with green and adjectives with blue color.

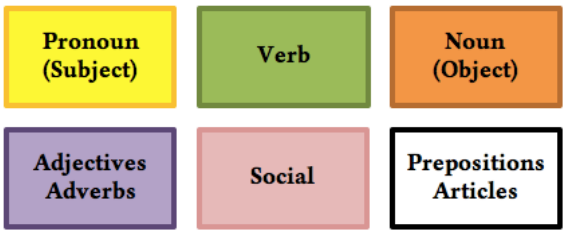


Figure 9. Fitzgerald Key Strategy.

This color code can be different depending on the educational institution (EI), which is why it is very important to know the color code used to create a tool consistent with

current teaching practices for every particular institution. In case this method is not used by the EI, a new color code can be established between the design/development team and the EI.

The second method (Logogenia) was created by the Italian linguist Bruna Radelli, who based this method in Noam Chomsky's generative grammar theory. This states that deaf children can learn any language just by being exposed to it, in this case, a written language. The way Logogenia works is by presenting the child the minimal pair of sentences, i.e. two sentences that are differentiated only by one word (e.g. take the pen / take the eraser).

As mentioned before, both strategies (Fitzgerald Key and Logogenia) have been used in this study to support literacy teaching. The Fitzgerald Key can be used to teach grammar structure either in Spanish or English, but Logogenia has been mostly used to develop reading and writing skills in Spanish and Italian, and to the best of our knowledge, there are no studies about the use of this strategy for English teaching, so the method must be adapted for this language.

The Department of Education at the University of Oxford has developed a program to help improve Deaf children's literacy. This program is currently being used by different schools in the United Kingdom and is also used and recommended by the National Deaf Children's Society (NDCS), which is a British charity dedicated to providing support to the Deaf community. The strategies provided in this program are aimed at English literacy, but they can also be adapted for Spanish literacy. One of these strategies is called "who does what" which is a way to teach grammar structure by letting children know that this kind of sentences are created by a subject (who), a verb (does) and a complement or noun (what).

4.2.4 Storytelling

The second stage of the framework is about design for engaged learning. For this stage, one way to do so is by introducing stories into the process to start making literacy learning meaningful. Storytelling can be defined as the art of depicting a tale with different kinds of resources like words, movement, images or other embellishments

[87]. This strategy has been used in the education of Deaf children to develop or strengthen skills in literacy or sign language [22][39][88][44]. According to the chosen LG to achieve, the teacher should select an appropriate topic to either find a storybook or design a new one. If the story will be designed, an opportunity arises to get a collaborative/interactive storytelling approach. The path to achieve it will be described in the following section, based on the results obtained after carrying out case studies for two years about storytelling for literacy learning in two educational institutions for Deaf children in Colombia. The whole process is divided into three stages (design of the story, paper prototyping and high- fidelity prototype) and it is very important during the sessions of these stages to get some additional information about children involved in them, so, the profile of the children can be analyzed and it will be necessary for the third stage of the framework (Collaborative Learning). This information can be gathered by direct observation and comments, suggestions or reviews given by the children after every session.

Design of the story

A topic or context for the story must be defined by the teacher who knows better what his/her children are interested in and what elements of the story (characters, places, objects, situations) are appropriate according to the age and academic level of the students. This is important since children may not feel engaged with the story if they cannot fully understand the context or elements that play a key role. This was evidenced in our first attempt with a story, where one of the main characters was a creature from outer space. The youngest children had difficulties trying to figure out what it was, while older children had no problem with it when creating the story.

The story must be designed with a first narrative, i.e. a first order of events, and with it, the team can start the design of the images (scenes) that will support the story to be told. It is mentioned that this will be the first narrative because in the next stages children will have the opportunity to create their own narratives and probably their own stories. It is recommended to design short stories of 7 to 8 scenes for children who are starting to develop communication and literacy skills.

Paper Prototyping

Once the story and its first narrative are defined, a paper prototype of it should be created dividing the story into scenes that will be transformed in images on a set of

cards. These cards will be used in the first session with children, where they will have the opportunity to create a story with these cards by arranging them in the order they think is right for them. When they finish the arrangement, they should tell the story using sign language with as much detail as possible.

A short survey should be done with children involved in the session, aiming to get information and suggestions from them about the cards, the story and the drawings. This valuable information given by children will make them part of the design process and will help identify small details that are usually overlooked by the designer and the teacher. For instance, in one of the sessions, the designer drew one of the characters expressing surprise, but children thought he was actually scared. They also confused clothes on a table with dough for making bread. For Deaf children, most of the information is obtained through the visual input and as users of a sign language, they pay close attention to facial expressions of the characters and elements that are part of the scene, which is why it is important to identify these aspects during the paper prototype stage.

It is recommended to do this first session with one or two children (individually) since this activity may not be compelling for larger groups due to the low-fidelity of the prototype, but it could attract children's attention to see one of their peers working on it, that is why it is important to let the rest of the group observe and intervene, if they want, allowing the dialog among children.

High-Fidelity Prototype

In this stage, a high-fidelity prototype of the cards must be created having addressed all suggestions and problems found in the paper prototype. A new session must be carried out, preferably with different children, who do not have an idea about the story behind the cards. If the session will involve children to work with classmates, it is recommended that groups are made with a maximum of two children, since the number of cards for the story is usually low and it allows children to reach an agreement. Larger groups may lead children to discuss and never come to terms.

4.2.5 Collaborative Learning

For this part of the “design for engaged learning” stage, a collaborative learning approach could promote peer work and thus motivate children to learn from peers and construct knowledge as a team. Collaborative learning is an interactive approach to construct knowledge among students who share a common goal [89]. The success of one student is dependent on the success of the group; this is known, as positive interdependence which is what makes an activity to be actually collaborative [19]. This learning strategy may be used in different educational contexts, and for Deaf children has proved to be an effective way to allow them to work in teams while improving motivation and confidence when learning with peers [90]. The previously gathered information on the children's profiles will be needed to decide on the collaborative strategies to be used. In a previous study [90], a model was proposed for the design of collaborative strategies in serious games for children with hearing impairments.

The CollabABILITY Cards/Templates

When the theoretical part of this approach was first published, an expert review was carried out through a survey to evaluate the DesignABILITY framework [91] where one of the stages is this CL design proposal. 26 researchers answered the questions of the survey, where 92.3% of them have experience on HCI, 46.2% on design and 73.1% on software development. No deaf education educators were part of this first evaluation since it was meant to be made by the people who may use the whole DesignABILITY framework (not just the CL stage of the framework) in the design of educational tools.

The answers to the main question about CL design show the following result:

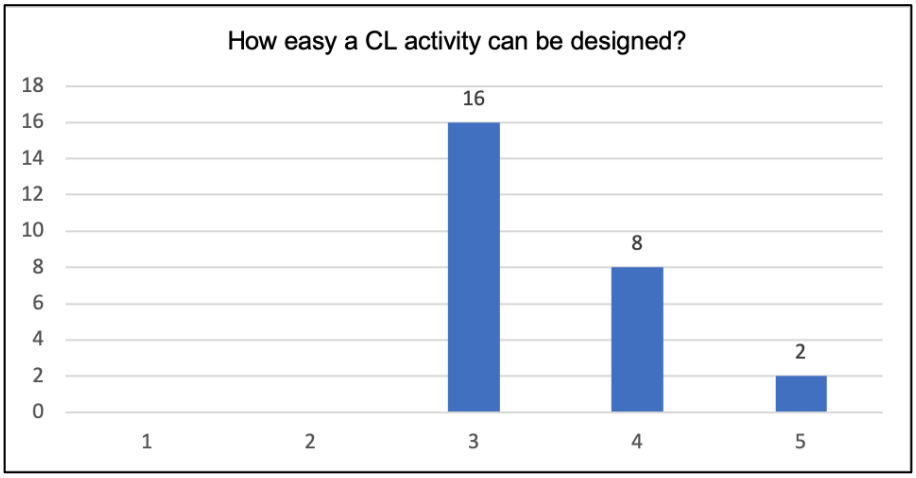


Figure 10. How easy a CL activity can be designed by following this approach.

From a 5-Likert scale rating (where 1 is very difficult and 5 is very easy), 16 researchers (61.5%) rated this CL design approach with a score of 3, while 8 researchers (30.8%) rated it with 4 and the remaining (7.7%) with 5. The average evaluation is 3.54 which means that it is not easy to design CL activities with this proposal. Reviewers had the chance to comment on their evaluation and most of them agreed that due to the extent of the information provided for the design of CL activities, it was not easy to understand and implement all the steps suggested. Based on these results, it was decided to design the CollabABILITY cards/templates to make this process easier to follow.

The cards were designed dividing them into 4 categories, each category defined by a color and a letter, and each card numbered from 1 to N, where N is the last card of each category. The cards and the templates follow a fixed path during the design of a collaborative learning activity. These cards are tagged with letters from A to D and numbers in ascending order (1, 2, 3…N). Templates were designed in order to record the information of the whole design process of a CL activity and must be used along with the cards.

The path to be followed when using the cards goes as follows:

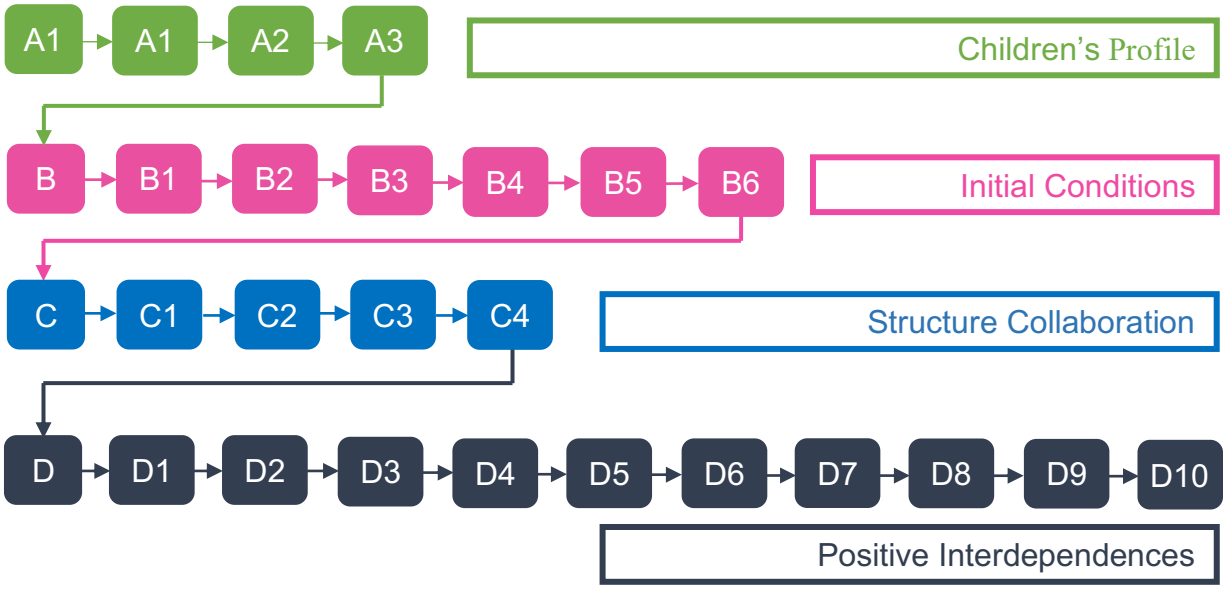


Figure 11. Path used in the final version of the cards.

Children's Profile

The creation of the children's profile must be done with the information gathered in the previous stages. The information that may be part of the profile is: Personal data that are not sensitive (age, gender and academic year), skills/abilities, learning methods and strategies, degree of hearing impairment, school level, use of sign language or cochlear implants, interests and language level.

The front side of the card shows the title of the subcategory and the back side shows additional information about what has to be done during the design. The full version of the cards can be seen in Appendix B.

The first category is *Children's profile* tagged with letter A and it consists of 4 cards (A, A1, A2, A3). Figure 12 shows how the first category looks like (the first two cards). The front side of the card is on the left, and the back side on the right.

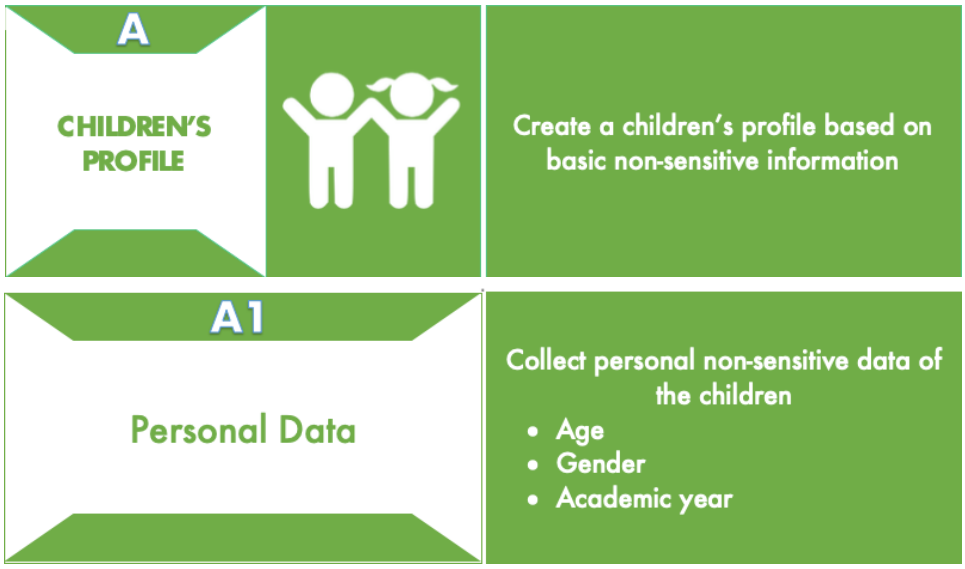


Figure 12. Children's profile category.

- A -> This is the front card of this category. On the back side it explains that a children's profile must be created based on non-sensitive information
- A1 -> Personal Data. The back side shows the information to be collected (Age, gender, academic year)
- A2 -> Deafness-related information. Information such as degree of hearing loss, use of sign language, cochlear implants, etc.
- A3 -> Learning related information. Data about children's skills, abilities, learning methods and strategies, school level, interests, language level.

Initial Conditions

Once the profile is defined, initial conditions (IC) must be set. This refers to carefully designing the situations where and how the collaboration will take place. The second category is tagged with letter B and it consists of 7 cards (B, B1 to B6). Figure 13 shows how this category looks like (Cards B, B1).

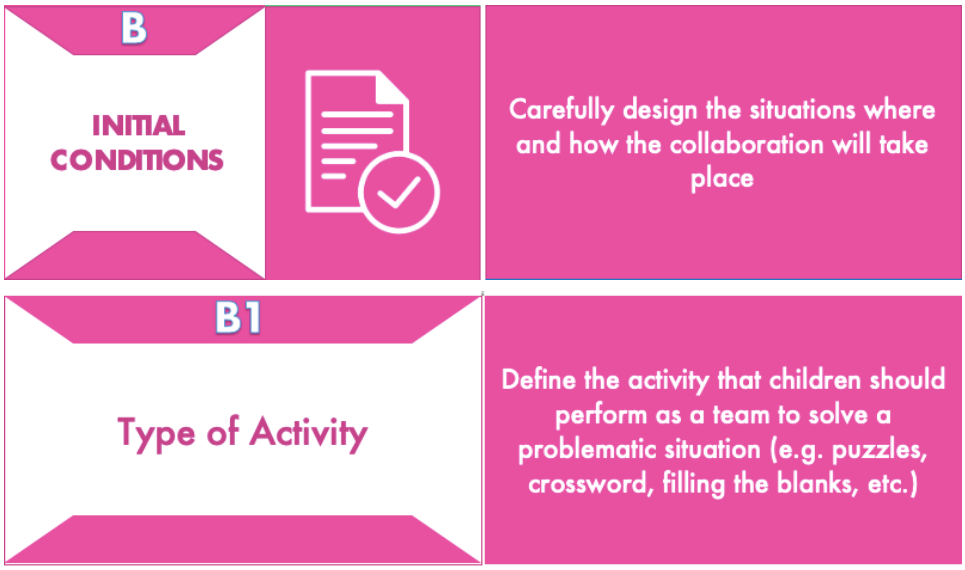


Figure 13. Initial conditions category.

- B -> This is the front card of this category. On the back side it explains that this category is about designing the situations where and how the collaboration will take place.
- B1 -> Type of activity. Define the activity that children should perform as a team to solve a problematic situation (e.g. puzzles, crossword, filling the blanks, etc.).
- B2 -> Nature of collaborators. Specify the type of interaction (peer-to-peer, teacher-student, student-computer).
- B3 -> Group heterogeneity. Define variables such as size of the group, gender or academic level.
- B4 -> Setting of collaboration. Define the place where the collaborative activity should take place (e.g. classroom, home, virtual environment).
- B5 -> Conditions of collaboration. Define how the collaboration will be mediated (physically, computer-mediated) and if it will be synchronous or asynchronous.
- B6 -> Period of collaboration. Time that will be invested by children during the activity.

Structure Collaboration

Finally, the collaboration must be structured by defining four elements (activities, roles, communication, shared resources). This category is tagged with letter C and consists of 5 cards (C, C1 to C4). Figure 14 shows how this category looks like.

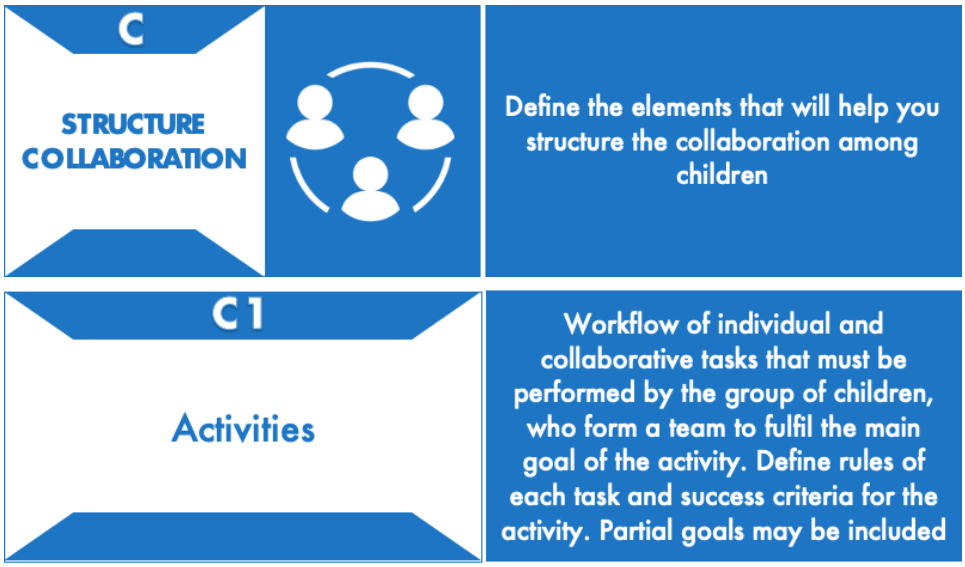


Figure 14. Structure collaboration category.

- C -> Front card of the category. On the back side it explains that this category is about defining the elements that will help to structure the collaboration among children.
- C1 -> Activities. Workflow of individual and collaborative tasks that must be performed by the group of children, who form a team to fulfil the main goal of the activity. Define rules of each task and success criteria for the activity. Partial goals may be included.
- C2 -> Roles. Each member of the group should be assigned a role during the activity with its own responsibilities. The role of the teacher must be also defined. Every member should have the opportunity to play a different role to balance work load of the activity.
- C3 -> Communication. During the activity, members of the group should have the means to communicate and coordinate properly among themselves (either by text or sign language).
- C4 -> Shared resources. Each member of the group should be provided with the necessary resources to achieve the partial and main goals. Resources will be shared and represent the knowledge each member has to contribute for the activity and the success of the group.

Finally, the last category was created for positive interdependences (PI). As mentioned before, PI are necessary to assure collaboration between members of a team. Johnson

and Johnson [92][93][94] states that team members perceive that they need each other in order to complete the group's task ("sink or swim together"). To successfully design a CL activity, 9 positive interdependences are defined and one or more can be integrated to achieve collaborative work. As part of this research, these PI were mapped [95] with learning mechanics and game mechanics from the LM-GM (Learning Mechanics - Game Mechanics) framework [96] as well as with collaborative game mechanics (CGM) from [97].

GM and CGM are the rules and procedures that provide interaction with a game and for CGM, these rules promote collaboration among players. LM are pedagogical practices that support learning [96].

From the LM-GM framework [96], its mechanics were mapped with the CGM given in [97]. Then, from collaborative learning literature, the positive interdependences found in collaborative situations [19] were mapped with the previous LM-GM-CGM mapping. This new mapping will allow to determine how collaborative learning could be implemented during the design of a system along with GM and LM to increase motivation towards achieving group goals.

(PI)	(GM)	(CGM)	(LM)
-Role -Identity	-Role play -Behavioral momentum		-Guidance -Instructional
-Goal	-Collaboration -Cooperation	-Common objectives	-Participation -Demonstration -Action/Task
	-Token -Selecting/Collecting -Goods/Information		-Observation -Generalization/ Discrimination
	-Cascading information -Cut scenes/Story		-Questions & answers
-Environmental	-Questions & answers -Communal discovery	-Questions -Common discovery -Exploration of real places	-Identify -Explore -Discover
-Resource	-Resource management -Strategy planning -Pareto optimal	-Information exchange -Group planning -Sharing ideas	-Plan -Objectify

(PI)	(GM)	(CGM)	(LM)
	-Appointment	-Generation of ideas	
	-Tiles/Grids -Capture/Eliminate -Infinite gameplay		-Experimentation -Hypothesis
-Task	-Action points -Game turns -Levels		-Repetition
	-Pavlovian interactions -Time pressure -Feedback	-Feedback	-Reflect/Discuss -Analyze
-Outside enemy	-Protégé effect -Meta-game		-Imitation -Shadowing
-Fantasy	-Movement -Design/Editing -Simulate/Response -Realism	-Suggestion of images -Participatory design	-Modelling -Simulation
	-Assessment -Tutorial	-Self-assessment	-Assessment -Tutorial
	-Competition		-Competition
	-Ownership -Urgent optimism		-Ownership -Motivation -Accountability
-Celebration/ Reward	-Status -Reward/Penalties -Virality	-Common stimuli	-Responsibility -Incentive
-Role -Identity	-Role play -Behavioral momentum		-Guidance -Instructional

Table 3. Mapping of CSCL approach with GM and LM.

This last category is a great way to communicate ideas between educators, designers and developers. For instance, if an educator suggests that the activity should provide a learning mechanic such as *incentive*, this can be translated to a game designer language as a game mechanic such as *reward/penalty* which is present in all games. This can also be mapped as a positive interdependence (*celebration/reward*), which guarantees that the activity promotes some kind of collaboration.

This category is called *Positive interdependences* tagged with letter D and consists of the following cards (D, D1 to D10). Figure 15 shows how this category looks like.

Figure 15. Positive Interdependences category.

- D -> Front card of the category. On the back side it explains that one or more PI should be included to guarantee collaboration.

- D1 -> PI-GM-LM. Specify the types of PI that will assure true collaboration among students and encourage them to think as “we” instead of “me”. GM (if necessary) and LM should also be specified in order to promote engagement and motivation in the learning activities

- D2 -> PI – Role. Combined roles and responsibilities are required for the group to fulfill a common task.

  GM – Role Playing**:** The player acts out the role of a fictional character.

  LM – Guidance: Provide guidance for learning.

- D3 -> PI – Identity. Makes unity and cohesion, increasing friendship and affinity through a shared identity expressed upon a common logo, motto, name, flag or song. No GM or LM were found for this PI.

- D4 -> PI – Goal. It is the belief that each team member can reach his or her goals only when the goals of the group are met.

GM – Progression: The success is granularly displayed and measured through the process of completing itemized tasks.
Example: a progress bar.

GM – Goal: Sort of victory condition. Can be broad enough to encompass any method of winning, but here refers to game-specific goals.
Example: Checkmate of a king in chess.

GM – Cooperative play: Encourages players to work together to beat the game. There is little or no competition between players. Either the players win the game, or all players lose it.

LM – Collaborative: More than one learner participates in a common learning activity to pursue a common goal.

LM – Self - regulate: Focus attention on one's own progress and cannel this towards achieving a goal.

LM – Assist: Help, promote or support an equal or companion.

- D5 -> PI – Environmental. A physical environment that unifies the members of a group in which they work. No GM were found for this PI.

  LM – Situate: Position learning in the context in which it is to be applied

  LM – Discover: Gain understanding and solve problems by exploring/interacting with and manipulating the environment

- D6 -> PI – Resource. Each individual has only a part of the information, resources or materials needed for his/her task. Therefore, the resources should be combined in order to accomplish the shared goal.

  GM – Communal discovery: An entire community is rallied to work together to solve a problem/challenge. Immensely viral, a lot of fun.

GM – Cascading information: Information should be released in the minimum possible snippets to gain the appropriate level of understanding at each point during a game narrative.

GM – Resource management: The games' rules determine how players can increase, spend, or exchange their resources (tokens, money, etc.). The skillful management of resources under such rules allows players to influence the outcome of the game.

LM – Connect: Build knowledge by connecting information.

- D7 -> PI – Task. The organizing of the group works in a sequential pattern. When the actions of one group member have been accomplished, the next team member can proceed with his/her responsibilities.

  GM – Turn: Segment of the game set aside for certain actions to happen before moving on to the next turn, where the sequence of events can largely repeat.

  LM – Master: Proceed step by step, completing learning of one aspect before tackling a more difficult/complex one.

- D8 -> PI – Outside enemy. Putting groups in competition with each other. Group members feel interdependent as they do their best to win the competition. No LM were found for this PI.

  GM – Micro leader - boards: The rankings of all individuals in a micro-set. Often great for distributed game dynamics where you want many micro-competitions or desire to induce loyalty.
  Example: Be the top scorers at Joe's bar this week and get a free appetizer.

- D9 -> PI – Fantasy. Giving an imaginary task to the students that requires members to assume they are in a life-threatening situation and their collaboration is needed to survive. No LM were found for this PI.

  GM – Narrative: Draws the players into a story within the game.

Example: Zombie Run, uses narrative to make the players believe that zombies are after them

- D10 -> PI – Celebration/reward. A mutual reward is given for successful group work and members' efforts to achieve it.

  GM – Achievement: Segment A virtual or physical representation of having accomplished something. Often view as rewards.
  Example: A badge, a level, a reward, points.

  GM – Fixed ratio reward schedule: Provides rewards after a fixed number of actions. This creates cyclical nadirs of engagement.
  Example: Kill 20 ships, get a level up, get a badge, visit five locations.

  GM – Chain schedule: Linking a reward to a series of contingencies.
  Example: Kill 10 orcs to get into the dragon's cave, every 30 min. the dragon appears.

  LM – Amplify: Provide learner with high output in return for little input.

  LM – Reward: Recognize achievement tangibly.

This new version of the cards is available in both physical (printed) and digital versions. The digital version is an Android app that can be downloaded from the Play Store.

4.2.6 Prototyping

This stage is dedicated to start the design of the tool based on all the information gathered in previous stages and features defined for the activities. Elements of the User Interface (UI) and User Experience (UX) should be embodied in a first prototype, bearing in mind that the tool must be usable and accessible for children, who do not use the auditory channel and instead rely mainly on visual input. This first prototype can be either low-fidelity or high-fidelity and UI/UX design elements should be considered in this first version of the tool.

UI Design

During the research that has been carried out in the last years, a Graphical User Interface Design Guide (GUI-DG) was created for applications aimed at Deaf children. The purpose of the GUI-DG is to help designers and developers make the right choices when creating content that will be used by Deaf children. The guide is the result of carrying out case studies in institutions for the Deaf in Colombia. In these case studies, the profile of the children was analyzed and the developed prototypes and other existing applications for deaf children were evaluated with the help of teachers, experts and students. The final guide can be found in [98] (guiaappssordos.firebaseapp.com) and is divided into the following categories and sub-categories:

Style

- Color
    - Ideally, place the text on a solid background, avoiding images with too much elements as a background.
    - Use the same color in objects, texts or elements that have the same or similar meanings.
    - Prevent texts from losing legibility with the contrast of colors between text and background.
    - Interfaces should be designed with bright and appealing colors to capture children's attention.
    - There should be a contrast of the content in the foreground with the background color.

- Icons
    - It should not be assumed that icons that are valid for hearing children, are valid for deaf children.
    - Design colorful icons as deaf children find black and white icons harder to recognize.
    - Use specific icons within the application, avoiding the use of abstract icons as much as possible, since these are difficult for deaf children to understand.

- Images
    - Avoid images that may have more than one interpretation. Its meaning must be clear and concrete.
    - Depending on the focus and theme of the application, images that resemble real life or animated images should be used. Real images allow the association of concepts, while animated images stimulate the child's imagination.
    - Use an image to represent a concept instead of text.
    - The illustrations must be designed according to the genre of the application or game.
    - Use images or illustrations along with text to show the meaning of a word. The use of just text is not recommended.
    - The images associated as visual clues must be clear and known by deaf children, it is important to take into account the sign language of the population to which the application is directed.
    - Prevent two images representing different concepts from being visually similar.

- Animations and Video
    - Animations should be used to represent content, instructions or new concepts, without it becoming a distraction.
    - Videos with sign language (first language) should be incorporated so that the deaf child can perceive the message effectively.
    - Sign language videos must be represented by interpreters who are certified by an entity recognized and endorsed by each country.
    - Use visual clues or animations to highlight relevant textual information.
    - The use of multimedia tools to improve accessibility is recommended, such as the use of televisions that allow the application to be projected, device sensors that provide information and feedback to the child through the use of vibration and lights. These tools can be combined to help improve the understanding of the actions that the deaf child must perform within the application.
    - Sign language videos must additionally provide titles and hypertexts.

- Typography
    - The font used must be easy to visualize and read within the application. Geometric 415 and the typefaces of the Script family, which are used in school texts, are recommended.
    - Use the symbols or annotations in the usual way.
    - It is recommended to use different sources that allow obtaining the different representations of a letter, as long as the application is aimed at deaf children who have already acquired literacy.
    - Use writing rules (accent, uppercase, lowercase, among others) according to the language in which you will work within the application.

- Writing
    - The questions within the application must be clear, understandable and legible, avoiding ambiguous questions. It should also be avoided that the questions include the answers.
    - It is recommended that written content is also available in sign language.
    - The syntax within the application must be simple and clear.
    - For the teaching of abstract concepts, for example *values*, the use of short stories depicted in illustrations is recommended.
    - The stories must be told in sign language and complemented with simple texts and images.
    - Avoid complex idioms, words and long phrases, on the contrary, use simple texts adapting them to the child's level and with a straightforward use of the language. The text is an important factor to familiarize a child with the written language.
    - Do not use animated text.
    - The texts must contain clear and unambiguous words.
    - To achieve the understanding of homophonic words, various drawings or graphics should be used.

- Labels
    - Label all items that are not text based.

Components

- Buttons
    - They must be strictly functional, when touched they must execute an action and give immediate feedback (visual and/or haptic).
    - For buttons, it is possible to use icons with sign language representation instead of the normal image. In addition, each icon used must be presented with a text label.

- Dialogs
    - Use dialogues moderately because they interrupt and can lead the child to lose focus from the task s/he is doing.

- Menus
    - An image that clearly represents each menu option must be used and must be accompanied by text and sign language.
    - Avoid using hierarchical menus with various levels of depth.
    - The menu options must always be visible on the screen, thus avoiding the use of drop-down menus.

- Lists
    - Use a grid list if the main distinctive content consists of images
    - Classification by categories is recommended so that the information is organized and classified.

- Progress and activity
    - Provide visual representations such as maps, icons, avatars, etc., to give information about the current state of the game.
    - Elements used as stimulus for children, for example, stars won or trophies obtained, must be constantly displayed on the interface.
    - Allow to save and recover the status of activities.
    - Allow users to view, check and compare their progress within the application.

Patterns

- Navigation patterns
    - Allow users to use shortcuts. There must be an option to skip the intro or help when starting an application.
    - Use a simple and easy-to-understand progress map in sign language when the application is comprehensive and comprises several levels. In addition, both text and images should be used to describe each section of the map.
    - Provide an option to exit the application, if it is an image, its meaning must be understandable.
    - The navigation design should avoid depth, since this produces confusion for deaf children. It is recommended that the different activities can be accessed directly from the main menu or from a submenu.
    - Navigation must have a simple/usable design for children and must be presented with minimum delays.
    - Interpretation and navigability through the user interface should require the least possible working memory capacity.

- Search
    - Textual search components should be simple and easily understood by deaf people. The use of visual clues is recommended and must be accompanied with sign language.
    - To perform the search and display the results, use the entire screen of the application.

- Errors
    - Children should be helped to avoid mistakes, for which it is recommended that potentially erroneous actions be confirmed before performing them. If there are errors, clear and understandable messages must be provided in sign language.

- Confirmation
    - When executing an irreversible action in the application, a confirmation message must always be displayed in text and sign language.

- Instructions and help
    - Provide an easy-to-access help and search section. Focus the help around the tasks that the deaf child must execute.
    - Use help text before, during or after the user interacts with each field within the application.
    - Tasks or actions must be accompanied by a help icon / button.
    - The use of symbols is recommended as a guide for deaf children through the application (example: arrows). Similarly, the use of sign language videos is recommended to give instructions to children.
    - The instructions within the application should be easy to understand and remember.
    - Provide instructions that can always be accessed and that are available in sign language.

- Feedback
    - Provide information immediately when the child takes an action on the application.
    - The feedback of the actions of the players must be quick and understandable. Feedback should inform the child if his/her actions were correct and motivate him to continue interacting with the interface, and if the actions were incorrect they should direct him to the correct behavior or at least give a clue.
    - To make the feedback understandable, deaf children can use feedback based on sign language, check marks and smiley faces.
    - A screen should be included at the end of an activity or a level within the application that indicates whether you want to go to the next activity, repeat the activity or return to the main menu, all with the support of sign language.

- Notification
    - Provide notifications of the achievements made by their peers in text and sign language (In a CL activity).
    - Avoid using sounds for important information (Warning, errors, etc.), since deaf children may ignore these warnings and make mistakes.

- Selection
    - Highlight the default options when deaf children are required to make selections in the application.
    - Highlight the selected elements with a remarkable contrast with the background color.

- Settings
    - Allow the child to make customizable adjustments to the application.

Learning

- Introduction to the application
    - Explain the use of the application in a bilingual way accompanied by images and videos to guide the child.

- Future discovery
    - Make the rules and instructions of the activities clear and easily accessible at any stage of the activity.

Content

- Content
    - The activities must be organized by levels according to their complexity.
    - Activities should not have time limits unless they are for the assessment of learning.
    - The activities should be short so that the child does not lose concentration and interest in the application.
    - Use basic geometric shapes. Avoid complex shapes.
    - In memory activities do not exceed the number of elements, ideally between 6 and 10.
    - Include activities where animals are presented and their corresponding interpretation in sign language.
    - Design the activities in such a way that users can carry them out independently.
    - For designing games, it must have different levels of difficulty, since children do not have the same level of learning. New challenges must be provided at an appropriate pace.

- Design well-structured and well-organized content.
- Make the application enjoyable and eye-catching, using stories, role-playing games and activities to capture attention and maintain motivation in children.
- Ensure that the objects in the application work similarly to the real world.
- The use of a model for coloring activities is recommended, which will serve as a reference for children to paint the object properly.
- For the activities of completing sentences, it is recommended to use pictograms that serve as support to perform this action.
- Include activities that require children to mentally invest actions such as combining, ordering, separating and recombining elements. Sign language belonging to the region for which the application will be available must be taken into account.
- The content of the text in the application should be simple since, the literacy skills of deaf children are low compared to hearing people.
- Recognize the fact that young children have difficulty translating between the formal system of mathematics symbols and the quantities, operations and concepts they represent. That is, do not make assumptions about children's understanding of the number and symbols of operation.
- To teach a new concept it is important to use the text, the image and the sign as a whole.
- It is recommended to use more than one image to represent a color.

- Interaction
  - Include interactive exploration and manipulation of different types of representation within applications.
  - Limit the actions of the deaf child on the application with rules. These rules have to be explicit and unambiguous.
  - Allow the deaf child to control the reproduction of video or multimedia elements.
  - Activities must present only one task at a time per screen.

- Stimuli and rewards
  - Reward deaf children with stimuli through videos, text or animations once they have successfully completed the activity.

  - For stimulation per achievements, it is recommended to use symbols such as medals, trophies, stars, among others, since it is more stimulating for deaf children to see a quantity of accumulated elements than simply to see a number as a score.
  - For congratulations messages, the use of happy faces or thumbs up is recommended, since these elements are frequently used in the interaction with deaf children. If necessary, it should be accompanied with videos in sign language.

- Elements on screen
  - Avoid distracting stimuli for the peripheral visual field of the child. It is recommended the use of objects and movement stimuli on the edge of the screen that do not distract the child from the main task.
  - There must be complete interfaces and with good layout organization.
  - The application must have a panel for each category, with an associated background color to differentiate it from the others.
  - Items that have the same meaning or perform the same action on each screen should be organized in the same position to help deaf children remember them.
  - The application screen must adapt to the device's full screen, thus avoiding scrolling.
  - Use boxes to highlight important information within the application.
  - It is recommended that the welcome screen of the application is not overloaded with many elements, since the child could expect to be able to perform an action on these elements and can be confused.

Other aspects

- Other aspects
  - Application controls must be easy to learn, intuitive and must follow the standard conventions of similar applications.
  - Applications for deaf children could use vibration feedback or movement of objects to (re) direct the deaf child's attention to specific objectives, for example, the correct or incorrect action of an activity.
  - Use objects within the application that are clear about their functionality and that provide clues about their purpose.

- The pace of presentation of information should be slow for a clear understanding of texts and information in general.

Even though the GUI-DG was designed for mobile devices, all guidelines can be applied to other type of devices with bigger screens.

UX Design

Six attributes influence UX and they will help teachers and deaf children to find value in the tool under development:

- **Useful.** The tool should fulfil a need, and this is exactly what will be achieved by developing a system to support literacy teaching, so this factor is by default present in the tool that is being designed.

- **Usable.** Since the tool will be used by children and will support teacher's work, it is important to design a product that can be easy to use in order to achieve the learning goal.

- **Accessible.** The tool should be usable by deaf children and also by hearing children. This ensures that it is actually accessible for people with different kinds of abilities.

- **Findable.** All the content or elements of the tool must be easy to find and well organized.

- **Credible.** Taking into account that the tool is being designed with teachers and children as part of the process, the credibility of the tool is partially guaranteed. It depends on the final product to earn full credibility.

- **Desirable.** If the tool guarantees the previous five attributes, and it is also engaging and motivating for children, then it will be desirable.

There are several variables that must be taken into account to achieve all attributes, in fact, they change depending on the kind of tool being developed, the target users or even the context where it will be used. For that reason, it is not possible to list a set of

guidelines to guarantee a UX design that meets all attributes, as Don Norman states: “Focus on Results, Not on Perfect UX” [99]. The GUI-DG contains guidelines that can help in the fulfilment of requirements to get a better user experience for deaf children as it is not only focused on UI, but also in some aspects that affect the UX.

4.2.7 Evaluation

The final stage of the framework is about evaluating the designed tool. Taking into account that the tool is being designed to support teaching, it should be first reviewed by experts in the pedagogical and the engineering/design aspects through heuristic evaluation, including teachers and UI/UX/HCI experts, and finally through usability tests by children. Collaboration must also be evaluated as the tool is supposed to promote CL.

Experts’ Reviews

A group of people, from teachers to engineers and designers, can be part of an expert review in search of usability or pedagogical problems. This framework recommends a set of 10 heuristics proposed by Nielsen [100] and principles by Tognazzini [101] and some others from our research to help reviewers find specific problems with tools designed for deaf users. According to their expertise in the domain, they will identify problems following more heuristics and principles than those given in this document.

Heuristics

- Visibility of system status
- Match between system and real world
- User control and freedom
- Consistency and standards
- Error prevention
- Recognition rather than recall
- Flexibility and efficiency of use
- Aesthetic and minimalist design
- Help users recognize, diagnose, and recover from errors
- Help and documentation

Principles

- **Anticipation.** Bring to the user all the information and tools needed for each step of the process.

- **Appropriate help.** Ensure that help is provided in both, text and sign language videos.

- **Simplicity.** Learning activities should be designed with simple interfaces and simple information. Use common/simple words and increase complexity according to children's academic level.

- **Contextualization.** Stories and learning activities should be designed according to the context of the children (cultural, social, academic).

- **Explorable interfaces.** Make actions reversible, always allow a way out.

- **Human interface objects.** Human-interface objects have a standard way of being manipulated.

- **Protect users work.** Ensure that users never lose their work.

The designer/developer team of the tool may add more heuristics and principles depending on what they think should be reviewed. The GUI-DG proposed for the previous stage, addresses some of the heuristics and principles given, so making it part of the design process will increase the probabilities of complying with them.

Usability Testing

Taking into account that deaf children have specific knowledge and needs, it is important to carry out usability tests to identify issues in the UI and the UX that experts may have not thought of. For this reason, usability testing must be done after addressing all expert's observations and suggestions.

Before carrying out tests with final users, be sure to create a Usability Test Plan (UTP) that includes:

1. Name of the tool

2. Introduction

3. Purpose and goals of the test: It is important to know beforehand what exactly you expect to get from the test. For instance, to find UI problems, to know how easy to use the tool is or if the activities and their content are suitable for children's age. Define research questions to identify such goals.

4. Methodology: How the usability test will be carried out by defining the following:
    - Objectives (what children should achieve).
    - Format and setting of the study (where, when and how the test will be done, how many sessions, how long they will take).
    - Equipment required: Indicate the equipment needed for the test (hardware/software).
    - Tasks (that match the goals of the test) to be performed by the children.

5. Pre-test and post-test questionnaires: If subjective measurements will be collected directly from users.

6. Participants: Number of users, profile of the users.

7. Results: The kinds of outputs expected from the test, like qualitative metrics (questionnaires and observation), quantitative metrics (time on task, success rate, error rate), perception of the users, recommendations.

8. Team members: The ones that will take part during the tests and their roles (moderator, note taker, observer).

With the UTP you can now conduct a pilot study. This is recommended to identify possible issues that can occur during the test and fix them for the real study with more users. For this pilot, one or two children are enough (preferably deaf children but not mandatory) as this pilot is more about testing the UTP and the execution rather than the tool.

Finally, recruit the participants that match the profile defined in the UTP and carry out the usability test. During the execution of the test, the following methods are recommended to be used with deaf children according to the results from our previous research [9][102][10]:

Direct observation. This method does not require the child to express their opinions or feelings directly, instead, their actions are analyzed. It is important not to make the child feel observed, as this could make
him feel uncomfortable or shy and it can influence the outcome of the test. It is better to have people the children feel comfortable with during the activities (e.g. the teachers) or video record the session (consent forms from parents are needed to have permission to do so).

Questionnaires/surveys. These should be applied to both, children and teachers before and after the usability test. Teachers can give their impressions about the tool and how it supports their teaching process, while children can express their emotions and points of view about the experience, the story, the tools, the interaction, etc.

Smileyometer. A Likert-scale represented by faces showing different emotions (from sad to happy) can help get information without the need of requiring the child to use sign language or any other communication method. From our experience, it is better to use a binary scale (only sad and happy) since children, especially the youngest ones, tend to be confused by intermediate expressions.

Collaborative Learning Evaluation

The evaluation of CL is essential to guarantee that the tool actually promotes learning among peers. In previous section it was shown how positive interdependences can be mapped with game/learning mechanics, so, based on the work done by Tondello et al. [103] and our experience in previous studies with deaf users, the following heuristics are defined for CL evaluation:

- **Purpose and meaning.** Children identify a meaningful goal that will be achieved through the system and can benefit the team.

- **Completeness and mastery.** Children satisfy their intrinsic need of competence by completing series of tasks or collecting virtual achievements.

- **Autonomy and creativity.** The team find meaningful choices and opportunities for self-expression.

- **Relatedness.** Children satisfy their intrinsic need of relatedness through social interaction with team members and teacher.

- **Immersion.** Children are immersed into the activities through the story behind them.

- **Ownership and rewards.** The team is motivated through extrinsic rewards or possession of real or virtual goods.

- **Feedback.** Children receive feedback from peers, teachers or the system.

- **Identity and role-playing.** Each member of the team sticks to their role.

- **Resource sharing and management.** Team members share different resources (information, knowledge, tools, etc.) with peers to achieve goals.

Some of the metrics proposed by Collazos in [104] are included to evaluate collaboration. These metrics are indicators of system, user, and group performance that can be collected, individually or collectively, while executing group activities. Metrics such as time, length of turn, and other countable events are directly measurable and can often be collected automatically by the system.

- **Number of Errors.** Total number of mistakes made by the group member within a collaborative activity.

- **Solution to the problem.** The group is able to solve a problematic situation.

- **Use strategy.** Outline a strategy for the problem solution in an explicit way.

- **Maintain strategy.** Use the defined strategy during the whole activity

- **Communicate strategy.** Negotiate, reaching consensus and disseminate information about strategy.

- **Strategy messages.** Messages that propose guidelines to reach the group goal.

- **Work messages.** Messages received by the person who coordinates the activity.

- **Coordination messages.** Messages sent by the person who coordinates the activity.

- **Success criteria review messages.** Messages that review the boundaries, guidelines and roles of the group activity.

- **Total messages.** Total number of messages received and sent by the group during the activity.

Chapter 5

Evaluation of the Framework

To evaluate the framework, an expert's review was carried out through a survey and a prototype was developed by following each stage of the framework.

5.1 Expert's Review

To evaluate the framework, a survey was conducted to evaluate each stage of the framework and get some feedback on how it could be improved. 26 researchers from different countries (Colombia, Belgium, Spain, Argentina, México and Scotland) reviewed the framework and answered the questions of the survey. 92.3% of them have experience on HCI, 46.2% on design and 73.1% on software development. No deaf education researchers were part of this first evaluation since it was meant to be made by the people who may use the whole framework in the design of educational tools. A later survey with 4 school teachers (educators) of deaf children was carried out to evaluate just the first 2 stages of the framework (Learning Requirements and Design for Engaged Learning). The low number of educators that participated in the survey is on one hand only three educational institutions were part of this research, one of them is located in Popayán-Colombia with 1 teacher of deaf children, and two institutions in Cali-Colombia, one of them with 4 teachers and the other one with 6. On the other hand, some of these teachers claimed to have no time to take the survey. The following section shows the results of every question that was asked per stage:

5.1.1 Results

Learning Requirements (Learning Goals and Learning Strategies)

For the evaluation of the first stage, questions about the learning goals and strategies were asked aiming to find out how researchers felt about these pedagogical aspects and how they can help in the design of an educational tool.

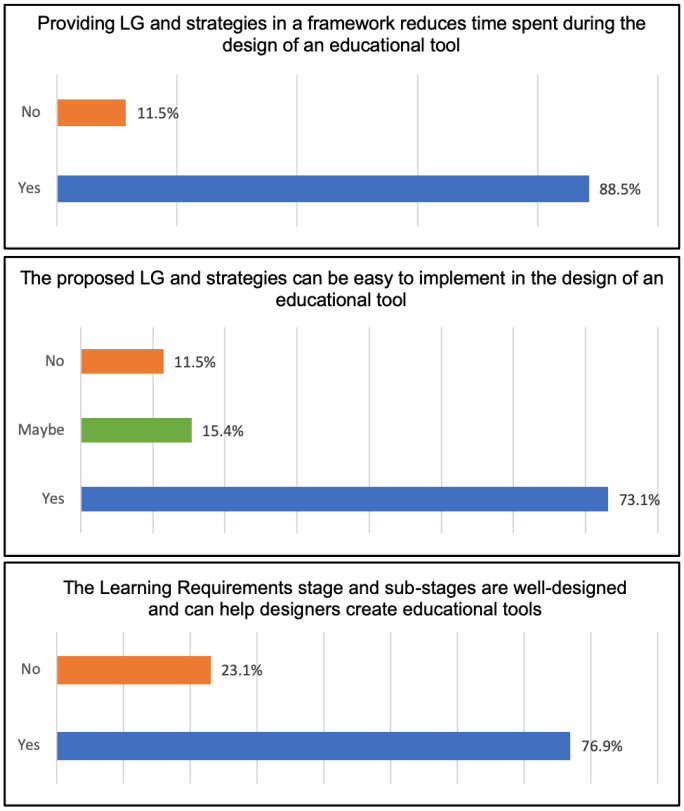


Figure 16. Evaluation of the Learning Requirements stage.

From a 5 Likert-scale rating (where 1 is very bad and 5 is very good), 53.8% rated this stage (Learning Requirements) with 4, 23.1% with 5 and 23.1% with 3. Average rating for this stage is 4.0. This was the evaluation of researchers with HCI/design/development background.

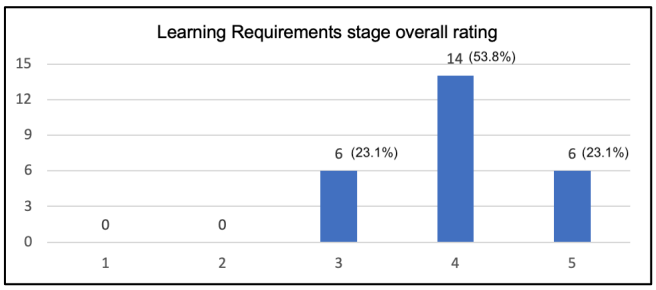


Figure 17. Overall evaluation of the Learning Requirements stage.

Educators evaluated this stage of the framework focusing only on the pedagogical aspects. The first question asked was:

What do you think about the proposed learning goals in this research to develop deaf children's literacy skills?

The 4 educators think that learning goals were correctly chosen and divided into the right categories. One of them thought that Learning Goals (LG) should be differentiated by school grade, for instance, some of the LG are suitable for children in 1st grade, while others are appropriate for children in 2nd grade.

Three of the educators think that strategies proposed in the framework (Fitzgerald Key, Logogenia and Who-Does-What) are appropriate for the development of deaf children's literacy skills, the other one answered *maybe* because she does not know one of the strategies (Logogenia) and she is not sure how effective it could be.

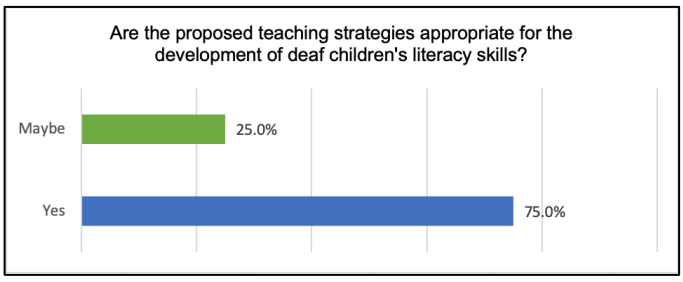


Figure 18. Evaluation of teaching strategies made by educators.

Once again, from a 5 Likert-scale rating (where 1 is very bad and 5 is very good), three educators (75%) rated this stage (Learning Requirements) with 5 and one educator rated it with 4. The average rating (by educators) for this stage is 4.5.

Design for Engaged Learning (Storytelling and Collaborative Learning)

When researchers were asked about how easy a storytelling activity could be designed by following the framework, the results show that most of them do not think it is very easy to implement.

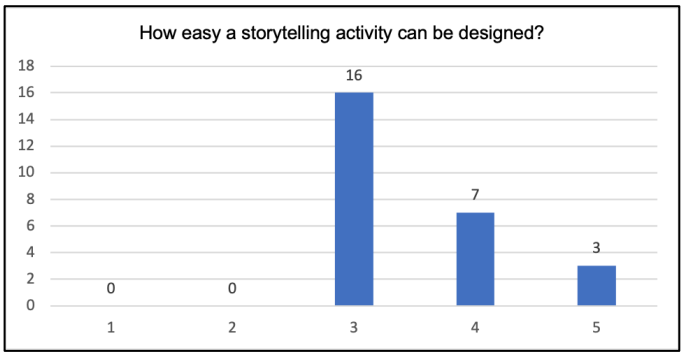


Figure 19. Evaluation of storytelling sub-stage.

From the 5-Likert scale rating, 61.5% of the reviewers rated the ease of this sub-stage with 3 while 27% rated it with 4 and only 11.5% think it is very easy. When asked about their response, most of the reviewers said that it is difficult to determine how easy it could be designed until they actually do it in a real case study, so their rate was not based on the information given by the framework but on the lack of experience doing this kind of storytelling design.

Educators were also asked about this storytelling sub-stage with the same question, and their responses show something different because all of them (100%) rated the ease of this sub-stage with 5. Since educators use storytelling activities as part of their teaching process, this proposal to design stories was actually very appealing and easy to follow for them.

The same previous question was asked for the design of CL activities. The answers were very similar.

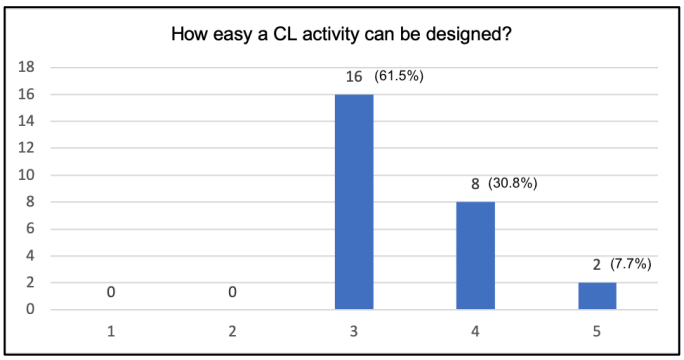


Figure 20. Evaluation of CL strategy made by researchers.

Reasons given by researchers to this question show that there was too much theoretical information about how to design a CL activity and it was difficult for them to be sure about how easy it could be, especially with deaf children. It is important to highlight that the survey was done before the CollabABILITY cards were designed, in fact, this was the reason why the idea of the cards came up, so the design of these kind of activities could be easier to follow, especially by researchers with HCI/design/development background.

When educators were asked the same question, the cards were already designed. They thought this was actually a great idea and all of them rated it with 4. Note that the cards were not used, they were just analyzed based on the information they provide.

From a 5 Likert-scale rating (where 1 is very bad and 5 is very good), 42.3% rated this stage (Design for engaged learning) with 4, 23.1% with 5 and 34.6% with 3. Average rating for this stage is 3.9.

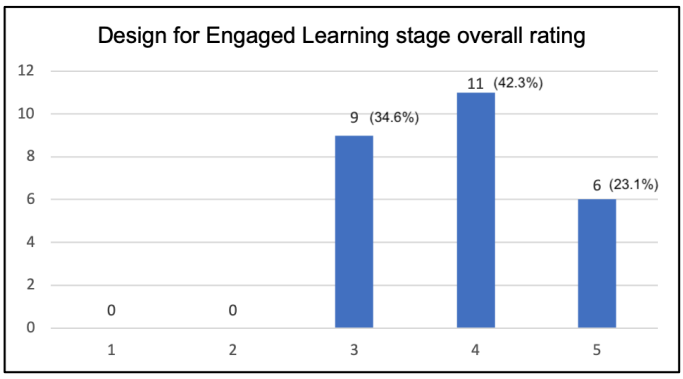


Figure 21. Evaluation of Design for Engaged Learning stage made by researchers.

Prototyping (UI/UX Design)

For the prototyping stage, the UI design proposal was evaluated. This includes the Graphical User Interface Design Guide (GUI-DG) and researchers had the opportunity to review every guideline and give their opinion.

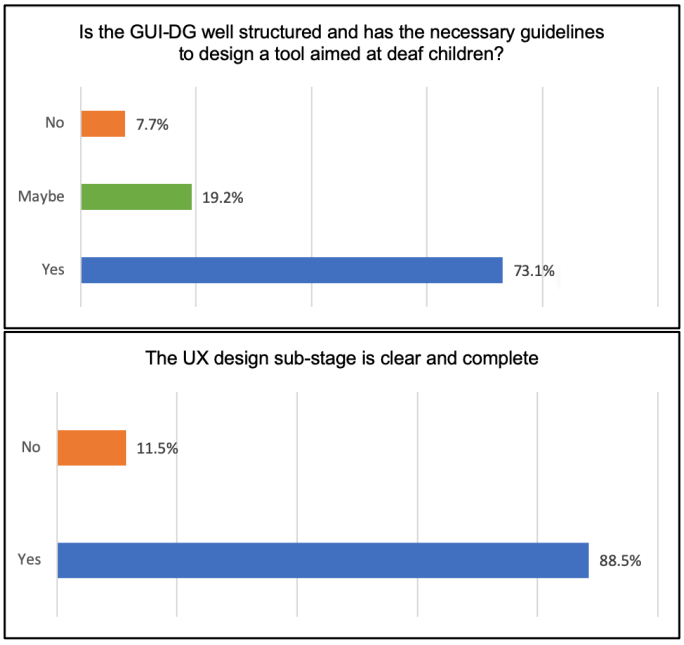


Figure 22. Evaluation of Prototyping stage.

On one hand, 19 researchers (73.1%) think the GUI-DG is well structured and its guidelines are appropriate for designing tools aimed at deaf children. 5 researchers (19.2%) are not entirely sure. Some suggestions were made by researchers who answered *maybe* or *no*. On the other hand, 23 researchers (88.5%) approved the UX design sub-stage and the remaining 3 gave some comments and suggestions on how it could be improved.

From a 5 Likert-scale rating (where 1 is very bad and 5 is very good), 46.2% rated this stage (Prototyping) with 4, 26.9% with 5 and 26.9% with 3. Average rating of this stage is 4.0.

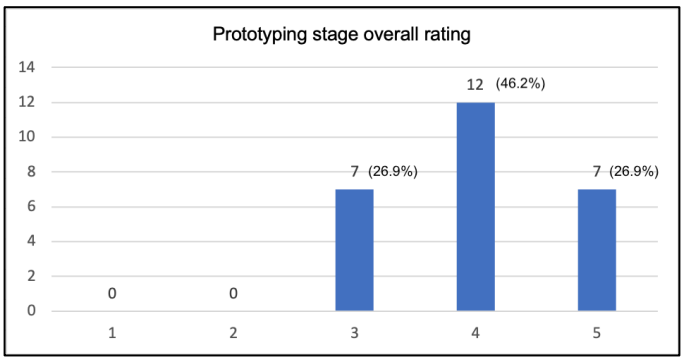


Figure 23. Overall rating of the Prototyping stage.

Evaluation (Experts' Review and Usability Testing)

The elements evaluated for the last stage of the framework include the heuristics and principles proposed in this study.

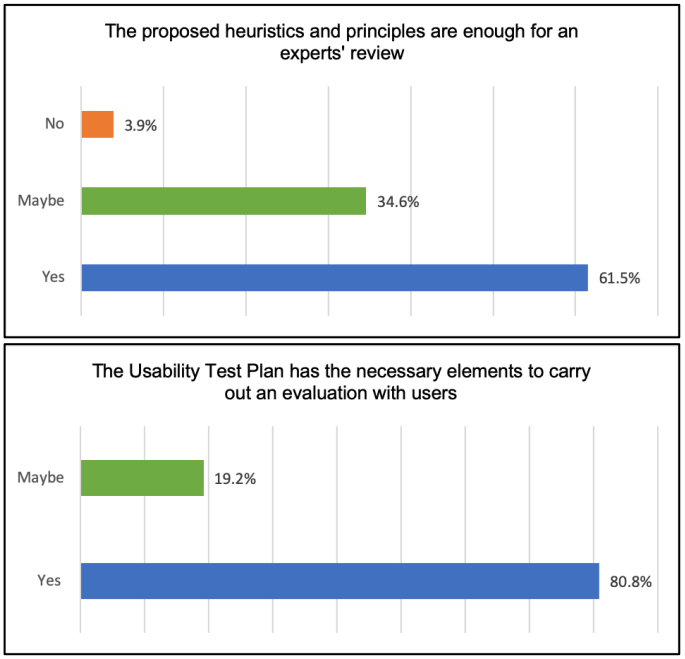


Figure 24. Evaluation of the heuristics, principles and usability test plan proposed in the evaluation stage.

The evaluation methods to be used with deaf children and the collaborative learning evaluation were also reviewed by the experts.

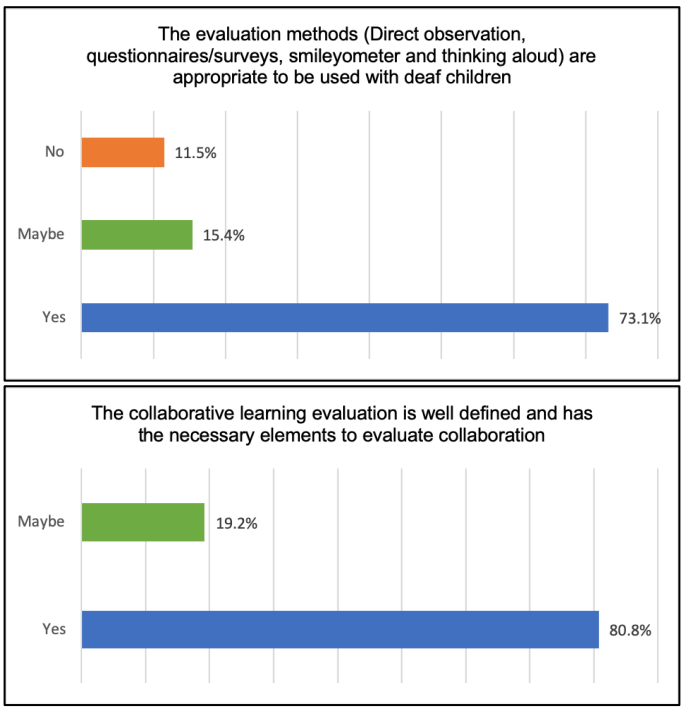


Figure 25. Evaluation methods and Collaborative Learning evaluation proposed in the final stage.

From a 5 Likert-scale rating (where 1 is very bad and 5 is very good), 73.1% rated this stage (Evaluation) with 4, 15.4% with 5 and 11.5% with 3. The average rating of this stage is 4.04.

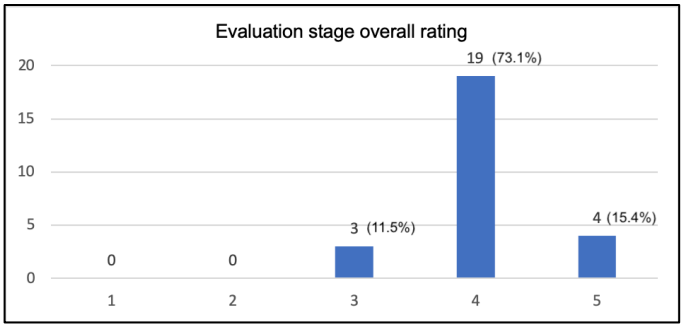


Figure 26. Overall rating of the Evaluation stage.

Overall Framework

73.1% think the framework can be adapted for other disabilities and learning goals. 26.9% answered *maybe*.

From a 5 Likert-scale rating (where 1 is bad and 5 is very good), 73.1% rated the overall framework with 4, 15.4% with 5 and 11.5% with 3. The average is 4.04.

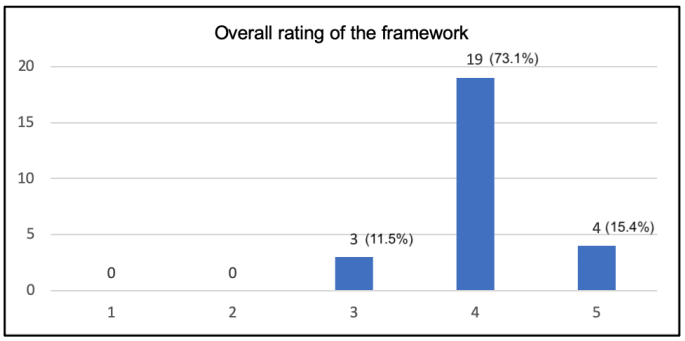


Figure 27. Overall rating of the Framework.

5.1.2 Discussion

Based on the evaluation of the framework, the results show that it has been well accepted by researchers and educators who took the survey. Every stage and the overall framework were evaluated from 1 to 5 with an average rate of 4 which is a good result for this proposal. Another evaluation of the CollabABILITY cards was carried out during the design of a prototype and those results would increase the overall rating of the framework (This will be shown in following section).

The researchers and educators who took the survey had the opportunity to express their opinions and give suggestions when an answer was not positive, this additional information helped in the improvement of some stages of the framework. Some of the researchers' concerns were mainly about the first 2 stages (pedagogical aspects), for instance, the framework proposes a set of learning goals, but some researchers think it may not work for schools that work by competences, which is not a problem since the framework can be modified and substitute the learning goals for the required competences. This is something that adds value to the framework as the adaptation made in this study is not a fixed solution, instead, it is a solution tailored to the needs of the educators and institutions who participated of the process. If the framework is going to be adapted for math, the learning goals/competences will change as well as the strategies used.

Some other concerns on the pedagogical aspects refer to the storytelling and collaborative learning activities, specially the latter. They think the CL approach needs more simplified information to ease the process, especially for designers and developers who are not involved in education. Both sub-stages need a multidisciplinary team in order to succeed in their implementation. Actually, teachers must be part of the whole process as the tool will be designed to support their teaching. Based on the results of this evaluation, the CollabABILITY cards were designed to make the process of designing a CL activity easier and more comprehensible, also it is a great way to facilitate the communication between educators and designers/developers.

For the last stage (evaluation), more information is needed about how to use the proposed evaluation methods and add more heuristics and principles aimed at the evaluation of tools for deaf people. Some of these are proposed based on the findings of the case studies carried out, and more will be added as this research continues. The thinking aloud evaluation method was removed from the framework thanks to the suggestions made by the experts, the main reason is that children would have to use their hands to “think aloud” and this would interrupt the usability test and thus affect the user experience.

Final thoughts of researchers indicate that the framework can be adapted for other disabilities and learning goals and the DesignABILITY framework is a good starting point to design specific-purpose tools instead of general-purpose ones with traditional frameworks or methodologies.

Chapter 6

Prototype Development Using the DesignABILITY Framework

A prototype was designed, developed and evaluated by following each stage of the framework. During the whole process, a multidisciplinary team composed of a designer, a developer and an educator worked together in order to come up with a well-designed system. It is important to highlight that educators changed during the process, for instance, teachers involved in the storytelling activities were not the same who worked in the design of the collaborative learning activity. This was due to some teachers were not available all the time for the different activities, mostly for time constraints.

6.1 Learning Requirements stage

This stage aims to define the learning goals to focus on during the design of the educational tool and the teaching/learning strategies to be integrated. Two Colombian institutions were involved in this phase and only one meeting was necessary to finish the first stage of the framework.

Institutions

- La Pamba educational Institution in Popayán, Colombia.
- Institute of Special Therapy of the Senses (ITES for its acronym in Spanish) in Cali, Colombia.

Participants

- 1 designer
- 1 developer
- 2 educators (1 from each institution)

6.1.1 Learning Goals Definition

In this stage, learning goals were defined to be taken into account during the whole design process. One teacher from the Institute of Special Therapy of the Senses (ITES for its acronym in Spanish) in Cali-Colombia and one teacher from La Pamba Educational Institution in Popayán-Colombia participated in this stage. Because of the available time, a limited number of goals were selected. These were selected also bearing in mind that some of children who will end up testing this prototype are just learning their first words in Spanish, so it was decided to focus on reading and vocabulary goals. The goals were selected by one teacher and approved by the other one.

- **Reading**
    - Associate written words with their respective signs
- **Vocabulary**
    - Match initial vocabulary with the appropriate signs

6.1.2 Learning Strategies Definition

The strategy to be used was also selected by the teachers, which is the Fitzgerald Key. No other strategy was used due to the learning goals selected that aim to improve early development of literacy skills. Fortunately, this strategy is used in both institutions, so teachers feel comfortable with it. One thing the teachers had to agree with was the

selection of colors to be used as each institution has their own color code to identify different kinds of words. The colors that were used for this strategy are:

- **Brown**
  - Pronouns, characters names and nouns
- **Orange**
  - Verbs
- **Purple**
  - Adjectives

6.2 Design for Engaged Learning

In this stage, an interactive storytelling activity was designed, from a paper prototype to a high-fidelity prototype for desktop devices that was later implemented on mobile devices. Also, a collaborative learning activity was designed with the CollabABILITY cards/templates provided by the framework.

6.2.1 Storytelling Procedure

For this sub-stage of the framework, once again the same institutions from the previous stage participated in this one. Three case studies were carried out, 2 of them at ITES (Cali) and the other at La Pamba (Popayán). For every case study, a short evaluation was made with children. Consent forms were signed by the legally authorized representatives of the children in order to guarantee that all the information collected will be used only for research purposes and no sensitive or private information would be exposed, such as names or the faces of the children.

Institutions

- La Pamba educational Institution in Popayán, Colombia.
- Institute of Special Therapy of the Senses (ITES for its acronym in Spanish) in Cali, Colombia.

Participants

- 1 designer
- 1 developer
- 3 educators (1 from La Pamba and 2 from ITES)
- Deaf students from both institutions

Case Study 1 (Storytelling at ITES)

For this first case study, two sessions were carried out at the Institute of Special Therapy of Senses (ITES) (Cali, Colombia). The purpose of this case study is to involve children in the design of a set of cards with some drawings to create a story. The first session was done with a paper prototype of the story and the second one with printed and colorful cards based on suggestions given by students in the first session. For the design of this prototype used in the first session, the teacher agreed to do it with only one girl and thought that the story was suitable for the age of the children.

Participants

In this case study, children from ITES institution participated during two sessions. The first session involved children from the fifth grade and their ages range from 10 to 13 years old. The second session involved children from the third grade (9 to 11 years old). The reason to carry out the sessions with different students was because children from the first session already knew the story behind the cards and the idea was to allow children to create a story on their own with no previous information about it. It is important to note that the work must be done according to the availability of teachers, so it makes it difficult to carry out consecutive sessions with the same students.

Material

Paper prototype of a set of cards with images to create a story.

Session 1

The designer of this study created a story with 8 cards as a paper prototype and each card had a pre-defined position for that particular story (See Figure 28). Each card had an image with no color, they were drawn with just a pencil on a piece of paper. The story has 2 characters, a boy (Kevin) and a creature from another planet (Koos). The context of the story is Halloween. The description of each card is given below:

1. This is the cover of the story.
2. Kevin is preparing his Halloween costume
3. Kevin puts his costume on
4. Kevin goes out to get some candies
5. A strange creature (Koos) appears in front of Kevin with a broken device
6. Kevin is helping Koos to repair the device
7. Kevin returns the repaired device to Koos
8. Koos leaves happy and Kevin feels proud of himself.

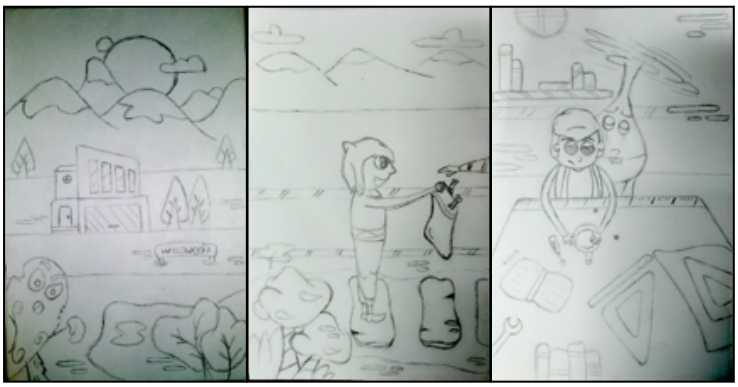


Figure 28. Paper prototype of the cards for the first story.

Children for this first session are in fifth grade (10 to 13 years old). The objective of this first case study was to get feedback about the design of the cards, the characters and the situations of the story, which is why the case study was carried out with only one child for a period of 30 minutes. One girl was selected for this purpose, she is 12 years old and she seated in the middle of the classroom with a set of scrambled cards. By using sign language, the teacher explained to the girl, and the rest of the group, that the student should arrange the cards to create a story. It was really important to tell the child that there were no right or wrong positions of the cards and that she was supposed to create a story of her own (See Figure 29).

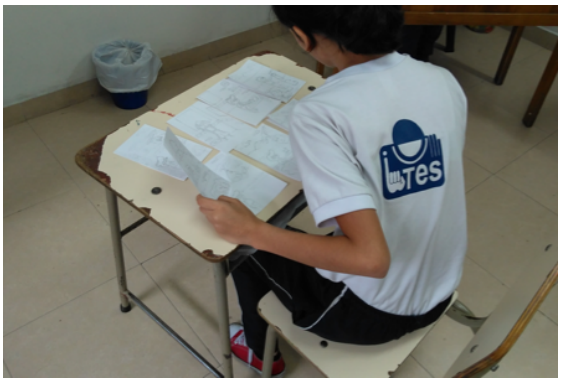


Figure 29. Student arranging the cards to create a story.

Something curious about this first session, is that the rest of the children who were seating, started to stand up around the girl and wanted to collaborate giving opinions about the specific position of certain cards. The girl selected to do this activity, instead of rejecting the opinions of her classmates, she started an exchange of ideas in sign language which in the end, gave as a result a similar story to the one created by the designer (See Figure 30).

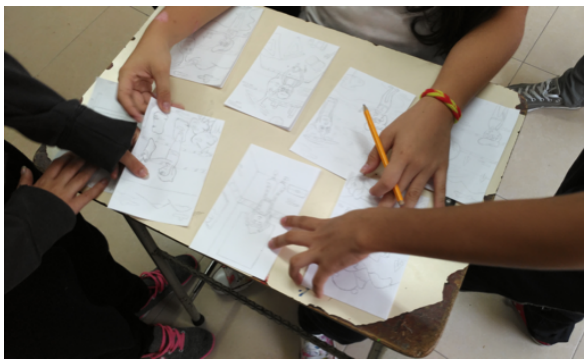


Figure 30. Children collaborating to create a story.

Once the cards were arranged, the girl was asked to tell the story she and her classmates created. She did it using sign language and her teacher was our interpreter. From the story told by the student, we identified some mistakes in the design of the cards, one of them was that the expressions of the characters we wanted to show were not always right, for instance, an expression of surprise was confused with fear. This is important when working with deaf children since their main input channel is visual and facial gestures are part of their mother language, so they pay special attention to the little details, which is why working with them during the design of a system is really

helpful. After this part of the activity, the children were told the story we had in mind when the cards were created. The teacher, again, played the role of interpreter for the children.

When the activity ended, the children were asked to give their opinions about the design of each card. In general, they had a good impression of the cards and they liked the drawings. One obvious improvement they suggested was to use colors for the cards so they could identify more easily what a card is supposed to tell. Another issue with the paper prototype of the cards was that some elements of the story were not easy to understand, for instance, some children thought that Kevin was making bread (kneading dough), when he actually was preparing his costume and some others did not realize that Koos' device was broken. All issues found during this first session are mainly due to the lack of colors in the prototype and some of the key elements of the images were not accurately drawn.

Session 2

For this second session, the same story and set of cards were used but this time, cards were designed and printed with colors. The designer was more careful when drawing facial expressions and little details like making Koos' non-functional device to actually look broken. It was also decided to leave the first card (Cover) out of the activity since it could confuse the children about the position of the card (see Figure 31).

Figure 31. Final design of printed cards for the first story.

It was decided to carry out this session with different children because the ones from the previous case study already knew what the story was about. Children from this

session are a little bit younger (9 to 11 years old). The duration of this session was 1 hour due to the number of participants (see Figure 32).

Figure 32. Children working in groups with printed cards.

Three sets of 7 cards were printed and there were 9 children in the classroom, so the students were divided into 3 groups of 3 children. The teacher explained the activity to the groups and we immediately noticed that 1 girl wanted to assume the leadership of her group, unfortunately, she did not take into account the suggestions of her classmates. In the other 2 groups, children worked together, but apparently, they did not understand the activity at the beginning because they were trying to make the cards match like a puzzle.

Once all the groups finished organizing the cards, they were asked to tell what their stories were about. At this point, it was expected that all children from the same group to tell the same story (see Figure 33).

In the first group, 2 of the children described each card but it was not a story, the remaining child did tell the story he understood. In group number 2, they just described the images on each card. Something curious about group number 3 is that one girl arranged the cards and told her story, but the second girl rearranged them according to what she believed was the right arrangement of the cards and told her own tale. The third child told his story with the same arrangement of the first girl.

Figure 33. Child explaining the story created in his group.

Something unexpected was that the teacher, who is also deaf, wanted to tell the story he understood. In this case, he told it with the cards arranged according to the story we thought from the beginning. Finally, another teacher who was playing the role of interpreter for the team of the activity told the real story for everyone.

Evaluation

For this second session, an evaluation was prepared which was reviewed by one of the teachers of the institution, to let the children express their opinions about the cards and some aspects about the activity. To achieve this, four questions were asked:

1. Was the activity clear to you?
2. Did you have fun with the activity?
3. What do you think about the drawings in the cards?
4. Were the images in the cards easy to understand?

To answer the questions, a three-scale smileyometer was used, which is a discrete Likert type scale composed by faces that show a different expression from Awful (sad face) to Brilliant (happy face) [105]. Figure 34 shows the original version of the smileyometer.

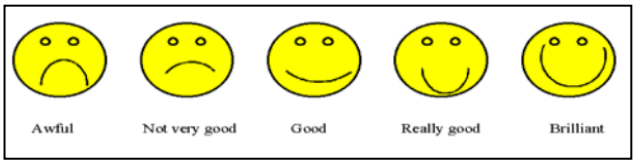


Figure 34. Five-scale smileyometer [105].

Children were asked to draw one of the three emotions to express their opinions about each question (happy, neutral and sad face). (See Figure 35)

Figure 35. Three-scale smileyometer.

Results

The evaluation was made with 7 out of 9 children since 2 of them did not understand the questions of the evaluation; according to the teacher, the level of sign language of these two children is lower than the rest of the group. Table 4 shows the answers of the students, where their names are not given in the results, instead, they will be identified as S1, S2, S3, S4, S5, S6, S7. Q1 to Q4 are the four questions asked and H, N, S correspond to the possible answers (Happy, Neutral, Sad). (See Figure 36).

Student	Q1	Q2	Q3	Q4
S1	H	H	H	H
S2	H	H	H	H
S3	H	H	H	H
S4	H	S	H	H
S5	H	H	H	H
S6	H	H	H	N
S7	H	H	H	H

Table 4. Results of first evaluation.

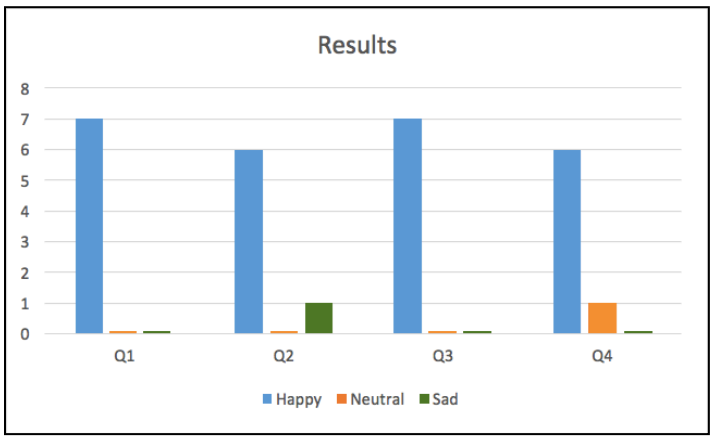


Figure 36. Results of first evaluation.

The results show that children enjoyed creating their own stories with printed cards.

Case Study 2 (Storytelling at La Pamba)

The purpose of this case study was to get information from children who study in different conditions and contexts, for instance, these children from La Pamba have a group of specialists in every class (teacher, linguistic model, interpreter), different from children at ITES where they only have the support of one teacher.

Participants

For this case study, four students (2 boys and 2 girls.) from the Educational Institution La Pamba (Popayán, Colombia) participated during one session. Three of them (2 boys and 1 girl) are 14 years old, the other girl is 22 years old but her mental age is around 12 due to a late acquisition of a first language (sign language).

Material

Printed cards used in session 2 of the previous case study.

Session

This session was carried out at another school called La Pamba. Here, we had the support of the teacher, a deaf linguistic model, an interpreter and two undergraduate students. This session lasted 45 minutes due to a low number of students who participated. The same cards for the second session of the first case study were used and it was decided to create two groups of 1 boy and 1 girl each. The teacher and the interpreter explained the activities to the students with a lot more detail than the

teachers from ITES, giving examples and even mimicking the activity as they were giving the explanation, which gave students enough information to understand what they had to do collaboratively.

While the students were working together, we noticed that the boys were not very enthusiastic about the activity. Once the students arranged the cards, we asked them to tell what the story was about. In this opportunity, we wanted them to tell it as a group and not individually, so they had to decide which part of the story was going to be told by each of them. The first group did a good job not just arranging the cards as close as the real story, but also using their imagination and working as a team. The second group did not work as a team mainly because the boy from this group did not feel comfortable doing the activity, the girl of this group, who is the 22-year-old student, was more enthusiastic and tried to make his classmate help her to create the story. In the end, they told a simpler and shorter story.

Evaluation

The same evaluation for the second session of the first case study was used with the same questions:

1. Was the activity clear to you?
2. Did you have fun with the activity?
3. What do you think about the drawings in the cards?
4. Were the images in the cards easy to understand?

The smileyometer from the previous case study was also used to answer the questions.

Results

Table 5 shows the answers of the students, where their names are not given in the results, instead, they will be identified as S1, S2, S3, S4. Q1 to Q4 are the four questions asked and H, N, S correspond to the possible answers (Happy, Neutral, Sad). (see Figure 37).

Student	*Q1*	*Q2*	*Q3*	*Q4*
S1	H	H	H	H
S2	H	N	H	H
S3	H	N	H	H
S4	H	S	H	H

Table 5. Results of second evaluation.

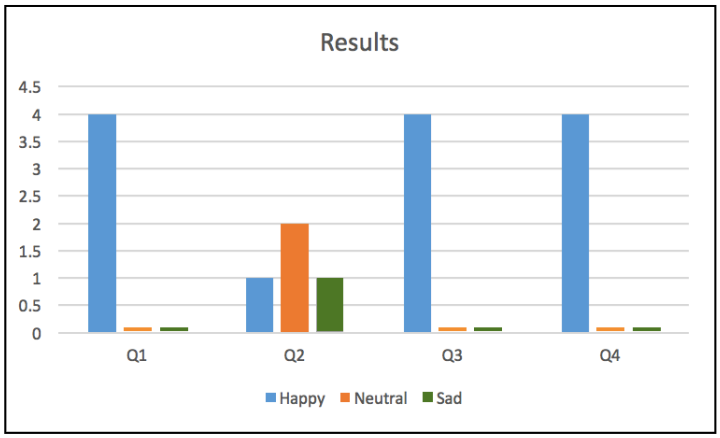


Figure 37. Results of second evaluation.

These results show that children who are preadolescents may not find interesting these kind of activities as can be seen in the responses of question 2.

Case Study 3 (Card-based Storytelling Vs Digital Storytelling)

The purpose of this last case study was to compare how children interact with two different approaches, one of them based on printed cards and the other one based on digital cards through a computer. The new story was designed based on recommendations given by the teachers who suggested to use the context of daily life for children.

Participants

For this case study, children from ITES participated during one session. These children are in fourth grade and their ages range from 10 to 14 years old.

Material

Printed cards used in previous case studies (Halloween story) and a software application for desktop computers with digital cards and different drawings (Biology class story).

Session

In this session, six children were divided into three groups to work in pairs. The designer of the study created another story with seven cards, in this case, the cards were designed using colors and taking into account the suggestions and findings from previous case studies. This second story has one main character (Kevin). The context of the story is Biology class. The description of each card is given below:

1. Biology teacher is explaining about the lifecycle of plants.
2. Kevin plants a seed in a pot
3. Kevin is worried because his plant is not growing
4. A classmate tells Kevin that the plant needs water and sunlight
5. Kevin starts watering his plant and places it near a window with direct sunlight
6. Kevin's plant starts to grow
7. Kevin shows his results and a beautiful plant in front of the class.

For this session, two different activities were carried out with two sets of cards (Halloween and Biology class) for a period of 1 hour and the reason to use both stories is because we did not want children to create the same story in both activities taking into account that one of them was with printed cards and the other one with digital cards. For the first activity, the children worked in pairs using the cards from the previous case studies (Halloween) to create a story as can be seen in figure 38. It is important to notice that before this activity, children were not enthusiastic about it, they did not want to participate because the activity was not attractive to them. Once they arranged the cards, they were asked to tell the story using sign language while the teacher played the role of interpreter to us.

Figure 38. Children working in pairs to arrange the physical cards.

The second activity consisted of a new approach for these children and the teachers, in this occasion, the students had the opportunity to do the same activity of creating a story by arranging a new set of scrambled digital cards with the second story (biology class) using a computer through an interactive software application developed with Processing IDE (figure 39). The application allowed children to type their names and after that, they could drag and drop each card in a particular space according to the story they wanted to create. When the last card is placed in the last available position, the application rewards the student with a trophy, a congratulation message with his/her name and the time spent creating the story. The name and the reward were included to apply two positive interdependences, which are Identity and Celebration/Reward, the latter is also a game mechanic that can be found in all video games and is necessary in order to keep the player/learner motivated.

Figure 39. Children working in pairs to arrange the digital cards.

Once the students used the software application, their motivation increased to the point that they did not want to leave the classroom waiting for another chance to use the software, which confirms that ICTs are a valuable resource to engage children into learning. At the end of both activities, students were asked to answer a short survey about their experience. The questions and the results are shown below.

For this case study, additional pictograms were included with vocabulary related to the cards used by the children. The idea was first to make sure if the children knew this vocabulary and in case they did not, it was taught first by showing the corresponding sign of the words and then they were asked to associate each word with a particular card (scene) of the story. From this moment on, the teacher starts the process of teaching literacy from the stories created by the students and the selected vocabulary which was chosen based on current children's literacy knowledge and age.

Evaluation

The questions asked to the children about the use of the cards and the app are:

1. How did you feel using the cards?
2. How did you feel using the app on the computer?
3. The activities were clear to you?
4. Did you have fun using the cards?
5. Did you have fun using the app on the computer?
6. What do you think about the drawings?
7. The drawings were easy to understand?
8. Did you like to work with your classmate? Why?
9. Next time, do you prefer to use the cards or the app on the computer?
10. Why would you prefer to use the cards/app?

The smileyometer from the previous case studies was also used to answer most of the questions.

Results

The results of the survey are shown in table 6; once again, their names are not given in the results, instead, they will be identified as S1, S2, S3, S4, S5 and S6. Q1 to Q7 are the first seven questions asked and H, N, S correspond to the possible answers

(Happy, Neutral, Sad) (See figure 40). Answers to Q8, Q9 and Q10 are shown in table 7.

Student	Q1	Q2	Q3	Q4	Q5	Q6	Q7
S1	H	H	H	H	H	H	H
S2	H	H	H	H	H	N	N
S3	H	H	H	H	H	N	N
S4	H	H	N	H	H	H	H
S5	H	H	H	H	H	H	H
S6	H	H	H	H	H	H	N

Table 6. Results of third evaluation (part 1).

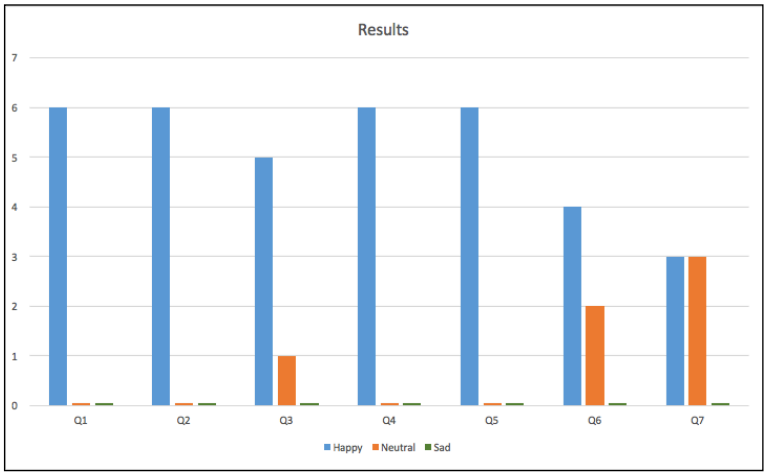


Figure 40. Results of third evaluation.

These results show that images in the cards must be improved since the drawings are not completely easy to understand according to children's responses. The digital drawings could have been more difficult to understand since the size of the images is restricted by the size of the computer's screen.

Student	Q8	Q9	Q10
S1	Yes, I liked to work with my classmate because we had the chance to share and choose the cards	Next time, I prefer to use the app on the computer	Because I like to use the computer
S2	Yes, I liked to work with my classmate because he helped me and joined me	Next time, I prefer to use the app on the computer	Because I had much more fun
S3	Yes, I liked to work with my classmate	Next time, I prefer to use the computer	The student did not answer
S4	Yes, I liked to work with her because we were playing, exchanging and choosing the right place of the cards	Next time, I prefer to use the computer	Because I liked the images and it was fun
S5	Yes, I liked to work with him because we shared the cards during the process, we played, and it was fun	Next time, I prefer to use the app	Because I liked it and it was interesting
S6	I felt good, the activity was nice.	Next time I would like to use both (the cards and the app).	I liked both activities.

Table 7. Results of third evaluation (part 2).

Discussion

Each of the 3 case studies gave us relevant information to be taken into account in the design of interactive storytelling. First of all, the paper prototype of the cards can give some insights about the elements to be carefully designed in the images to be part of the story. It is also important to have children's opinion from the beginning since they can give relevant information about the drawings, especially when emotions of the

characters play an important role in the story, for instance, a surprise expression was confused with fear. One of the suggestions given by the teachers was to use stories that are related to the children's daily living, avoiding strange characters like Koos (first set of cards), at least with children that are in the first stages of a written language acquisition since it can be difficult to explain words that do not exist or situations that are not real. Assigning a sign name to the characters before doing the activity is also suggested so the children may refer to them by their sign when telling the story.

Age is an important fact when working with children since they can find this kind of activities boring or childish when they are becoming teenagers, that is why it is important to know about the potential future users, not just their chronological age but also their mental age, as noticed in one of the case studies, a girl who is 21 years old was excited about the activity due to her mental age is 12.

The activities to be carried out in a collaborative way must also be carefully designed because the result may not be the desired one just by making groups and tell them to work together. Positive interdependences play an important role when children are wanted to collaborate in order to achieve a common goal. When working in groups, the number of children in an activity must be adequate to avoid conflicts among members of the group, as evidenced in the second case study, groups of three children were too big to create a story with just seven cards, so a common agreement among children of some groups was not seen. On the other hand, working in pairs resulted in a better group work and consensus of the groups. The cards were not used for this activity because they were not fully designed by the time this case study was carried out.

Children's motivation increased when technology was part of the activity, for the third case study, children had to take turns to use the computer because only one of the computers available in the classroom had Internet access and this was necessary to install a Java update needed for the software to work, this limited the activity to be used individually, but even though children were told to work on their own, they could not resist to work with their respective classmate from the previous activity.

The results of the three evaluations show that the storytelling activities were attractive to children, only two children from the second evaluation felt this activity was not for them due to their age. They also show that involving students and teachers in the

design process, was necessary to create a solution that is both, usable and accessible, with the limited available resources in both institutions. The developed tool complements the current teaching strategies used and meets the needs of the teachers and the students.

This study coincides with others like [27] and [26] where it is demonstrated how technology can improve a storytelling strategy for literacy teaching by engaging and motivating children. To the best of our knowledge, and based on literature review and teacher's requests, there is no other digital storytelling approach that can actually be used as part of their teaching process, either because the educational institutions don't have the necessary technological resources or because some digital resources are not meant to be used for teaching Spanish to deaf children.

This proposal can be easily adapted for literacy teaching of any language for both, hearing and Deaf children. Even though the results of this study are positive, there is still more research to do about the assessment of children's learning after using this approach in a regular basis.

The results of this study will be used by teachers from both institutions to improve their teaching strategies and also as part of the validation process of the DesignABILITY framework.

6.2.2 Collaborative Learning (Design of the activity)

For this sub-stage of the framework, the design of a collaborative learning activity was made with 6 experts from Colombia, 3 of them are researchers with an HCI/software development background and 3 school teachers (educators) of deaf children, 2 of them from the Association of Deaf People from Valle (ASORVAL by its acronym in Spanish) in Cali (Colombia) and 1 from La Pamba educational institution.

Institutions

- La Pamba educational Institution in Popayán, Colombia.
- Association of Deaf People from Valle (ASORVAL) in Cali, Colombia.

Participants

- 3 designers/developer
- 3 educators (1 from La Pamba and 2 from ASORVAL)
- Deaf students from both institutions

Case Study

The researcher and educators worked in pairs (1 researcher and 1 educator) and they were asked to use the cards in the design of a collaborative learning activity. One group of experts used the digital version of the cards (mobile app). No evaluation of the designed activity was made with children in this stage, it was left for the evaluation of the final prototype which includes the selected collaborative learning activity designed by one of the groups (researcher/educator). Researchers and educators evaluated the cards along with their respective templates of every category through an adapted System Usability Scale (SUS) based on the one proposed by John Brooke [106] and a questionnaire.

The 10 SUS statements presented to the experts were:

1. I think that I would like to use these cards/templates frequently.
2. I found the cards/templates unnecessarily complex
3. I thought the cards/templates were easy to use
4. I think that I would need the support of a technical person to be able to use these cards/templates
5. I found the various functions in these cards/templates were well integrated
6. I thought there was too much inconsistency in these cards/templates
7. I would imagine that most people would learn to use these cards/templates very quickly
8. I found the cards/templates very cumbersome to use
9. I felt very confident using the cards/templates
10. I needed to learn a lot of things before I could get going with these cards/templates

The response format used for each statement can be seen in Figure 41.

Strongly Disagree 1	2	3	4	Strongly Agree 5
□	□	□	□	□

Figure 41. Response format for the SUS evaluation.

A series of open-ended questions were asked after the SUS evaluation to allow the evaluator to express what s/he thinks about the cards, the process, the time invested during the design of the collaborative learning activity, and how these can be improved.

Results

The 10 statements of the SUS evaluation were presented to both, researchers (R1, R2, R3) and educators (E1, E2, E3) and their responses are shown in figure 42. The SUS score was mapped along with adjective and acceptability ranges proposed by Bangor et al. in [107]

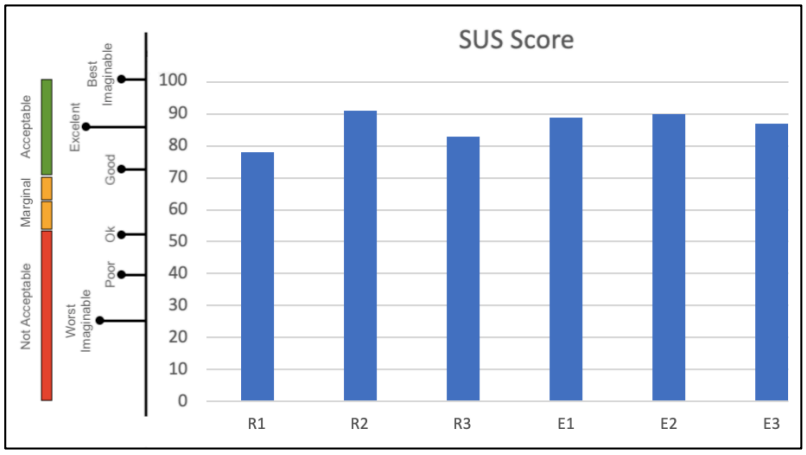


Figure 42. SUS Score mapped with adjective and acceptability ratings.

The open-ended questions show some really good comments and reviews about the cards, such as: *"the underlying idea was excellent and really helped me to develop the activity"* says E1; *"The cards were very appealing visually. Clear font, bright colors and pleasant to use"* says R2; *"I think the cards are very useful as a stimulus for the teacher to consider how collaboration can best be achieved in an activity. I think a workshop on this design process would be very useful for student teachers and for experienced teachers. I would definitely use the cards again"* states E3.

As a result of the activity, three collaborative learning activities were designed. Two of the activities ended as a paper prototype for desktop computers and one of them was implemented as a mobile app that was tested in a case study with deaf children in two Colombian educational institutions. Only the last CL activity (implemented as a mobile app) will be discussed in this section. The mobile app and the case study with deaf children will be shown in the following sections (Prototyping and Evaluation).

First, the children's profile was defined by the educator.

- **Children's Profile**
  - **Ages.** 12-15
  - **Gender.** 4 girls and 2 boys
  - **Academic year.** 4 kids from 5th grade and 2 kids from 4th grade.
  - All 6 children are profoundly deaf, 1 of them has Jervell and Lange-Nielsen syndrome and another has a cognitive deficit, probably due to a mental disorder
  - All 6 children use sign language to communicate, none of them have a cochlear implant
  - Their literacy skills are very low, they only know a few words of written Spanish, no grammar, no reading comprehension

Once the children's profile was defined, both educator and designer decided which would be the initial conditions for the activity. This included the type of activity, how would children interact, how the groups would be formed, where and how the collaboration would take place.

- **Initial Conditions**
  - **Type of activity.** Charades-type activity
  - **Interaction.** peer-to-peer
  - **Group heterogeneity.** Mixed (boys and girls when possible) and mixed academic level
  - **Setting of collaboration.** Classroom
  - **Condition of collaboration.** Physically
  - **Period of collaboration.** 10 minutes

With the initial conditions set, the collaboration was structured by defining the activities to be performed (tasks, workflow) as well as the roles and resources to be shared.

- **Structure Collaboration**
  - **Activities.** Students will have a short period to learn new vocabulary, then, they must take turns (changing roles), while one of them see the word to find (this is called THE SIGNER) and sign it to his/her peer, the other one (this is called THE WORD FINDER) has four options on the tablet to choose from. The main goal will be to choose the correct words on the tablet based on an image shown to both students, THE SIGNER may help the WORD FINDER just by signing the word to be found. Since they must take turns, partial and individual goals consist of choosing the right word in every turn and the resource they share will be through sign language.
  - **Roles.** THE SIGNER will be the student who sees the word and make the sign to his peer. THE WORD FINDER will be the student holding the tablet with four options to choose from and match the sign given by his/her peer with one of the words on the screen. The teacher moderates the activity making sure they do not break the rules (no watching the word seen by THE SIGNER or helping THE WORD FINDER to select the right word).
  - **Communication.** Members of the team communicate through sign language.
  - **Shared resources.** Each student will have a resource to complete the activity. On one hand, THE SIGNER has the word to be found and THE WORD FINDER will have the options to choose from.

- **Positive Interdependences**
  - **Role.** Two roles must be played, taking turns.
  - **Identity.** The students must come to terms and choose a flag to identify them as a team
  - **Goal.** Partial goals and one main goal (Selecting the correct words based on the sign)
  - **Resource.** Two resources are shared

- **Task.** They take turns every time one word is correctly matched with the sign
- **Celebration/Reward.** Every time a word is correctly matched, the students will receive a STAR and a numeric score.

Discussion

As can be seen in figure 42, the usability of the cards had an acceptable rating. Both the digital and printed versions of the cards got a high score which means that previous suggestions made by experts in the first evaluation of the framework were addressed correctly.

The qualitative evaluation made through the questionnaire reveals that the evaluators consider that this is a great resource for them, not just educators, but also researchers as it helps design collaborative learning activities that can be later integrated with a digital system.

The collaborative learning activity designed and implemented by one of the groups of experts demonstrates that co-designing this kind of activities requires an interdisciplinary team (designers and educators). All of the evaluators agreed that these kind of resources (cards and templates) make this process easier as long as educators work along with designers as it is necessary to have a pedagogical and HCI/design/software development background to end up with a useful system designed for deaf children.

6.3 Prototyping

Based on the work done in the 2 previous stages, a mobile prototype was developed, focusing on the learning goals and strategy selected by the teachers. The story designed for the interactive storytelling activity was also used and the collaborative learning activity designed in the previous section was implemented. Guidelines from the GUI-DG were used during the design of both prototypes (low-fidelity and high-fidelity).

6.3.1 Low-Fidelity Prototype

A paper prototype was developed based on the suggestions given by the teacher from La Pamba educational institution in the city of Popayán. This paper prototype was first approved by her and then presented to another educator from ASORVAL in the city of Cali who also approved it. Their feedback was very valuable in order to start designing a high-fidelity prototype for mobile devices. They made suggestions about the content of every screen and the final result can be seen in figures 43 to 45.

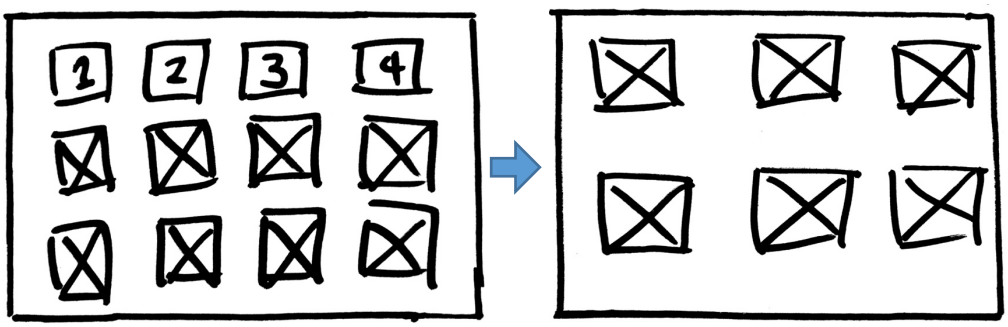


Figure 43. Level screen and Team Identity screen.

In figure 43, the image on the left is a screen that shows the available levels, which means that for future versions of the prototype, more complex activities may be added appropriate for different literacy levels. The image on the right let members of the team select an image that represents and gives identity to the team (It could be animals, figures, characters, etc.).

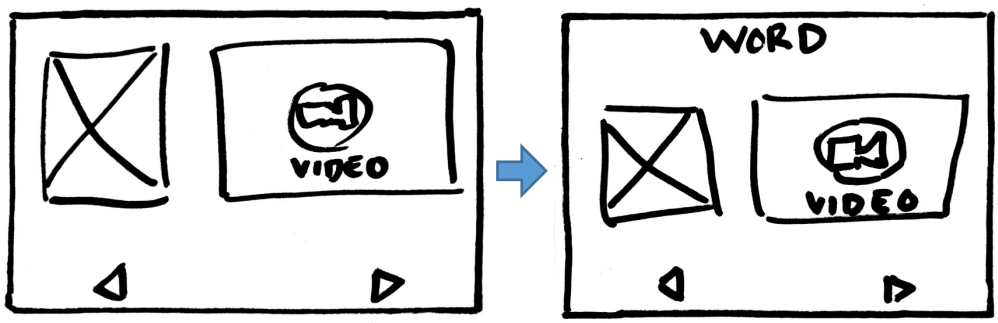


Figure 44. Storytelling screen and Word Training screen.

Figure 44 shows on the left the screen where the children will see the story to be told and where the new vocabulary will come from. This story is the same used in stage 2 for the storytelling activity with deaf children.

The content of the screen (left) is:

- An image with the scene of the story.
- A video with an interpreter telling the scene in sign language.
- Two buttons to go to the previous/next scene.

On the right is the screen where children will train to learn the new vocabulary from the story.
The content of this screen (right) is:

- The word to be learn on top.
- An image that represents that word.
- A video with the sign of the word.
- The buttons to go to the previous/next word to learn.

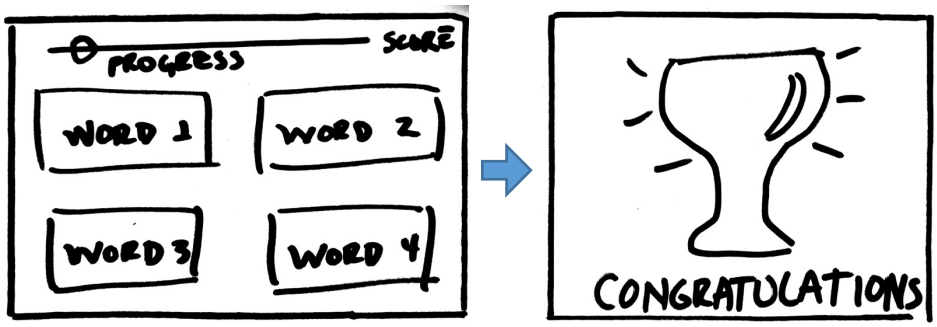


Figure 45. Collaborative learning screen and Achievement screen.

Finally, figure 45 shows on the left the screen that will see the WORD FINDER (role defined in the previous stage during the design of the CL activity). Here, the student with this role will have to choose the correct word from 4 options given. The word chosen must match the sign given by the SIGNER (role defined in previous stage for this CL activity).

The content of this screen (left) is:

- A progress bar that shows how the team is doing
- A numeric score with points obtained for every word found correctly

- The four options to choose from (word 1, word 2, word 3, word 4).

The image on the right shows a reward once all the words are found by the team.

6.3.2 High-Fidelity Prototype

The high-fidelity prototype was designed and developed in Android Studio for Android devices. The user interface was done with XML and programming in Java programming language. The prototype was developed to fit any screen of any Android device. In order to find out if children prefer to work individually or as a group, another activity was implemented to be done individually (level 1) and that way the collaborative learning activity is unlocked (level 2). Figures 46 to 53 show the final result of the prototype.

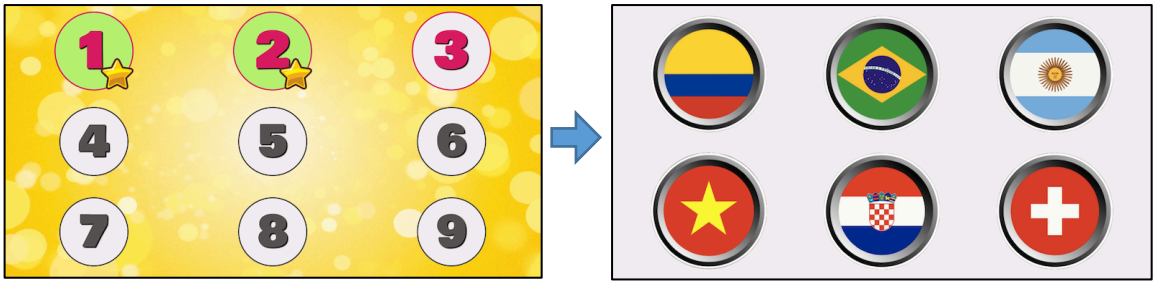


Figure 46. Level screen and Team Identity screen.

The image on the left in figure 46 is the level screen where children can select the level to work in.

The content of the screen (left) is:

- A series of number showing the available levels (1 to 9).
- Numbers in red and green background with a star means that level has been completed (1 and 2).
- Numbers in red and white background means that level is available but not completed.
- Numbers in gray are for level that have not been unlocked. Every time a level is completed, the next one is unlocked.

The image on the right shows the screen for team identity, where students must come to terms and select a flag that identify them as a team.

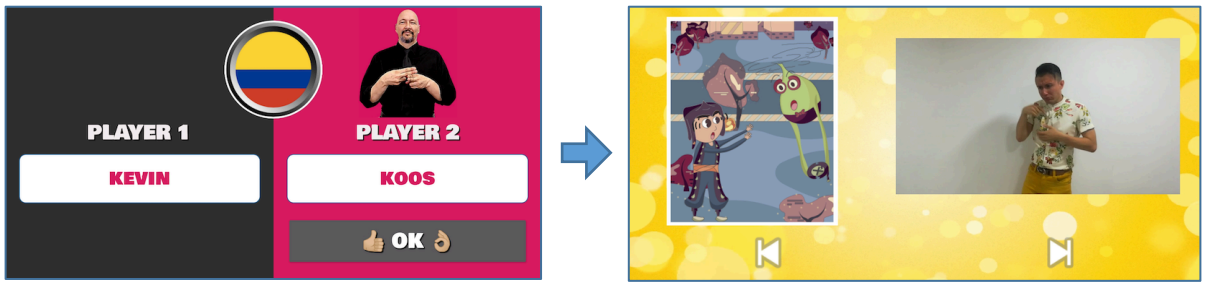


Figure 47. Members Names screen and Storytelling screen.

Figure 47 shows on the left the screen where students can type their names. This screen was not designed in the low-fidelity prototype but was designed in this prototype to give individual accountability to students, so every time they see their name on the screen, they know that part of the activity depends on them.

The content of the screen (left) is:

- Sign language on top (the sign for the word ‘name’).
- Text fields for every player’s name.
- A button to continue.

The image on the right shows how the story is told.

The content of the screen (right) is:

- An image with the scene of the story.
- A video with an interpreter telling the story in sign languages.
- Two buttons to go to the previous/next scene.

Figure 48. Introduction to Vocabulary.

Figure 48 shows the screen that indicates that a vocabulary section is about to start. The content of the screen is:

- The word VOCABULARY on top.
- A video with an interpreter signing the word VOCABULARY.

Figure 49. Word Training screens.

Figure 49 shows the screens where children will learn new vocabulary from the story they just read in sign language. Note how the color of the background changes depending on the kind of word. This was made to apply the Fitzgerald Key strategy chosen in the first stage (orange for verbs and purple for adjectives).

The content of the screen is:

- The word to learn on top of the screen (verb or adjective).
- An image from a scene of the story that represents the word to learn.
- A video with an interpreter signing the word to learn.
- Two buttons to go to the next/previous word.

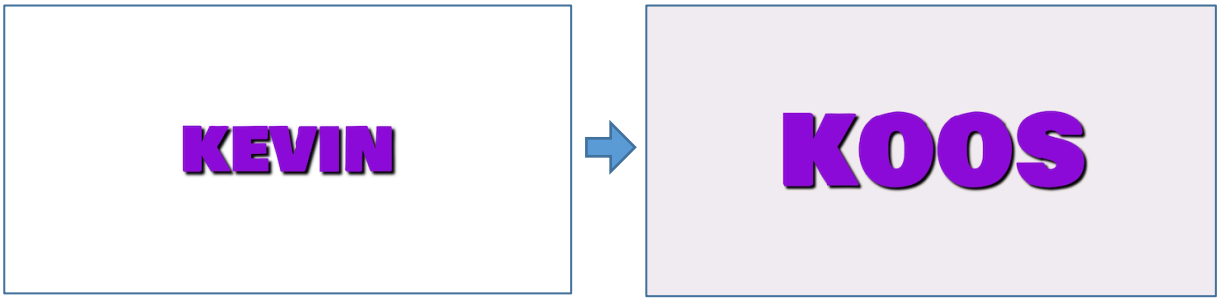


Figure 50. Turns screen for the CL activity.

The screen seen in figure 50 show the name of the student that will play the WORD FINDER role for the CL activity and thus take turns for every word they find (this was established in the design of the activity). The other student will then be the SIGNER. The content of the screen is:

- The name of the student who will be the WORD FINDER (will hold the tablet with the 4 options).

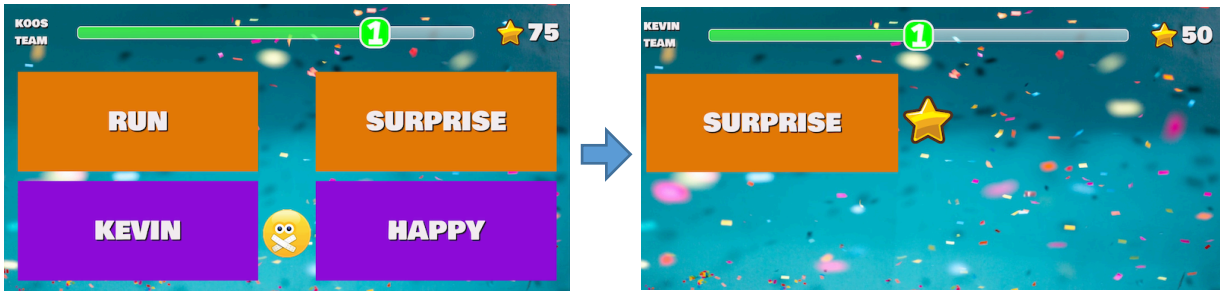


Figure 51. Screens showing the player selected an incorrect word (KEVIN) or the correct word (SURPRISE).

The screen seen by the WORD FINDER in the CL activity is shown in figure 51. This student will receive the word to find by his teammate (SIGNER). Then s/he will have to find the correct word. If the WORD FINDER makes a mistake, an icon will appear from behind the word s/he chose, and haptic feedback is received (no points are subtracted from the score). If the word matches the sign given by the SIGNER, the incorrect words disappear and a start appears from behind the selected word, then the score is incremented. Note how the buttons have a background color (orange or purple). There could be words in a button with the wrong color. Words that are not part of the story are also included to make it easier to find the right word (taking into account this would be level 1 of the app).

The content of the screen is:

- Name of the student playing the WORD FINDER.
- A progress bar showing how the team is doing.
- A numeric score with the number of stars earned.
- Four buttons with options to select from.

Figure 52. Achievement screen.

Figure 52 shows the screen seen by the students when all the words were found as a team.

The content of the screen is:

- A message (CONGRATULATIONS) and an image (STAR).

Finally, figure 53 shows the activity to be performed individually by students. To get to this screen, students first have to watch the story in sign language (figure 47), then learn new vocabulary (figure 49) and finally the individual activity.

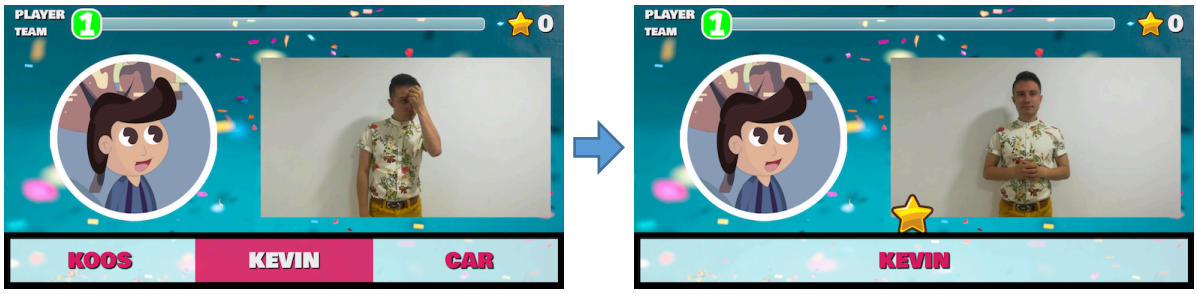


Figure 53. Individual Activity screen.

The prototype designed meets all the requirements and information gathered in previous stages, this includes, learning goals/strategies, story and collaborative learning activity designed. In the following section, the prototype is tested and evaluated by deaf children as well as by the teachers.

6.4 Evaluation

A usability test plan (UTP) was designed to test and evaluate the prototype with deaf children from two institutions (one in Cali and the other one in Popayán).

6.4.1 Usability Test Plan

Following the framework evaluation stage, the UTP is structured as follows:

Name of the tool

ABC-DEaF

Introduction

The ABC-DEaF mobile application was developed with the purpose of serving as a support tool for the teaching and reading processes of deaf children. The application will be submitted for the first time to usability tests with potential users who will be deaf children of the educational institution La Pamba and the Association of Deaf People from Valle (ASORVAL).

Purpose and goals of the test

The purpose of this test is to evaluate the user experience of deaf children from two educational institutions with a mobile app called ABC-DEaF. The goals of usability testing include identifying potential design concerns to be addressed to improve the efficiency, productivity, and end-user satisfaction.

The objectives of this test are:

- To determine design inconsistencies and usability problem areas within the user interface and content areas. Potential sources of error may include:
    - Navigation errors – failure to locate functions, excessive keystrokes to complete a function, not following recommended screen flow.
    - Presentation errors – failure to locate and properly act upon desired information in screens, selection errors due to iconic ambiguities.
    - Control usage problems – improper toolbar or entry field usage.

- Establish baseline user-satisfaction levels of the user interface for future usability evaluations.
- Determine if children prefer to work as a team over individually.
- Identify how difficult or complex to understand is the user interface and navigation of the app.

Methodology

24 deaf children will participate in the usability test, 12 from an institution in Cali-Colombia and 12 from an institution in Popayán-Colombia. The test will be carried out in both institutions. Android devices will be used to run the prototype and some of the information that will be collected includes demographic information, satisfaction assessment, and suggestions for improvement. No tasks were defined for this test, since children prefer to explore technology by themselves (based on findings of previous case studies). 2 sessions will be carried out in ASORVAL (6 children per session) and 1 session in La Pamba. 4 Android tablets will be used in every session, so a maximum of 4 children will interact with the prototype at the same time. First, the individual activity will be done (level 1), once it finishes, the collaborative learning activity will be unlocked (level 2).

Consent forms will be signed by the legally authorized representatives of the children to guarantee that all the information collected will be used only for research purposes and no sensitive or private information would be exposed, such as names or the faces of the children.

Participants

Twelve deaf children from ASORVAL (Cali) participated in 2 different sessions (6 per session). Children from the first session are in 4^{th} and 5^{th} grade and their ages range from 12 to 15 years old. All children are profoundly deaf and one of them has a cognitive deficit and a possible mental disorder (they will be identified as S1 to S6). Children from the second session are in 4^{th} and 5^{th} grade and their ages range from 11 to 15 years old. All children are profoundly deaf and 5 of them have other types of disorders (they will be identified as S7 to S12). S8 has a mental disorder and low vision, S9 has a cognitive deficit, S10 also has a cognitive deficit, S11 has seizure syndrome and S12 has behavioral problems.

Twelve more children from La Pamba (Popayán) participated in 1 session. These children are in 2nd and 3rd grade and their ages range from 8 to 15 (they will be identified as S13 to S24). All children are deaf, S13 also has a cognitive deficiency, S15 has a mild cognitive deficiency, S17 is just learning sign language, S20 has also a cognitive and physical disability, S24 has a cognitive deficit.

Every child will answer a series of open-ended questions about the experience, the activities carried out and the prototype in general.

Post-test questionnaire

Open-ended questions will be asked at the end of the individual activity as well as at the end of the collaborative learning activity in order to get children's perception of the activity and the prototype. Questions to be asked per activity are:

Individual activity questions

- How do you feel after using the app? Why?
- Was the app easy to use?
- What did you like about the app?
- What did you not like about the app?
- Did you like the story?
- Would you like to play again?

Collaborative activity questions

- How do you feel after this new activity with your classmate? Why?
- What did you like about this new activity?
- What did you not like about this new activity?
- Which of the activities did you like more? Why?
- Do you prefer to play by yourself or with a classmate?

Evaluation Techniques

The techniques that will be used are the same proposed in the framework: direct observation, questionnaires and smileyometer. The principles given by the framework to evaluate collaboration will be also used.

The first click (tap) test was used to identify if children can locate the first interactive element of every screen to move forward in order to complete the activity.

Metrics

Some metrics to evaluate collaboration were selected from the ones given in the framework. Due to the simplicity of the activity, only 2 metrics were defined.

- Number of errors
- Solution to the problem

Results

The test will provide qualitative information about the user experience, the user interface, interaction and ideas on how to improve the prototype and the framework.

Team Members

During the test, a designer/developer will take notes and pictures/video of the children interacting with the prototype. One teacher will act as interpreter for children and the designer/developer.

6.4.2 Usability Test with Deaf Children (ASORVAL and LA PAMBA)

The usability test was first carried out at ASORVAL with 12 children (4 children at a time due to number of available devices). The first activity was done individually and the second one was done collaboratively. 6 children participated in the first session and the remaining 6 in the second session.

Figure 54. Children using the prototype at ASORVAL.

No instructions were given to the children, the tablets were handed in the *level screen* with only the first level unlocked.

For the individual activity, the *first tap test* passes if children start using the app by tapping the number 1 (first level).

Figure 55. First tap test (level 1).

For the second screen (storytelling screen), the *first tap* passes if children change the scene and move forward by tapping the right button with *next* icon.

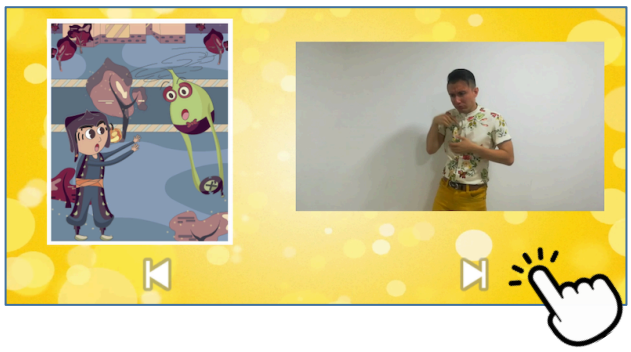


Figure 56. First tap test (storytelling screen).

For the third screen (vocabulary screen), the *first tap* passes if children move to the next word by tapping the right button with *next* icon.

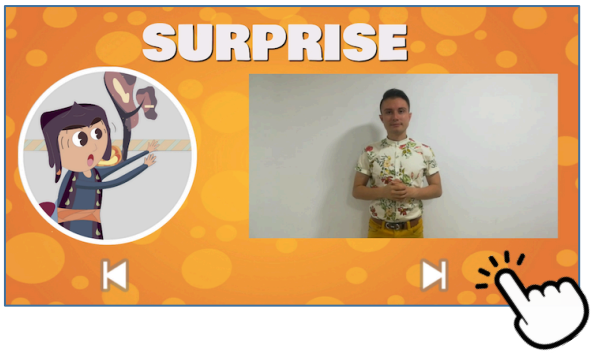


Figure 57. First tap test (vocabulary screen).

Finally, in the last screen (individual activity screen) the *first tap* passes if children press any of the 3 words to choose from (for this screen, a hint to choose the correct word is given only for the first word).

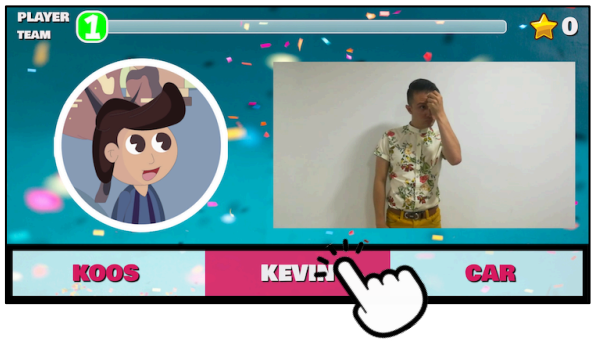


Figure 58. First tap test (individual activity screen).

For the collaborative activity, children were split in groups of 2 children. Once again in the level screen, the *first tap test* passes if children choose the number 2 (second level) which is now unlocked after finishing the individual activity.

Figure 59. First tap test (level 2).

The second screen shows the team identity options (flags) to choose from (see figure 46).

The third screen gives team members the option to type their names. The first tap test passes if children tap on the text field to make the keyboard appear (see figure 47).

The fourth screen shows new vocabulary to learn from the story. The first tap test passes the same way as seen in figure 57.

Finally, for the collaborative learning activity, the first tap test passes if THE WORD FINDER selects any of the 4 options to choose from (hopefully the correct one). See figure 51.

Once children ended every activity (individual and collaborative), questions were asked to let them express how they felt after using the app.

The usability test was then carried out in La Pamba educational institution with 12 children (4 children at a time) in 1 session.

Figure 60. Children using the prototype at LA PAMBA.

Results of Usability Test

For the *first tap* test on each screen, the results were satisfactory. For the level screen, all children identified which were the available levels in both activities. They also identified that level number 2 was available after finishing level 1. For the storytelling screen, 1 child from session 1 in ASORVAL and 2 children from session 2 in ASORVAL had trouble identifying the button to move forward on the story and asked for help. None of them had trouble identifying the first interactive element of the rest of the screens (team identity, individual activity screen and collaborative activity screen).

Two metrics were selected to evaluate this CL activity, one of them is the number of errors made by each team. 12 teams of 2 children were created (G1 to G12) and the number of errors made by each of them is shown in figure 61.

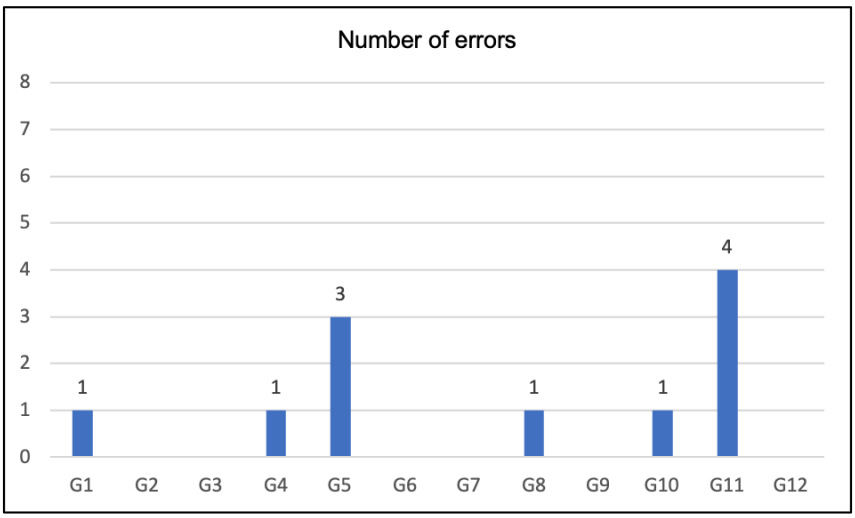


Figure 61. Number of errors made by each team.

Two groups made a significant number of errors (G5 from ASORVAL and G11 from LA PAMBA) compared to the rest of the groups.

The other metric was the solution to the problem, which was achieved by all groups, some with difficulties due to understanding the activity of 1 of the team members, but in the end the main goal was achieved by all groups.

A short survey was taken for each child after each activity. Due to the extent of all the answers given by the 24 children, the information with these results is shown in appendix C. A summary of these answers is given in this section and discussed in the next one.

The 6 questions asked to the children after the individual activity were:

- Q1: How do you feel after using the app and why?

All the children felt either good or happy. Some of the reasons were because they understood what they had to do, they also had fun and some of them enjoyed reading the story in sign language.

- Q2: Was the app easy to use?

For Q2, 3 children did not answer, 1 of them said it was difficult because it was hard to learn the new words for her. 20 children said the app was easy to use, some of them expressed that sign language was helpful and they easily understood what they had to do.

- Q3: What did you like about the app?

1 child did not answer, and the rest said they liked either the story, the instructions in sign language, the vocabulary, the haptic feedback or the way they learned with it.

- Q4: What did you not like about the app?

3 children did not answer, and the remaining 21 said they liked it, so there was nothing to say about this question.

- Q5: Did you like the story?

1 child did not answer, and the rest said they enjoyed the story, some of them said because they understood the sign language.

- Q6: Would you like to play again?

All the children wanted to continue using the app.

The 5 questions asked to the children after the collaborative activity were:

- Q7: How do you feel after this new activity with your classmate and why?

All children felt either good or happy, for some it was because they played with a partner, for some others it was the sharing and for others it was the new vocabulary.

- Q8: What did you like about this new activity?

1 child did not answer, the remaining 23 gave different opinions on what they liked, for instance, playing with a classmate, helping each other, the new signs and vocabulary, the rewards, the feedback (when they were right or wrong) and some enjoyed feeling in some kind of competition.

- Q9: What did you not like about this new activity?

3 children did not answer this question, the rest said they liked it.

- Q10: Which of the two activities did you like more and why?

2 children liked the first activity more without giving reasons, while the other 22 children preferred the second activity. The reasons include that it was more fun, and they prefer working with friends.

- Q11: Do you prefer to play by yourself or with a classmate?

2 children prefer to do the activities by themselves (same 2 children who liked the first activity more) and one of the said it was because her partner did not understand the activity. The rest of the children prefer to do the activities with a peer.

Discussion

All 24 children enjoyed using technology as part of the learning process. Some of them had little trouble identifying the button to move forward on the storytelling screen, but once it was learned they easily identified it in the vocabulary screen.

In general, they enjoyed everything about the app, they said it was easy to use and helpful. Some of the results to highlight are that children enjoyed feeling the haptic feedback (vibration) when they selected the wrong option in both activities. Also, they enjoyed having sign language as support for the activities.

Some of the findings from direct observation are that for some teams, it was not easy to come to terms when deciding which flag will identify them, in most cases, one of the

kids just pressed the one he liked before asking his peer. Also, some children spelled every new word they learned.

Most of the answers were similar among children, except for the last 2 questions, where 2 children said that they preferred to work by themselves rather than with a partner. It is no coincidence that both answers come from 2 children who did the collaborative activity with a classmate that had trouble understanding the activity (due to his/her cognitive issues) and it made them feel like they did not have support by their teammates to achieve the main goal, this could also be seen in figure 61 that shows that those groups made more mistakes than the rest of the groups and thus it took longer to complete the activity. However, these children were especially willing to help their classmates whenever they had trouble understanding the activity.

Is then important to take into account how children with different academic levels (and with additional difficulties like cognitive issues) are going to collaborate and how those with higher academic levels help their peers to achieve their individual goals and thus achieve the main goal as a team without the feeling that they are in some kind of disadvantage. Activities with this kind of challenges must be carefully design in order to increase the motivation of all team members and promote learning for all of them even at different levels.

6.4.3 Evaluation of the Prototype (by Educators)

After the usability test with children, educators who participated during the design of the activities and the prototype, took a short online survey to evaluate the prototype. The questions asked are:

- Q1: What do you think about the prototype developed?
- Q2: How do you think this prototype could be improved?
- Q3: Do you think this kind of tools could support your teaching process? Why?
- Q4: The prototype is useful to develop literacy skills in deaf children (1 to 5)
- Q5: The prototype is useful to promote collaborative learning (1 to 5)

Results

Responses to the questions are:

What do you think about the prototype developed?

- I think this prototype is a great way to involve technology in the classroom that is not distractive but supportive for deaf children.
- The prototype is a great idea to support learning a second language for deaf children, but there are not enough activities to see significant results.
- I love the idea behind the whole design process, involving storytelling is great to engage children and the use of sign language all over the app is very helpful for them.
- This prototype meets the needs of the children and mine too as a teacher. The way it guides children from the story to the learning activities is very clever.

How do you think this prototype could be improved?

- Increase the number of levels and make the activities last longer to keep children motivated.
- As a prototype, the number of implemented levels is not enough, it needs more stories and activities.
- The interpreter (sign language) in the videos, should use a shirt with a solid color instead of a shirt with images or figures that could distract children when doing signs.
- The implementation of more activities, both, individual and collaborative.

Do you think this kind of tools could support your teaching process? Why?

- Definitely, there are no applications that cover this literacy process in such detailed way. At least not in Spanish. I hope the `prototype becomes a complete application full of stories and activities.
- Sure. It is a great way to complement the activities carried out during the school year.
- Yes, but I would also need access to this technology like tablets, unfortunately, there are not enough resources to have these kinds of devices.
- Yes, actually, it could be very helpful for children to have this application at home and improve their literacy skills by their own.

The prototype is useful to develop literacy skills in deaf children (1 to 5)

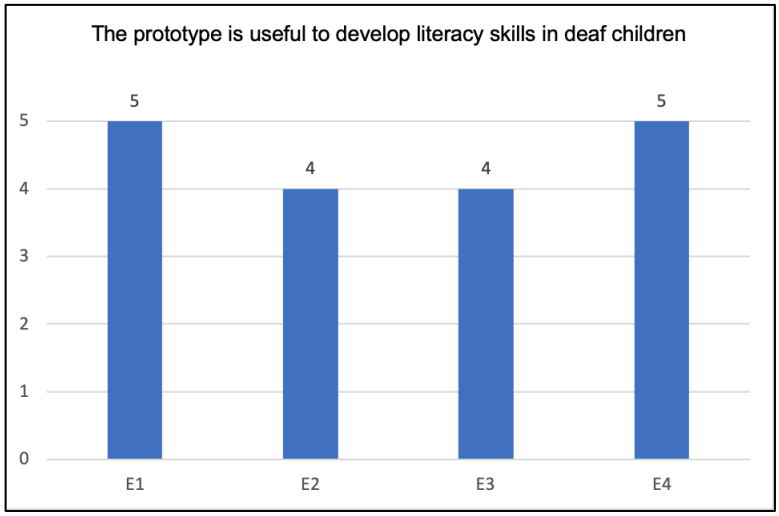


Figure 62. Usefulness of the prototype to develop literacy skills.

All educators (E1 to E4) rated the prototype (5-Likert scale) in terms of usefulness to develop literacy skills. The average rate is 4.5 out of 5.

The prototype is useful to promote collaborative learning (1 to 5)

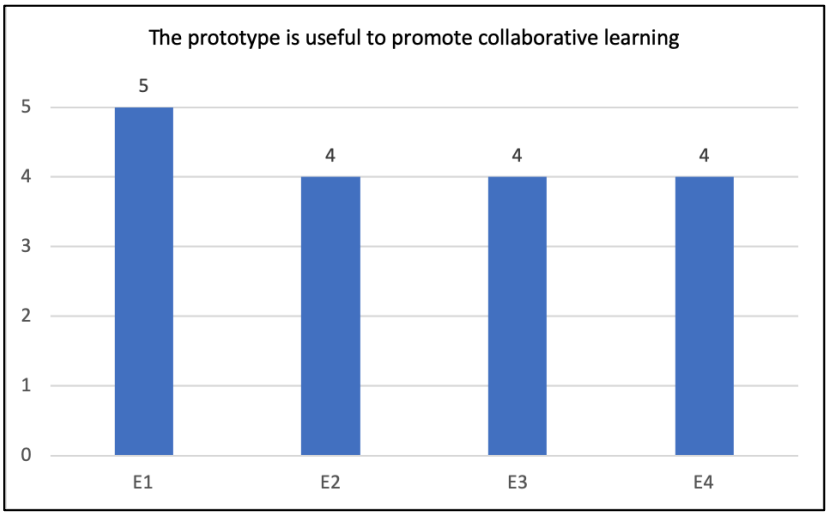


Figure 63. Usefulness of the prototype to promote collaborative learning.

All educators (E1 to E4) rated the prototype (5-Likert scale) in terms of usefulness to promote collaborative learning. The average rate is 4.25 out of 5.

Discussion

The questions asked aimed to find out how educators perceive this kind of technology and how useful they think it could be to promote collaborative learning among their pupils and support their teaching process.

All educators have a great impression of the work done with the prototype. They all think it is a good way to make use of technology in the classroom and see it as a resource to improve their teaching process. Unfortunately, there is a lot more to be done in order to have a complete application to support all learning goals (for a given grade), but according to the results of all the evaluations done, we are on the right track to get there.

They do think that the complete version of the prototype could help deaf children to develop literacy skills and promote collaborative learning among them.

Chapter 7

Conclusions and Future Work

The proposed framework makes it easy to break down the activities of every stage and adapt it to a particular set of learning goals/strategies to develop literacy skills for children with different abilities such as deaf children. The adaptation made in this research shows that the DesignABILITY framework is not a general-purpose framework, instead, it is a modular approach that can be transformed according to the final users' needs. An experts' evaluation of the framework is shown in this document, 26 researchers from different fields (HCI, design and software development) took the survey and the results demonstrate how promising this proposal is for addressing accessibility in the development of educational tools. All the recommendations given by the researchers in such evaluation were taken into account for the improvement of the framework.

For the adaptation of the framework (Deaf+literacy), the "Design for Engaged Learning" stage proposes a storytelling and collaborative learning approach which could support literacy teaching to Deaf children by engaging children into learning through stories, teamwork and technology. The words storytelling and collaboration, when used in the same context, promise to provide social, creative and fun aspects of learning as stated in [108]. Both strategies were successfully implemented in a prototype along with some learning goals and literacy teaching strategies like Fitzgerald Key. The evaluations made with children show that the framework does provide the necessary guidelines and steps to integrate these strategies in an educational tool aimed at deaf children.

During the review of the literature on storytelling [24] and collaborative learning (CL) [20] to support literacy teaching, it was found that there is a lack of research regarding the use of these two strategies for the education of Deaf children. Fortunately, the results of the studies that made use of any of these strategies on developing reading and writing skills, show the effectiveness of using technology with one or both approaches.

The new framework proposed in this research, and its adaptation for literacy, contributes to the design of educational/interactive technology for deaf people while making them part of the design process and taking into account their particular needs. This enables a better application of technology to education and consequently a better learning experience. The adaptation of the framework also gives specific details on how to structure collaborative learning and storytelling activities with/for deaf children during the design of an educational tool, which is not found in current HCI literature. Finally, this proposal suggests principles for experts' reviews to evaluate CL and also the tool aimed at deaf children (some of these principles are the result of our previous work with deaf children). Specific evaluation methods that can be used with deaf children are suggested to evaluate the UX of the designed tool.

Teachers from the institutions we worked with, expressed their joy about this study because they mentioned the traditional way to use storytelling with existing stories was limiting their work since it is not easy to find new books with different stories that are appropriate for deaf children, besides, it implies to keep buying this material which is not possible due to the lack of resources in the institutions we worked with. With this new approach, they can create all kind of stories through children's imagination. They also regret that there are not applications to be used in the institution, either because some of them are licensed or do not work in the old computers they have, that is why they requested a copy of the app which will be updated to include more game and learning mechanics, as well as more positive interdependences.

The use of technology can be a game-changer in the classroom, it was amazing to see how the same activity changed the mood of the students just by modifying the way to do it, from physical cards to digital ones. The use of technology as a resource in the classroom allows to collect data instantly and rewards students for their achievements as we did in one of the case studies. Although, these strategies where ICTs are

involved, may have an undesired result if they, or their content, are not used properly. In one of the case studies, students were shown the time taken to arrange a set of cards to create a story, unfortunately, students perceived this as a time to be beaten, so they continued using the tool, but they were not thinking about creating a story, instead, they were trying to order the cards as fast as possible to reduce the time stamp. This distorted the purpose of the activity which was to think about a story, so proper game and learning mechanics must be chosen during the design of a system that is supposed to support the teaching/learning processes.

It is important to mention that it is necessary to structure activities to convey a real collaboration, due to just making a group of people work around a task does not guarantee real collaboration and participation. As part of this research, the design of activities where aspects like positive interdependence, equal participation and individual accountability (fundamental aspects of collaborative learning processes) can be integrated along with the storytelling process through the CollabABILITY cards/templates. These cards/templates were validated by both, designers and educators, and the results during the design of collaborative learning activities demonstrate how useful these cards are, even for teachers who want to implement a CL strategy with the use of available technology in the classroom.

During the design process of the framework, and more specifically during the design of the storytelling approach, it is important to highlight that paper prototyping was an inexpensive and easy way to collect useful information for a later digital approach to create interactive storytelling (IS). The first case studies for this kind of activities did not make use of technology and it was a funny and interesting way to engage children into storytelling, on the other hand, a later case study did involve the use of technology and the results showed that the information gathered in case studies with paper prototyping was necessary to achieve a usable, accessible and engaging software-based application for IS. An interactive storytelling activity mediated by computers demonstrated to engage and motivate children in literacy learning. The process carried out in this study (from paper prototype to high-fidelity prototype) is recommended to guarantee a good design as children are involved during the whole process.

During the design of the GUI-DG guidelines, some existing mobile apps were reviewed and the existing gaps identified during the document review process, show that most

of the applications that are aimed at deaf children have been developed without taking into account their specific needs, in addition to the content that is shown, it is not oriented to teaching or reinforcement of learning, since they mostly show images and text, without this representing any meaning for the children.

The qualitative research process carried out during the design of the GUI-DG helped to identify the needs of deaf children in terms of the GUI design requirements of mobile applications aimed at these children. Through the recommendations of experts, observation of the interaction of the case studies with mobile applications and review of related works, the needs of deaf children were identified, and it was evident the importance of the design of inclusive tools, this can be seen in the notable lack of available mobile applications aimed at deaf children, especially in other languages different from English.

The DesignABILITY framework was designed for developers and designers of software-based applications who wish to develop applications/games for deaf children, which allows them to cover the needs of these children and take advantage of their abilities. Integrating storytelling and collaborative learning strategies is easier through this framework, which is a remarkable contribution of this research.

Collaborative learning strategies have been proven to promote different skills in learners, but its implementation is not easy, even with technology as a mediator. Tools should be designed taking into account the differences between learners, especially those with some type of disability. By creating systems with the DesignABILITY framework that support CSCL, children with disabilities (deafness in this study) may have the opportunity to collaborate not just with other deaf peers, but also with normal-hearing children.

For future work, the DesignABILITY framework will be adapted to support teaching to children with other disabilities like blindness, autism or with cognitive impairments. This is already being explored with the Institution of Deaf and Blind Children and Tobias Emmanuel Institution in Cali (Colombia). It is also important to adapt the framework for the development of other skills different from literacy and other areas of knowledge, like maths or science.

The developed prototype will be completed by adding more levels (learning activities) to support teaching of more learning goals. This completed version will be tested again with deaf children from Popayán and Cali in Colombia. The support of other languages (English, Portuguese, American Sign Language, British Sign Language, Brazilian Sign Language and Portuguese Sign Language) is necessary in order to provide a multi-language tool that supports literacy teaching to deaf children from other countries and cultures.

More prototypes will be also designed using the DesignABILITY framework along with emerging technologies, this includes hardware-based systems that make use of sensors and geolocation to provide an experience beyond the digital world. Augmented reality, the Internet of Toys and artificial intelligence will be also explored to deliver other kinds of experiences for deaf users.

Since one of the key elements of the DesignABILITY framework is involving deaf users during the design process of an educational tool, it could be adapted to integrate other design approaches such as Value Sensitive Design (VSD) considering human principles and standards when planning technology.

Chapter 8

Results

8.1 Publications

During this research a series of papers have been published in journals and as proceedings of different international conferences.

1. **Flórez-Aristizábal, L.** and Collazos, C. *Metodología para el desarrollo de aplicaciones interactivas móviles desde un enfoque de diseño centrado en el usuario para la enseñanza de la lectura a niños sordos*. XI Congreso Colombiano de Computación, Popayán, Colombia, 2016.

2. Cano, S; Collazos C.; **Flórez-Aristizábal, L.** and Moreira F. *Augmentative and alternative communication in the literacy teaching for deaf children.* 19th International Conference of Human-Computer Interaction, Vancouver, Canada, 2017.

3. **Flórez-Aristizábal, L.**; Cano, S. and Collazos, C. *Using storytelling to support the education of deaf children: A systematic literature review*. 19th International Conference of Human-Computer Interaction, Vancouver, Canada, 2017.

4. Cano, S; Collazos, C.; **Flórez-Aristizábal, L.**; González, C.; and Moreira, F. *Assessing user experience for serious games in auditory-verbal therapy for*

children with cochlear implant. 5th World Conference on Information Systems and Technologies, Madeira, Portugal, 2017.

5. **Flórez-Aristizábal, L.**; Cano, S.; Vesga, L. and Collazos, C. *Towards the design of interactive storytelling to support literacy teaching for deaf children*. In HCI for children with disabilities, Human-Computer Interaction Systems, Springer, 2017.

6. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Solano A. and Slegers, K. *Collaborative learning as educational strategy for deaf children: a systematic literature review*. XVIII International Conference on Human Computer Interaction, Cancún, México, 2017.

7. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Moreira, F.; Alghazzawi, D. and Fardoun, H. *Tools and methods applied in interactive systems to evaluate the user experience with deaf/hard of hearing children*. 5th International Conference on Technological Ecosystems for Enhancing Multiculturality, Cádiz, Spain, 2017.

8. Cano, S.; Collazos, C.; **Flórez-Aristizábal, L.**; González, C. and Moreira, F. *Towards a methodology for user experience assessment of serious games with children with cochlear implants*. Telematics and Informatics, Vol. 35, No. 4, pp. 993-1004, 2018.

9. Cano, S.; Collazos, C.; **Flórez-Aristizábal, L.**; Moreira, F.; Peñeñory, V. and Agredo V. *Designing collaborative strategies supporting literacy skills in children with cochlear implants using serious games*. World Conference on Information Systems and Technologies, Nápoles, Italia, 2018.

10. Enríquez, L.; Noguera, E.; **Flórez-Aristizábal, L.**; Collazos, C.; Daza, G.; Cano, S.; Alghazzawi, D. and Fardoun, H. *Graphical user interface design guide for mobile applications aimed at deaf children*. International Conference on Learning and Collaboration Technologies, Las Vegas, United States, 2018.

11. **Flórez-Aristizábal, L.**; Cano, S.; Manresa, C. and Collazos, C. *Towards a computer-supported collaborative learning approach for deaf children*. Second

International Conference on Accessibility, Inclusion and Rehabilitation using Information Technologies, Palma de Mallorca, Spain, 2018.

12. Cano, S.; **Flórez-Aristizábal, L.**; Collazos, C.; Fardoun, H. and Alghazzawi, D. *Designing interactive experiences for children with cochlear implant*. Sensors, Vol. 18, No. 7, 2018.

13. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Benavides, F.; Moreira, F. and Fardoun, H. *Digital transformation to support literacy teaching to deaf Children: From storytelling to digital interactive storytelling*. Telematics & Informatics, Vol. 38, pp. 87-99, 2019.

14. **Flórez-Aristizábal, L.**; Cano, S.; Collazos, C.; Solano, A. and Brewster S. *DesignABILITY: Framework for the design of accessible interactive tools to support teaching to children with disabilities*. CHI Conference on Human Factors in Computing Systems, Glasgow, United Kingdom, 2019.

8.2 Conferences

The results of this research were also shared through conferences. The following list shows the events where we participated with at least on accepted paper.

1. XI Congreso Colombiano de Computación, Popayán, Colombia, 2016.
2. 19th International Conference of Human-Computer Interaction, Vancouver, Canada, 2017.
3. 5th World Conference on Information Systems and Technologies, Madeira, Portugal, 2017.
4. XVIII International Conference on Human Computer Interaction, Cancún, México, 2017.
5. 5th International Conference on Technological Ecosystems for Enhancing Multiculturality, Cádiz, Spain, 2017.
6. World Conference on Information Systems and Technologies, Nápoles, Italia, 2018.

7. 20th International Conference of Human-Computer Interaction, Las Vegas, United Stated, 2018.

8. Second International Conference on Accessibility, Inclusion and Rehabilitation using Information Technologies, Palma de Mallorca, Spain, 2018.

9. CHI 2019. Conference on Human Factors in Computing Systems, Glasgow, United Kingdom, 2019.

8.3 Awards

The impact of this research was acknowledged by ELSEVIER with the ATLAS award. Each month, this award showcases research that could significantly impact people's lives around the world or has already done so. On April 2019, our paper *Digital transformation to support literacy teaching to deaf Children: From storytelling to digital interactive storytelling* published in a high impact journal (Telematics & Informatics – Q1) was selected to be worthy of the Atlas award which was given in a ceremony at Universidade Portucalense in Porto (Portugal).

Figure 64. Atlas Award by Elsevier.

8.4 Projects and Thesis Supervised/Evaluated

As part of the work done during this research, one undergraduate project was supervised, one undergraduate project was evaluated as well as one master thesis

1. **Undergraduate project (supervisor):** “Guía de diseño de interfaces gráficas de usuario para aplicaciones móviles dirigidas a niños sordos”. 2018. University of Cauca. **Students:** Leidi Jasmin Enriquez Muñoz and Edilson Yamid Noguera Zúñiga

2. **Undergraduate project (evaluator):** “Diseño de un MOOC mobile como estrategia para promover una colaboración efectiva en el aprendizaje”. 2018. University of Cauca.**Student:** José Manuel David

3. **Master thesis (Evaluator):** Análisis de efectividad y la diversión atributos de la gamificación a través de métricas de evaluación de experiencias de juego pervasivas. 2019. University of Cauca. **Student:** Jhonny Paul Taborda Mosquera

8.5 International Research Stays

1. Stay at KU LEUVEN with MINTLAB research group. From February 4th to April 4th, 2017. Leuven – Belgium.

2. Stay at Universidad Complutense de Madrid (UCM) with e-UCM research group. From Abril 15th to June 30th, 2017. Madrid – Spain.

3. Stay at Universitat de les Illes Balears (UIB). From April 30th to May 20th, 2018. Palma – Spain.

4. Stay at University of Glasgow (UoG) with GIST research group. From June 18th to August 31st, 2018. Glasgow – Scotland.

References

[1] School of Education, Johns Hopkins. 2018. Education Technology Resources.

[2] Kumar, Raju. 2008. Convergence of ICT and Education. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering* 2, 4: 300–303.

[3] Nganji, Julius T. and Nggada, Shawulu H. 2011. Disability-Aware Software Engineering for Improved System Accessibility and Usability. *International Journal of Software Engineering and its Applications* 5, 3: 47–62.

[4] Nganji, Julius T. 2012. Designing Disability-Aware E- Learning Systems : Disabled Students ' Recommendations. *International Journal of Advanced Science and Technology* 48: 61–70. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.642.1224&rep=rep1&type=pdf

[5] Granollers, Toni, Lorés, Vidal, Montse, Sendin and Perdrix, Ferran. 2005. Integración de la IPO y la ingeniería del software: MPIu+a. *III Taller En Sistemas Hipermedia Colaborativos Y Adaptativos*.

[6] Börjesson, Peter, Barendregt, Wolmet, Eriksson, Eva and Torgersson, Olof. 2015. Designing Technology for and with Developmentally Diverse Children: a Systematic Literature Review. *IDC '15 Proceedings of the 14th International Conference on Interaction Design and Children*: 79.

[7] Zimmermann, Gottfried and Vanderheiden, Gregg. 2008. Accessible design and testing in the application development process: Considerations for an integrated approach. *Universal Access in the Information Society* 7, 1–2: 117–128. https://doi.org/10.1007/s10209-007-0108-6

[8] Abud, Antonieta. 2009. MeISE: Metodología de Ingeniería de Software Educativo. *Revista Internacional de Educación en Ingeniería* 2, 1: 1–9. Retrieved from http://www.academia.edu/6834077/P_á_g_i_n_a_MeISE_Metodología_de_Ingeniería_de_Software_Educativo

[9] Flórez Aristizábal, Leandro, Cano, Sandra, Collazos, Cesar A., Moreira, Fernando, Alghazzawi, Daniyal M. and Fardoun, Habib. 2017. Tools and Methods Applied in Interactive Systems to Evaluate the User Experience with Deaf/Hard of Hearing Children. *TEEM '17*. https://doi.org/10.1145/3144826.3145365

[10] Cano, S., Collazos, C.A., Flórez Aristizábal, L., Gonzalez, C.S. and Moreira, F. 2017. *Assessing user experience for serious games in auditory-verbal therapy*

for children with cochlear implant. https://doi.org/10.1007/978-3-319-56538-5_86

[11] Tang, Gladys. 2017. Sign Bilingualism in Deaf Education : From Deaf Schools to Regular School Settings. *Bilingual and Multilingual Education, Encyclopedia of Language and Education*: 191–203. https://doi.org/10.1007/978-3-319-02258-1

[12] Guimarães, Cayley, Pereira, Moisés H.R. and Fernandes, Sueli. 2015. A Framework to Inform Design of Learning Objects for Teaching Written Portuguese (2nd Language) to Deaf Children Via Sign Language (1st Language). In *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2–10. https://doi.org/10.1109/HICSS.2015.12

[13] Mellon, Nancy K., Niparko, John. K., Rathmann, Christian., Mathur, Gaurav., Humphries, Tom., Napoli, Donna. J., Handley, Theresa., Scambler, Sasha. and Lantos, John. D. 2015. Should All Deaf Children Learn Sign Language? *Pediatrics* 136, 1: 170–176. https://doi.org/10.1542/peds.2014-1632

[14] Klaudia, Krammer. 2013. The Benefits of Sign Language for Deaf Children with and without Cochlear Implant(s). *European Scientific Journal* 4: 341–349.

[15] World Federation of the Deaf. Sign Language. Retrieved September 1, 2016 from https://wfdeaf.org/human-rights/crpd/sign-language

[16] Michaud, Ln and McCoy, Kf. 2000. An intelligent tutoring system for deaf learners of written English. In *Proceedings of the fourth international ACM conference on Assistive technologies*, 92–100. https://doi.org/10.1145/354324.354348

[17] World Federation of the Deaf. 2011. Bilingualism as a basic human right for deaf children in education. Retrieved September 1, 2016 from https://wfdeaf.org/news/bilingualism-as-a-basic-human-right-for-deaf-children-in-education

[18] Flórez-Aristizábal, Leandro, Cano, Sandra, Collazos, César A., Moreira, Fernando, Benavides, Fernando and Fardoun, Habib M. 2019. Digital transformation to support literacy teaching to deaf Children: From storytelling to digital interactive storytelling. *Telematics and Informatics*, May: 87–99. https://doi.org/10.1016/j.tele.2018.09.002

[19] Laal, Marjan. 2013. Positive Interdependence in Collaborative Learning. *Procedia - Social and Behavioral Sciences* 93: 1433–1437. https://doi.org/10.1016/j.sbspro.2013.10.058

[20] Flórez Aristizábal, Leandro, Cano, Sandra, Collazos, Cesar Alberto, Solano, Andrés and Slegers, Karin. 2017. Collaborative learning as educational strategy for deaf children: A systematic literature review. In *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3123818.3123830

[21] Mich, Ornella. 2011. E-drawings as an evaluation method with deaf children. *ASSETS '11 The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*: 239–240. https://doi.org/10.1145/2049536.2049586

[22] Guimarães, Cayley, Antunes, Diego R., García, Laura S., Pires Guedes, André L. and Fernandes, Sueli. 2012. Conceptual meta-environment for deaf children literacy challenge: How to design effective artifacts for bilingualism construction.

Proceedings - International Conference on Research Challenges in Information Science: 12. https://doi.org/10.1109/RCIS.2012.6240426

[23] Kitchenham, Barbara and Charters, Stuart. 2007. *Guidelines for performing Systematic Literature Reviews in Software Engineering*.

[24] Flórez Aristizábal, Leandro, Cano, Sandra and Collazos, César. 2017. Using Storytelling to Support the Education of Deaf Children: A Systematic Literature Review. In *Design, User Experience, and Usability: Understanding Users and Contexts: 6th International Conference, DUXU 2017, Held as Part of HCI International 2017, Vancouver, BC, Canada, July 9-14, 2017, Proceedings, Part III*, Aaron Marcus and Wentao Wang (eds.). Springer International Publishing, Cham, 371–382. https://doi.org/10.1007/978-3-319-58640-3_26

[25] Colombia, Ministry of Health. 1993. Resolución Número 8430 de 1993. 19. Retrieved April 10, 2017 from https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/DE/DIJ/RESOLUCION-8430-DE-1993.PDF

[26] Alsumait, Asmaa, Faisal, Maha and Banian, Sara. 2015. Improving Literacy for Deaf Arab Children Using Interactive Storytelling. In *iiWAS '15 Proceedings of the 17th International Conference on Information Integration and Web-based Applications & Services*, 5.

[27] Malzkuhn, Melissa and Herzig, Melissa. 2013. Bilingual Storybook App Designed for Deaf Children Based on Research Principles. In *Interaction Design and Children*, 499–502.

[28] Egusa, Ryohei, Sakai, Tsugunosuke, Tamaki, Haruya, Kusunoki, Fusako, Namatame, Miki, Mizoguchi, Hiroshi and Inagaki, Shigenori. 2016. Preparatory development of a collaborative / interactive learning game using bodily movements for deaf children. *IDC '16*: 649–653. https://doi.org/10.1145/2930674.2936011

[29] Egusa, Ryohei, Sakai, Tsugunosuke and Tamaki, Haruya. 2016. Designing a Collaborative Interaction Experience for a Puppet Show System for Hearing-Impaired Children. 2: 424–432. https://doi.org/10.1007/978-3-319-41267-2

[30] Collazos, César A., Guerrero, Luis A., Pino, José A., Renzi, Stefano, Klobas, Jane, Ortega, Manuel, Redondo, Miguel A. and Bravo, Crescencio. 2007. Evaluating Collaborative Learning Processes Using System-based Measurement. *Educational Technology and Society* 10, 3: 257–274. https://doi.org/10.1126/science.1168450

[31] Bueno, F. Javier, Alonso, M. Goretti and del Castillo, J. Raul Fernandez. 2007. Assisting lecturers to adapt e-learning content for deaf students. *ACM SIGCSE Bulletin* 39: 335. https://doi.org/10.1145/1269900.1268903

[32] Flórez Aristizábal, Leandro, Cano, Sandra, Vesga Parra, Luz del Sol and Collazos, César A. 2017. Towards the Design of Interactive Storytelling to Support Literacy Teaching for Deaf Children. In *HCI for Children with Disabilities*, Josefina Guerrero-García, Juan Manuel González, Jaime Muñoz and César A. Collazos (eds.). Springer International Publishing, 115–126. https://doi.org/10.1007/978-3-319-55666-6_6

[33] Pretorius, E.J. 2002. Reading ability and academic performance in south africa: Are we fiddling while rome is burning? *Language Matters* 33, 1: 169–196.

https://doi.org/10.1080/10228190208566183
[34] Goldin-meadow, Susan and Mayberry, Rachel I. 2001. How Do Profoundly Deaf Children Learn to Read ? ∗. *LEARNING DISABILITIES RESEARCH & PRACTICE* 16, 4: 222–229. https://doi.org/10.1111/0938-8982.00022
[35] Riggs, Stephanie. 2016. “ Kanju ”: Integrating HCI to tell better stories in immersive environments. In *Proceeding SIGGRAPH International Conference on Computer Graphics and Interactive Techniques*.
[36] Riedl, Mark O. 2016. Computational Narrative Intelligence: A Human-Centered Goal for Artificial Intelligence. *CHI 2016 Workshop on Human-Centered Machine Learning*: 5. Retrieved from http://arxiv.org/abs/1602.06484
[37] Garzotto, Franca, Paolini, Paolo and Sabiescu, Amalia. 2010. Interactive storytelling for children. *Proceedings of the 9th International Conference on Interaction Design and Children IDC 10* 2, 1: 356. https://doi.org/10.1145/1810543.1810613
[38] Reyes, Agustín, Pich, Eva and García, Ma. Dolore. 2012. Digital Storytelling as a Pedagogical Tool within a Didactic Sequence in Foreign Language Teaching. *Digital Education review*, 22: 1–18.
[39] Peix Cruz, Susana. 2014. Carambuco : cuentos y actividades en lengua de signos. *Boletín de la asociación andaluza de bibliotecarios*, 107: 50–59.
[40] Beal-Alvarez, Jennifer. S. and Huston, Sandra. G. 2013. Emerging Evidence for Instructional Practice: Repeated Viewings of Sign Language Models. *Communication Disorders Quarterly* 35, 2: 93–102. https://doi.org/10.1177/1525740113514437
[41] Burke, Quinn and Kafai, Yasmin B. 2010. Programming & Storytelling: Opportunities for Learning About Coding & Composition. *Proceedings of the 9th International Conference on Interaction Design and Children - IDC ’10*: 348. https://doi.org/10.1145/1810543.1810611
[42] Moreno de León, Tomás Alfredo, Rangel, Liliana and De León, Esperanza. 2016. Promoviendo el desarrollo de la competencia lectora a través de cuentos con imágenes sin palabras en preescolar. *Revista Internacional de Educación Preescolar e Infantil* 2, 1: 49–64.
[43] Lissi, María Rosa, Svartholm, Kristina and González, Maribel. 2012. El Enfoque Bilingüe en la Educación de Sordos : sus implicancias para la enseñanza y aprendizaje de la lengua escrita. *Estudios Pedagógicos* 38, 2: 299–320. https://doi.org/10.4067/S0718-07052012000200019
[44] Prieto Soriano, Lyda Solange. 2016. La Pedagogía por Proyectos de Aula: una alternativa para enseñar castellano escrito a niños y niñas de primer ciclo. *Educação & Realidade* 41, 3: 789–806. Retrieved from http://www.scielo.br/scielo.php?script=sci_arttext&pid=S2175-62362016000300789&lang=pt
[45] National Storytelling Network. What is Storytelling? Retrieved September 1, 2016 from http://www.storynet.org/resources/whatisstorytelling.html
[46] Koenitz, Hartmut. 2016. Interactive Storytelling Paradigms and Representations : A Humanities-Based Perspective. 361–375. https://doi.org/10.1007/978-981-4560-52-8
[47] Alsumait, Asmaa and Al-Musawi, Zahraa S. 2013. Creative and innovative e-

learning using interactive storytelling. *International Journal of Pervasive Computing and Communications* 9, 3: 209–226. https://doi.org/10.1108/IJPCC-07-2013-0016

[48] Bottoni, Paolo, Borgia, Fabrizio, Buccarella, Daniel, Capuano, Daniele, De Marsico, Maria and Labella, Anna. 2013. Stories and signs in an e-learning environment for deaf people. *Universal Access in the Information Society* 12, 4: 369–386. https://doi.org/10.1007/s10209-012-0283-y

[49] Nations, United. 1994. *The Salamanca Statement and Framework for Action on Special Needs Education*. Salamanca.

[50] Domínguez, Ana. 2008. Educación para la inclusión de alumnos sordos. *Revista Latinoamericana de Educación Inclusiva* 3, 1: 45–61. Retrieved from http://www.rinace.net/rlei/numeros/vol3-num1/art4.pdf

[51] Bueno, F. Javier, Alonso, M. Goretti and del Castillo, J. Raul Fernandez. 2007. Assisting lecturers to adapt e-learning content for deaf students. In *ITiCSE '07 Proceedings of the 12th annual SIGCSE conference on Innovation and technology in computer science education*, 335–335. https://doi.org/10.1145/1269900.1268903

[52] Guerrero, Luis A., Mejías, Boris, Collazos, César A., Pino, José A. and Ochoa, Sergio F. 2003. Collaborative Learning and Creative Writing. *Proceedings of the First Latin American Web Congress*: 7.

[53] Bagheri, Shamsi, Rostami, Narges Pour, Pour Kivy, Soraya and Lahiji, Elham Raji. 2015. Collaborative Learning, Collaborative Teaching & Autonomy : A Survey Study on English as a Second/Foreign Language. 5, 3: 348–356.

[54] García, Ana, Basilotta, Verónica and López, Camino. 2014. ICT in Collaborative Learning in the Classrooms of Primary and Secondary Education. *Comunicar* 21, 42: 65–74.

[55] Buche, Mari W. 2013. Teaching Tip A Memory Game to Demonstrate the Power of Collaborative Efforts to Improve Team Performance. 24, 3: 167–176.

[56] Ruiz-muñoz, María Jesús and Ruiz-mora, Isabel. 2014. La recreación del universo profesional en el aula a través de técnicas de aprendizaje colaborativo : el Método del Caso y el Juego de Rol 1. 19: 223–234.

[57] Jenkins, Joseph R., Antil, Laurence R., Wayne, Susan K. and Vadasy, Patricia F. 2003. How Cooperative Learning Works for Special Education and Remedial Students. *Exceptional Children* 69, 3: 279–292. https://doi.org/10.1177/001440290306900302

[58] Antil, Laurence R., Jenkins, Joseph R., Wayne, Susan K. and Vadasy, Patricia F. 1998. Cooperative Learning: Prevalence, Conceptualizations, and the Relation between Research and Practice. *American Educational Research Journal* 35, 3: 419–454. https://doi.org/10.2307/1163443

[59] World Health Organization, World Health Organization and World Bank Group, World Bank Group. 2011. *WORLD REPORT ON DISABILITY*.

[60] Chowdhuri, Debabrata, Parel, Narendra and Maity, Amrita. 2012. Virtual Classroom for Deaf People. *2012 IEEE International Conference on Engineering Education: Innovative Practices and Future Trends (AICERA)*: 1–3. https://doi.org/10.1109/AICERA.2012.6306730

[61] Eh Phon, Danakorn Nincarean, Ali, Mohamad Bilal and Abd Halim, Noor

Dayana. 2014. Collaborative Augmented Reality in Education : A Review. *2014 International Conference on Teaching and Learning in Computing and Engineering Collaborative*: 78–83. https://doi.org/10.1109/LaTiCE.2014.23

[62] Klopfer, Eric, Perry, Judy, Squire, Kurt and Jan, Ming-fong. 2005. Collaborative Learning through Augmented Reality Role Playing. 311–315.

[63] Chen, Yu-chien. 2008. Peer Learning in an AR-based Learning Environment. *16th International Conference on Computers in Education*: 291–295.

[64] Freitas, Rubina and Campos, Pedro. 2008. SMART : a SysteM of Augmented Reality for Teaching 2nd Grade Students. *Proceeding of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction*: 27–30.

[65] Cadeñanes, Jonathan and González Arrieta, María Angélica. 2014. Augmented Reality : An Observational Study Considering the MuCy Model to Develop Communication Skills on Deaf Children. *IntelligenceLecture Notes in Artificial*: 233–240.

[66] Cadeñanes Garnica, Jorge Jonathan and González Arrieta, María Angélica. 2014. Augmented Reality Sign Language Teaching Model for Deaf Children. *Distributed Computing and Artificial Intelligence, 11th International Conference, Advances in Intelligent Systems and Computing*: 351–358. https://doi.org/10.1007/978-3-319-07593-8

[67] Cano, Sandra, Collazos, César A., Flórez Aristizábal, Leandro, Gonzalez, Carina S. and Moreira, Fernando. 2017. Assessing User Experience for Serious Games in Auditory-Verbal Therapy for children with Cochlear Implant. *Recent Advances in Information Systems and Technologies* 2: 861–871.

[68] State of Victoria (Department of Education and Training), S.O. V. 2013. Principles of Learning and Teaching P-12 Unpacked. Retrieved from http://www.education.vic.gov.au/school/teachers/support/Pages/unpacked12.aspx

[69] Danielson, Charlotte. 2013. *The Framework for Teaching- Evaluation Instrument*.

[70] Rigby, Scott and Ryan, Richard. 2007. The player experience of need satisfaction (PENS) model. *Immersyve Inc*: 1–22. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+Player+Experience+of+Need+Satisfaction+(+PENS+)#0

[71] Smeets, Ed. 2005. Does ICT contribute to powerful learning environments in primary education? *Computers and Education* 44, 3: 343–355. https://doi.org/10.1016/j.compedu.2004.04.003

[72] Falcinelli, Floriana and Laici, Chiara. 2011. *ICT in the Classroom: A new Learning Environment*. Simonelli Editore.

[73] Logogenia. 2016. Il metodo logogenia. Retrieved August 3, 2016 from http://www.logogenia.it/il-metodo-logogeniareg.html

[74] Fitzgerald, Edith. 1954. *Straight Language for the Deaf: A system of instruction for deaf children*. Volta Bureau, Washington D.C.

[75] Annetta, Leonard A. 2010. The “I’s” Have It: A Framework for Serious Educational Game Design. *Review of General Psychology* 14, 2: 105–112. https://doi.org/10.1037/a0018985

[76] Rooney, Pauline. 2012. A Theoretical Framework for Serious Game Design. *International Journal of Game-Based Learning* 2, 4: 41–60. https://doi.org/10.4018/ijgbl.2012100103

[77] Peláez Camarena, Gustavo and López Azamar, Bertha. 2006. Metodología Dinámica para el Desarrollo de Software Educativo (DESED). *UPIICSA*: 7–10. Retrieved from http://e-spacio.uned.es/fez/eserv.php?pid=bibliuned:1296&dsID=n05arias02.pdf

[78] Costa, António P., Loureiro, Maria J. and Reis, Luís P. 2010. Metodologia Híbrida de Desenvolvimento Centrado no Utilizador Aplicada ao Software Educativo. *Revista Ibérica de Sistemas e Tecnologias de Informação*, 6: 1–16.

[79] Newell, A..., Gregor, P., Morgan, M., Pullin, G. and Macaulay, C. 2011. User Sensitive Inclusive Design. *Universal Access in the Information Society* 10, 3: 235–243.

[80] Ladner, Richard E. 2015. Design for User Empowerment. *Interactions*: 6. https://doi.org/10.1145/2723869

[81] Wobbrock, Jacob O., Kane, Shaun K., Gajos, Krzysztof, Harada, Susumu and Froehlich, Jon. 2011. Ability-Based Design : Concept , Principles and Examples. *ACM Transactions on Accessible Computing*. https://doi.org/10.1145/1952383.1952384

[82] Guerrero-García, Josefina, González-Calleros, Juan Manuel and González, Claudia. 2017. FlowagileXML: An HCI-Agile Methodology to Develop Interactive Systems for Children with Disabilities. In *HCI for Children with Disabilities*. Springer, 1–28. https://doi.org/10.1007/978-3-319-55666-6_1

[83] Guerrero-García, Josefina. 2014. Evolutionary design of user interfaces for workflow information systems. *Science of Computer Programming* 86: 89–102.

[84] Alsumait, Asmaa and Fasial, Maha. 2018. CLTD: Collaborative learning tool for Deaf. *ACM International Conference Proceeding Series*, Marschark: 146–151. https://doi.org/10.1145/3282373.3282846

[85] Cano, Sandra P. 2016. Propuesta Metodológica para el Diseño de Juegos Serios para Niños con Implante Coclear. University of Cauca. Retrieved from http://www.unicauca.edu.co/doctoradoce/publicaciones/Monografia_Cano.pdf

[86] Cano, Sandra, Manresa-Yee, Cristina, Collazos, César A., Peñeñory, Victor and Varona, Javier. 2017. Interactive Systems Design Oriented to Children with Special Needs. In *HCI for Children with Disabilities*, Josefina Guerrero-García, Juan Manuel González, Jaime Muñoz and César A. Collazos (eds.). Springer International Publishing, 73–89. https://doi.org/10.1007/978-3-319-55666-6_4

[87] Alavesa, Paula and Zanni, Daniele. 2013. Combining storytelling tradition and pervasive gaming. *2013 5th International Conference on Games and Virtual Worlds for Serious Applications, VS-GAMES 2013*: 1–4. https://doi.org/10.1109/VS-GAMES.2013.6624224

[88] Chen Pichler, Deborah, Hochgesang, Julie A., Lillo-Martin, Diane, Müller de Quadros, Ronice and Reynolds, Wanette. 2016. Best Practices for Building a Bimodal/Bilingual Child Language Corpus. *Sign Language Studies*, January: 361–388. https://doi.org/http://dx.doi.org/10.1108/17506200710779521

[89] Lan, Yu-Feng and Huang, Shin-Ming. 2009. Designing an Efficient Collaborative Learning Model to Construct a Consensus Based on Binary Tree

Structure. *INC, IMS and IDC, 2009. NCM '09. Fifth International Joint Conference on*: 182–187. https://doi.org/10.1109/NCM.2009.98

[90] Cano, Sandra, Collazos, César A., Flórez Aristizabal, Leandro, Moreira, Fernando, Peñeñory, Victor M. and Agredo, Vanessa. 2018. Designing Collaborative Strategies Supporting Literacy Skills in Children with Cochlear Implants Using Serious Games. In *WorldCist' 18*, 1317–1326. https://doi.org/10.1007/978-3-319-77712-2_126

[91] Flórez-aristizábal, Leandro, Cano, Sandra and Brewster, Stephen. 2019. DesignABILITY : Framework for the Design of Accessible Interactive Tools to Support Teaching to Children with Disabilities. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*: 1–15.

[92] Johnson, David W. and Johnson, Roger. 1975. *Learning together and alone: Cooperation, competltion, and individualization*. Prentice Hall.

[93] Johnson, Roger and Johnson, David W. 1989. *Cooperation and Competition: Theory and Research*. Interaction Book Company.

[94] Johnson, David, Johnson, Roger and Smith, Karl. 1998. Active Learning: Cooperation in the College Classroom. *The Annual Report of Education Psychology in Japan*: 1–29. https://doi.org/10.5926/arepj1962.47.0_29

[95] Flórez Aristizábal, Leandro, Cano, Sandra, Manresa-Yee, Cristina and Collazos, César A. 2018. Towards a Computer-Supported Collaborative Learning Approach for Deaf Children. In *2018 Second International Conference on Accessibility, Inclusion and Rehabilitation using Information Technologies. AIRTech2018*, 11–12.

[96] Arnab, Sylvester, Freitas, Sara de, Bellotti, Francesco, Lim, Theodore, Louchart, Sandy, Gloria, Alessandro De, Berta, Riccardo and Suttie, Neil. 2015. Mapping Learning and Game Mechanics for Serious Games Analysis. *British Journal of Educational Technology* 46, 2: 21. https://doi.org/10.1111/bjet.12113

[97] André, Janaina and Tiradentes Souto, Virgínia. 2014. À procura de um framework para jogos colaborativos. In *Proceedings of SBGames 2014*, 185–192.

[98] Enriquez, Leidi J., Noguera, Edilson Y., Flórez Aristizábal, Leandro, Collazos, César A., Cano, Sandra, Alghazzawi, Daniyal M. and Fardoun, Habib. 2018. Graphical User Interface Design Guide for Mobile Applications Aimed at Deaf Children. *Lecture Notes in Computer Science* 10924: 58–72. https://doi.org/10.1007/978-3-319-91743-6

[99] Norman, Don. 2018. Focus on Results, Not on Perfect UX. *NN/g Nielsen Norman*. Retrieved August 2, 2018 from https://www.nngroup.com/videos/focus-results-not-perfect-ux-don-norman/

[100] Nielsen, Jakob. 2005. 10 Usability Heuristics for User Interface Design. *NN/g Nielsen Norman Group*. Retrieved August 3, 2018 from https://www.nngroup.com/articles/ten-usability-heuristics/

[101] Tognazzini, Bruce. 2014. First Principles of Interaction Design (Revised & Expanded). *Interaction Design Solutions for the Real World*.

[102] Cano, S., Collazos, C.A., Flórez Aristizábal, L., Gonzalez, C.S. and Moreira, F. 2017. Towards a methodology for user experience assessment of serious games with children with cochlear implants. *Telematics and Informatics*.

https://doi.org/10.1016/j.tele.2017.09.011
[103] Tondello, Gustavo F., Kappen, Dennis L., Mekler, Elisa, Ganaba, Marim and Nacke, Lennart. 2016. Heuristic Evaluation for Gameful Design. *CHI PLAY'16 Extended Abstracts*: 315–323. https://doi.org/10.1145/2968120.2987729
[104] Collazos, César A. 2003. UNA METODOLOGIA PARA EL APOYO COMPUTACIONAL DE LA EVALUACION Y MONITOREO EN AMBIENTES DE APRENDIZAJE COLABORATIVO. Universidad de Chile.
[105] Read, Janet C. and MacFarlane, Stuart. 2006. Using the fun toolkit and other survey methods to gather opinions in child computer interaction. *Proceeding of the 2006 conference on Interaction design and children - IDC '06*: 81–88. https://doi.org/10.1145/1139073.1139096
[106] Brooke, John. 2014. SUS: A "quick and dirty" usability scale. *Journal of Drugs in Dermatology* 13, 5: 7. https://doi.org/10.4236/9781618961020_0002
[107] Bangor, Aaron, Kortum, Philip T. and Miller, James T. 1996. An empirical evaluation of the system usability scale. *Usability Evaluation in industry*: 574–594. https://doi.org/10.1080/10447310802205776
[108] Göttel, Timo. 2011. Reviewing Children's Collaboration Practices in Storytelling Environments. *Proceedings of the 10th International Conference on Interaction Design and Children*, Idc: 153–156. https://doi.org/10.1145/1999030.1999049
[109] Herzig, Melissa and Malzkuhn, Melissa. 2015. Bilingual Storybook Apps: An Interactive Reading Experience for Children. *Odyssey Magazine*, 5.

Appendix A

Ethical Considerations

A.1 Association of Deaf People from Valle (ASORVAL) – Ethical Code

- Guarantee children and adolescents the necessary care and attention for their integral development, both physical and cognitive, relational, emotional, spiritual and ethical in accordance with the established care process of each modality.

- Prevent the occurrence of situations of abuse, discrimination, mistreatment, stigmatization or any action or omission against the fundamental rights of children and adolescents.

- Ensure the timely identification of situations that endanger the life and physical, emotional and mental integrity of children and adolescents you are in charge of, for as long as they are under your care or responsibility. In case of knowledge about possible abuse, you should inform the competent authority immediately.

- Have respect and reserve for the life history of the children and adolescents in charge, without exploring about it or trying to deepen specific information, that is outside contributing to the restoration of rights and that does not obey the best interests. The information recorded in these stories is restricted and must be kept under absolute reserve and confidentiality.

- Respect the privacy and the right to privacy of children and adolescents under your care.

- Establish a communication through healthy, assertive, kind and respectful messages to the children and adolescents in charge. In the case of indigenous children/adolescents, the ethnic approach in the section on differential approach of this document must be taken into account.

- Engage in the direct care of children and adolescents, without delegating their attention, or leaving them in charge of people who are not part of the mode of care, or the family, unless duly authorized by the administrative authority in charge.

- Share with children and adolescents, activities within the framework of respect, trust, empathy and good treatment. Establish relationships characterized by equity, justice and solidarity and non-discrimination.

- Assume a role of consideration and respect towards children and adolescents as subjects of rights and demand it equally from those who interact with them.

- Refrain from behaviors or expressions of discrimination, rejection, indifference, stigmatization or other treatment that affects the mental, emotional or physical health of children and adolescent.

The following are the actions that expose children and adolescents to non-observance, threat or violation of rights and are considered infringements of the ethical code:

a) Impose sanctions or punishments that attempt against physical or mental integrity and the development of the personality of children and adolescents.

b) Discriminate by race, sex, gender, religion, sexual orientation, physical, mental disability, or by any other condition.

c) Physical, verbal or psychological abuse or neglect in the care of children or adolescents.

d) Deprive children totally or partially of food or create delays in the meal schedules of children and adolescents under your responsibility or care.

e) Use in the preparation of food, ingredients that, prior to technical studies, the ICBF or administrative authority considers harmful to the health of children or adolescents.

f) Deprive of the supply of medications in accordance with those formulated, use medications whose date of expiration has been met or supply medications that have not been formulated by a doctor legally authorized for the exercise of the profession, to children and adolescents who are under your responsibility or care.

g) Not to carry out the necessary and pertinent steps in the timely provision of the health service when required by a child or adolescent under your responsibility or care.

h) Deny the provision of personal endowment (bed, mattress, bedding, clothing, toiletries, educational or recreational material, or provision according to the cultural practices of ethnic groups) to children or adolescents under your responsibility or supply inadequate equipment or in poor condition for its use.

i) Exclude children or adolescents from academic training or recreation programs, based on race, gender, sexual orientation, disability or any other discriminatory situation.

j) Deprive children or adolescents the right to have visitors or to communicate, with family or relatives, except in cases in which the competent administrative authority has justified it.

k) Permit and tolerate acts of abuse or harassment among children and adolescents, who interact in the different programs.

l) Deliberately omitting the complaint or communication of acts of abuse, harassment or sexual abuse of children or adolescents before the competent authority or authorities. Likewise, not taking any action to protect children or adolescents against such abuses.

m) Use children or adolescents for the purpose of economic exploitation or in jobs that threaten their physical and emotional health or personal integrity.

n) Failure to comply with safety and disaster prevention norms or any risk to the health and integrity of children or adolescents.

o) Failure to comply with safety norms in the transport of children or adolescents, in accordance with the provisions of the traffic code and other rules related to school transportation.

p) Give way out of the care process or suspend the attention of children or adolescents, without the authorization of the defense interdisciplinary technical team of family or of the competent authority in charge of the case.

q) Hide, delay or partially deliver to the ICBF the information about children or adolescents, which would eventually lead to a change of measure or decision making in the framework of the process of attention.

r) Not having the documents established by the ICBF and the health sector or performing inappropriate practices.

A.2 Consent Form

I agree to allow my child to participate in the usability study conducted by researcher Leandro Flórez Aristizábal, Ph.D. student at the University of Cauca.

I understand and allow the video recording of the activity by Leandro Flórez, bearing in mind that my child's face will not appear in such material. My child's identity will remain completely anonymous and that the collected data will be used for research purposes only.

I understand that the material obtained (photos and video) will be destroyed once the data is analyzed by the researcher.

Participation in this study is voluntary and I agree to let Leandro Flórez or teacher in charge know about any doubts or concerns that my child or I might have about the activity to be carried out.

Please sign below stating that you have read and understood the information on this form and that any questions you have had about this study have been answered

Date:_____

Name of child: _____

Child's parent or representative name: _____

Signature: _____

Thanks!

I appreciate your participation.

A.3 Consent Form (Signed)

Investigador: Leandro Flórez Aristizábal
Est. Doctorado de la Universidad del Cauca
Docente Investigador de la Institución Universitaria Antonio José Camacho

Formato de consentimiento

Acepto que mi hijo participe en el estudio de usabilidad realizado por el investigador Leandro Flórez Aristizábal, estudiante de doctorado de la Universidad del Cauca.

Entiendo y permito la grabación de video de la actividad por parte de Leandro Flórez, teniendo en cuenta que el rostro de mi hijo no aparecerá en dicho material. La identidad de mi hijo permanecerá completamente anónima y que los datos recolectados serán usados únicamente con propósitos investigativos.

Entiendo que el material obtenido (fotos y video) será destruido una vez los datos sean analizados por parte del investigador.

La participación en este estudio es voluntaria y acepto dar a conocer a Leandro Flórez o docente encargado, cualquier duda o preocupación que mi hijo o yo podamos tener sobre la actividad a realizar.

Por favor firme a continuación indicando que ha leído y entiende la información en este formulario y que cualquier duda que haya tenido acerca de este estudio ha sido respondida

Fecha: Agosto 14 — 2019

Nombre del niño: [redacted]

Nombre del padre o madre: [redacted]

Firma: [redacted]

Gracias!

Agradecemos su participación.

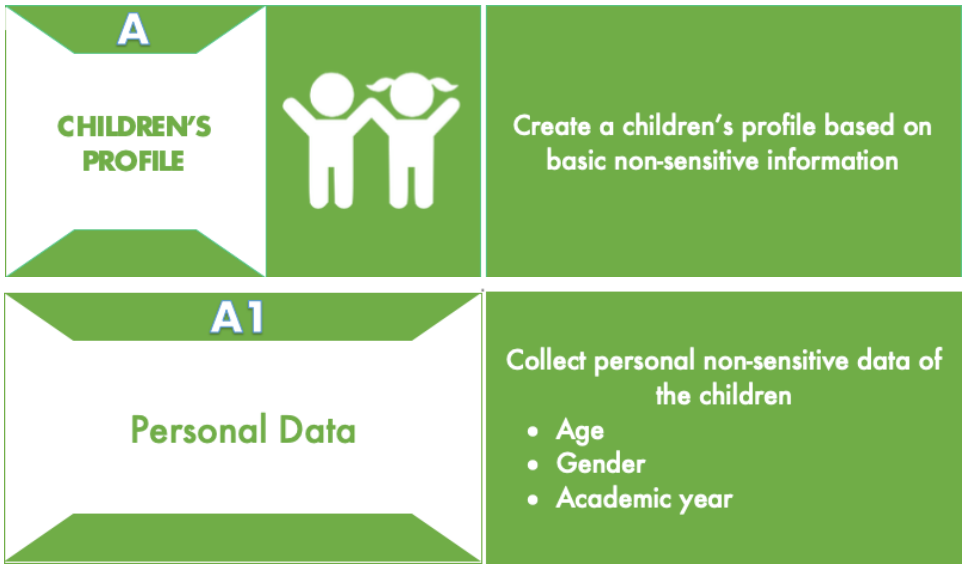
Appendix B

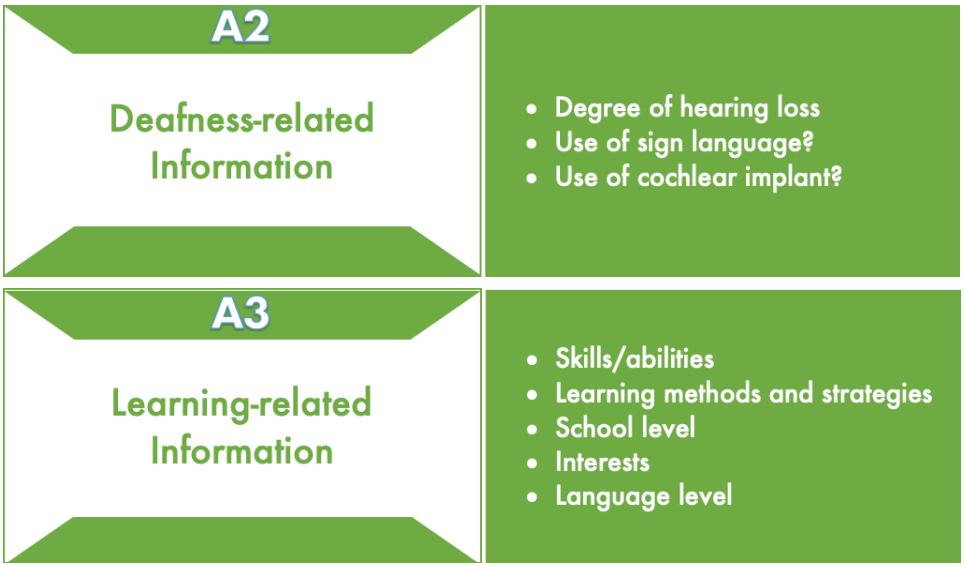
CollabABILITY CARDS/TEMPLATES

These cards/templates were designed to help users (teachers, designers, developers) design collaborative learning activities. The templates must be used in conjunction with the cards in order to understand in detail how a collaborative learning activity is structured.

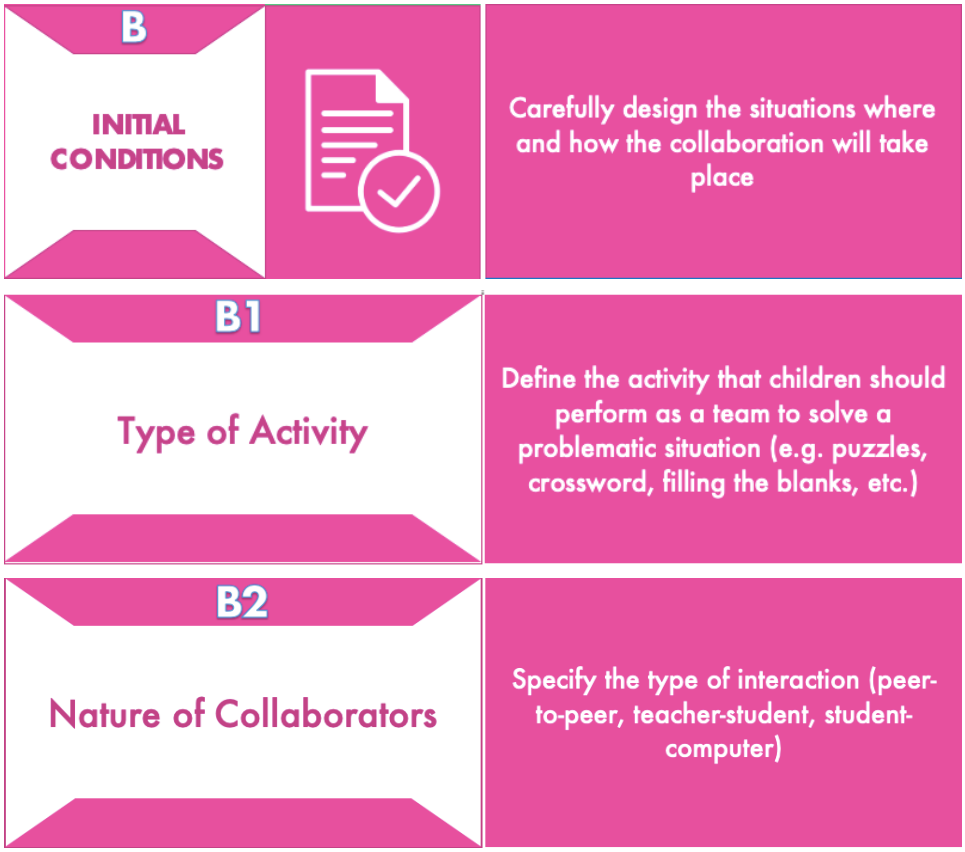
B.1 Cards

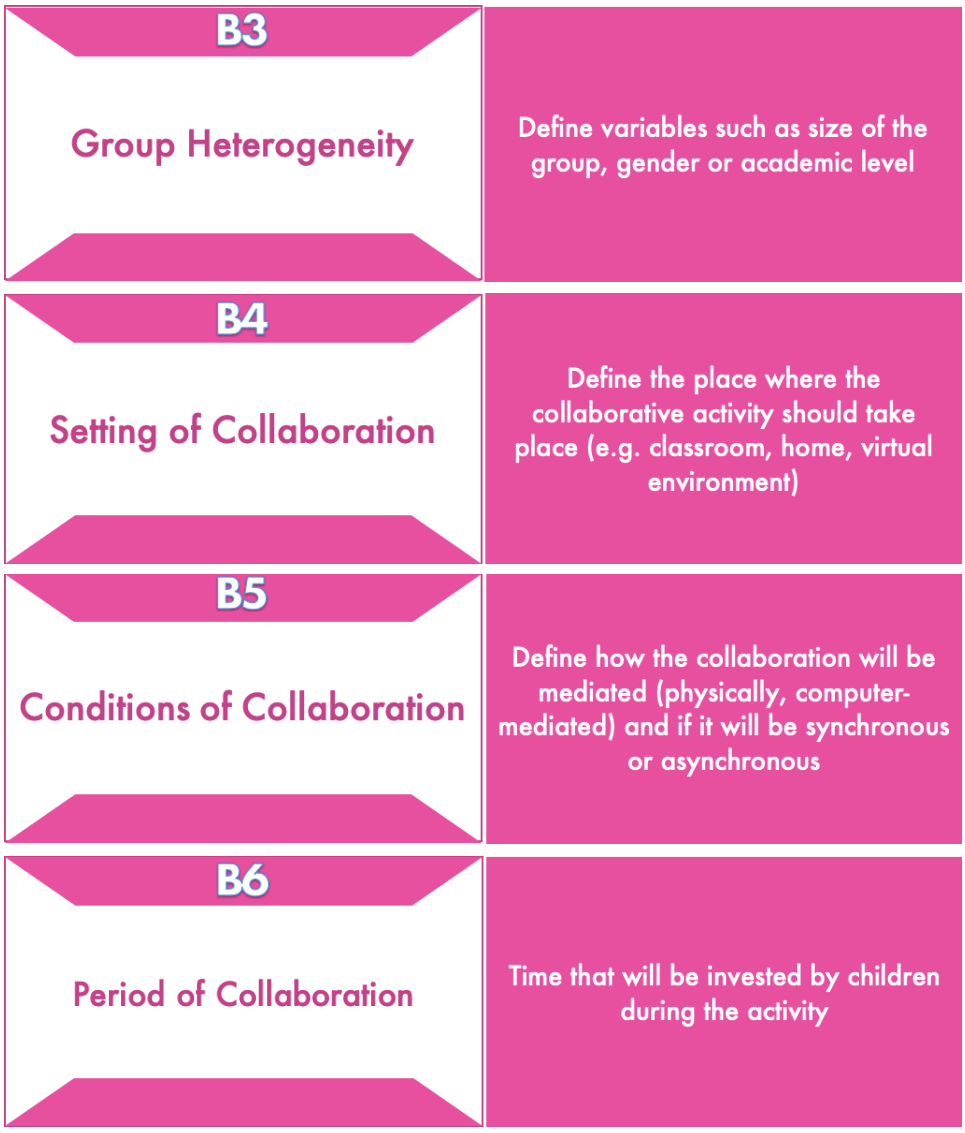
B.1.1 Children's Profile



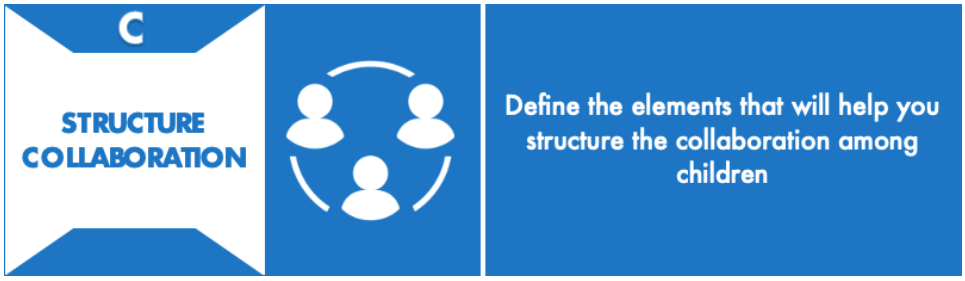


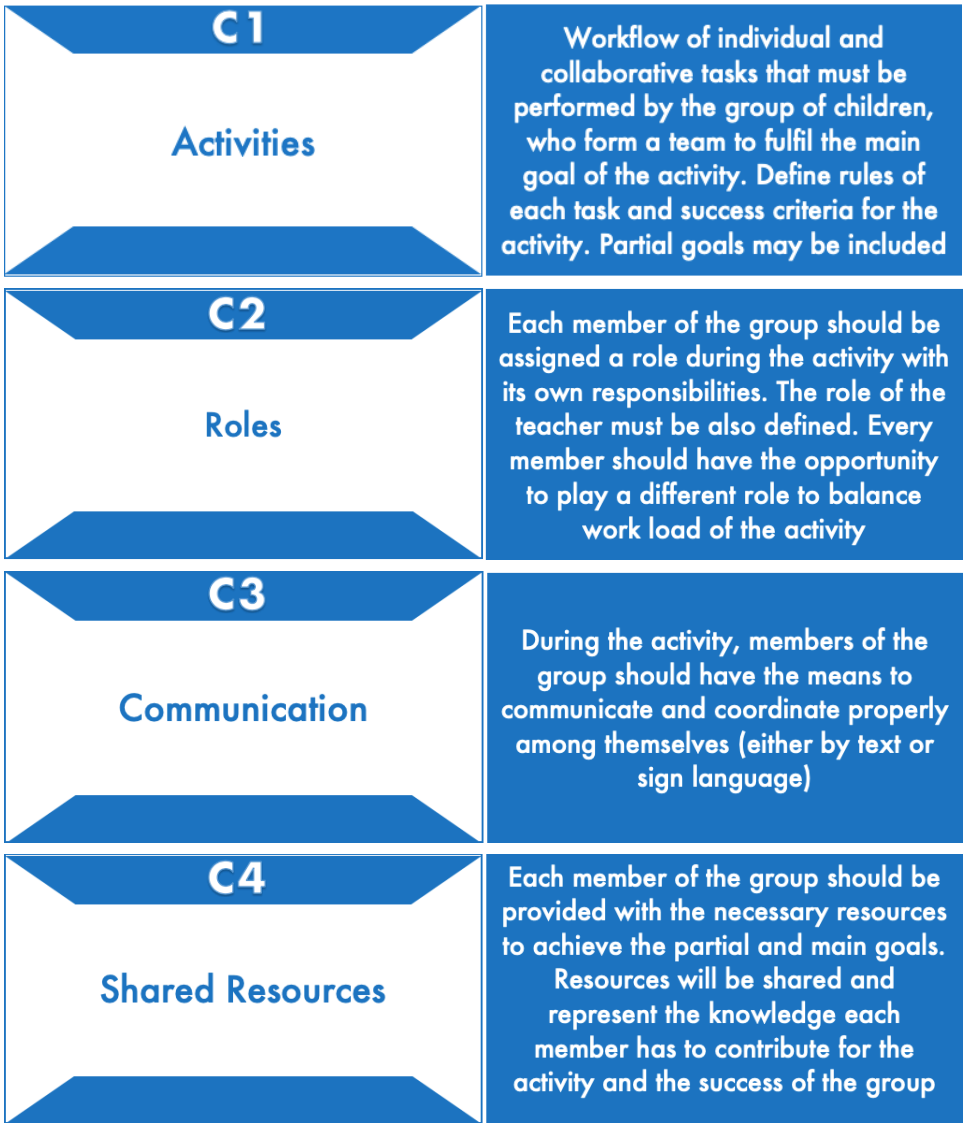
B.1.2 Initial Conditions





B.1.3 Structure Collaboration





B.1.4 Positive Interdependences – Game Mechanics – Learning Mechanics


D1
Positive Interdependences - PI
Game Mechanics - GM
Learning Mechanics - LM
Specify the types of PI that will assure true collaboration among students and encourage them to think as "we" instead of "me". GM (if necessary) and LM should also be specified in order to promote engagement and motivation in the learning activities
D2
Role
Combined roles and responsibilities are required for the group to fulfill a common task
GM – Role Playing: The player acts out the role of a fictional character
LM – Guidance: Provide guidance for learning
D3
Identity
Makes unity and cohesion, increasing friendship and affinity through a shared identity expressed upon a common logo, motto, name, flag or song
D4
Goal
It is the belief that each team member can reach his or her goals only when the goals of the group are met
GM – Progression: The success is granularly displayed and measured through the process of completing itemized tasks.
Example: a progress bar
LM – Assist: Help, promote or support an equal or companion
D4
Goal
It is the belief that each team member can reach his or her goals only when the goals of the group are met
GM – Goal: Sort of victory condition. Can be broad enough to encompass any method of winning, but here refers to game-specific goals.
Example: Checkmate of a king in chess
LM – Self - regulate: Focus attention on one's own progress and cannel this towards achieving a goal

D4 **Goal** It is the belief that each team member can reach his or her goals only when the goals of the group are met	**GM – Cooperative play:** Encourages players to work together to beat the game. There is little or no competition between players. Either the players win the game, or all players lose it **LM – Collaborative:** More than one learner participates in a common learning activity to pursue a common goal
D5 **Environmental** A physical environment that unifies the members of a group in which they work	**LM – Situate:** Position learning in the context in which it is to be applied **LM – Discover:** Gain understanding and solve problems by exploring/interacting with and manipulating the environment
D6 **Resource** Each individual has only a part of the information, resources or materials needed for his/her task. Therefore, the resources should be combined in order to accomplish the shared goal	**GM – Communal discovery:** An entire community is rallied to work together to solve a problem/challenge. Immensely viral, a lot of fun **GM – Cascading information:** Information should be released in the minimum possible snippets to gain the appropriate level of understanding at each point during a game narrative
D6 **Resource** Each individual has only a part of the information, resources or materials needed for his/her task. Therefore, the resources should be combined in order to accomplish the shared goal	**GM – Resource management:** The games' rules determine how players can increase, spend, or exchange their resources (tokens, money, etc.). The skillful management of resources under such rules allows players to influence the outcome of the game **LM – Connect:** Build knowledge by connecting information
D7 **Task** The organizing of the group works in a sequential pattern. When the actions of one group member have been accomplished, the next team member can proceed with his/her responsibilities	**GM – Turn:** Segment of the game set aside for certain actions to happen before moving on to the next turn, where the sequence of events can largely repeat **LM – Master:** Proceed step by step, completing learning of one aspect before tackling a more difficult/complex one
D8 **Outside Enemy** Putting groups in competition with each other. Group members feel interdependent as they do their best to win the competition	**GM – Micro leader - boards:** The rankings of all individuals in a micro-set. Often great for distributed game dynamics where you want many micro-competitions or desire to induce loyalty. Example: Be the top scorers at Joe's bar this week and get a free appetizer

B.2 Templates

The following are the templates to be used along with each category of the cards.

CHILDREN'S PROFILE

PERSONAL DATA (See Card A1)

Number of children: _____ Ages: From _____ To _____

Number of boys: _____ Number of girls: _____

Academic year: _____ grade

DEAFNESS-RELATED INFORMATION (See Card A2)

Degree of hearing loss: ☐ Normal hearing ☐ Mild hearing loss
☐ Moderate hearing loss ☐ Severe hearing loss
☐ Severe-to-profound hearing loss ☐ Profound hearing loss

Communication: ☐ Sign language ☐ Lip reading
☐ Oral

☐ Hearing aid ☐ Cochlear implant

LEARNING-RELATED INFORMATION (See Card A3)

Skills/abilities:

_____
_____
_____

Learning methods and strategies:

_____
_____

Children's interests:

_____
_____

Literacy level:

_____

INITIAL CONDITIONS

TYPE OF ACTIVITY (See Card B1)

_____
_____
_____

NATURE OF COLLABORATORS (See Card B2)

☐ Peer-to-peer ☐ Teacher student ☐ Student-computer

GROUP HETEROGENEITY (See Card B3)

Size: _____ children per group

Gender: ☐ Boys or Girls ☐ Mixed (Boys and girls)
Academic level: ☐ Same level ☐ Mixed (High and low level)

SETTING OF COLLABORATION (See Card B4)

☐ Classroom ☐ Home ☐ Virtual environment
☐ Other: _____

CONDITIONS OF COLLABORATION (See Card B5)

☐ Physically ☐ Computer-mediated

☐ Synchronous ☐ Asynchronous

PERIOD OF COLLABORATION (See Card B6)

The activity will last _____

STRUCTURE COLLABORATION

ACTIVITIES (See Card C1)

Main goal: _____
_____

Partial goals (optional): _____
_____
_____

Success criteria: _____
_____

Rules:
_____
_____
_____

Workflow:

1. _____
   _____
2. _____
   _____
3. _____
   _____
4. _____
   _____
5. _____
   _____
6. _____
   _____
7. _____
   _____
8. _____
   _____
9. _____
   _____
10. _____
    _____

Continue in the back if necessary

STRUCTURE COLLABORATION

ROLES (See Card C2)

Role 1: _____

Responsibilities:

_____
_____
_____

Role 2: _____

Responsibilities:

_____
_____
_____

Role 3: _____

Responsibilities:

_____
_____
_____

Teacher's role: _____

Responsibilities:

_____
_____
_____

COMMUNICATION (Among students and teacher) (See Card C3)

☐ Oral ☐ Sign language

☐ Lip-reading ☐ Text

STRUCTURE COLLABORATION

SHARED RESOURCES (See Card C4)

Role 1: _____

Resource(s):

_____
_____
_____

Role 2: _____

Resource(s):

_____
_____
_____

Role 3: _____

Resource(s):

_____
_____
_____

POSITIVE INTERDEPENDENCES

ROLES (See Card D2)

Already defined when structuring collaboration.

IDENTITY (See Card D3)

☐ Name ☐ Badge ☐ Logo

☐ Motto ☐ Flag ☐ Image

☐ Other: _____

GOALS (See Card D4)

Group goal(s): _____

ENVIRONMENTAL (See Card D5)

Environment:

_____

RESOURCES (See Card D6)

Already defined when structuring collaboration.

POSITIVE INTERDEPENDENCES

TASKS (See Card D7)

Role 1 - a. _____
b. _____
c. _____

Role 2 - a. _____
b. _____
c. _____

Role 3 - a. _____
b. _____
c. _____

OUTSIDE ENEMY (See Card D8)

How are groups going to compete against each other?

_____
_____
_____

FANTASY (See Cards D9)

_____
_____
_____
_____

CELEBRATION/REWARD (See Card D10)

What kinds of rewards will the group get?

_____
_____
_____
_____
_____

Appendix C

Survey Responses (Prototype Evaluation)

C.1 Children from ASORVAL and LA PAMBA

Questions for individual activity

- Q1: How do you feel after using the app and why
- Q2: Was the app easy to use?
- Q3: What did you like about the app?
- Q4: What did you not like about the app?
- Q5: Did you like the story?
- Q6: Would you like to play again

Questions for collaborative learning activity

- Q7: How do you feel after this new activity with your classmate and why?
- Q8: What did you like about this new activity?
- Q9: What did you not like about this new activity?
- Q10: Which of the two activities did you like more and why?
- Q11: Do you prefer to play by yourself or with a classmate?

Student	Q1	Q2	Q3	Q4	Q5	Q6
S1	I feel good because I liked the story about Kevin (one of the characters) and it was easy	It was easy because the story was in sign language and I understood everything	The new vocabulary	I liked everything	Yes, I liked it	Yes, I'd like it
S2	I liked the vocabulary, the story and signs	It was bit difficult because sometimes the signs were very fast and I got confused	The vocabulary and the story	Nothing bad	Yes, I liked the story	Yes
S3	I felt very good. I liked it a lot	Yes, it was easy	The story about Kevin and the images	Nothing bad, I think the vocabulary is interesting to learn	Yes	Yes
S4	It was interesting	Yes, it was easy	The story about candies	I liked everything	Yes, I liked the story	Yes, I'd like it
S5	I liked it, I feel happy	Easy	The story	I don't see anything bad	Yes	Yes
S6	I feel very happy	Easy to use	The Halloween story	I liked everything	Yes	Yes
S7	I feel happy	It was easy with the instructions	I liked it to learn	I liked it	Yes, it was fun, the way it was told on the video	Yes, I want to play again
S8	I liked it, I had fun	It was easy for me	Sometimes it's difficult to study but it's easier with this	Nothing, everything ok	Yes, it was clear	Yes
S9	I feel good	It was difficult, I have trouble learning the words	I liked it	It was good	I liked the story a lot	Yes, I would
S10	I liked it a lot	I understood what I had to do	I liked it	I liked it	Yes, it is understood easily	Yes
S11	Happy	No answer	No answer	No answer	Yes	Yes
S12	I like it	No answer	The story	No answer	It was good	Yes, I want

Table 8. Results of the individual activity (ASORVAL)

Student	Q1	Q2	Q3	Q4	Q5	Q6
S13	I feel good, I liked the app	It was easy	When it vibrated	I liked everything	Yes, because it was in sign language	Yes
S14	I like it because it is in sign language	Easy, it showed options to do it	Vibration	I liked it	Yes, we learned with sign language	Yes
S15	I like the questions, sometimes we make mistakes, but it is important	It was easy, with the sign language and I liked the vibration	The story	I liked everything	I liked the story and sign language	Yes, I would
S16	I feel very good, I like Halloween stuff	Easy because we started to watch and had options	Everything	I liked it	I liked everything	Yes
S17	I feel good, happy, I really like this app	Very easy	The story	I don't see anything bad	Yes, a lot	Yes
S18	I like it a lot and I have to practice	Easy but I have to practice	I liked using the tablet	I liked everything, I want to keep playing	Yes	Yes
S19	Good. I liked the story in sign language	Easy to use	The story and instructions in sign language	I liked everything	Yes, I liked it	Yes
S20	I feel good, I liked it a lot	It was easy	Practicing words	I liked the app	Yes	Yes
S21	I feel good with the story in sign language	It was easy and fast	I liked playing and learning	I liked everything	Yes	Yes, I would
S22	I feel happy, I learned a lot and understood the story in sign language	Easy	The story in sign language	Some words were difficult for me	Yes	Yes
S23	I feel very good	Very easy the app	The options to answer	I liked everything	Yes	Yes
S24	I feel good	No answer	The images	No answer	No answer	Yes

Table 9. Results of the individual activity (LA PAMBA)

Student	Q7	Q8	Q9	Q10	Q11
S1	I feel good because it had new vocabulary	I liked everything, shifting players, it was fun learning new vocabulary	I liked everything	The first one, because of the story and vocabulary	I'd prefer to play with someone because I can share, and I know my classmate
S2	I liked it because it was something new	Signs of new vocabulary	I liked everything, I liked sharing	First one	I like it more with my classmate
S3	Happy	I liked that I had to think, it was fun	I liked everything, I felt good	First one	I prefer with friends, alone you get bored
S4	Very happy	The vocabulary	It was interesting, I liked to play	Second one	It was fun in pairs, with someone is more motivating
S5	Happy	Everything	I liked playing	Second one	Better in pairs
S6	Very happy	First, I got confused, but then I saw the sign and won, I felt very happy	I liked everything	First one	Alone is boring
S7	Good	It is more fun because it's like a competition	I liked it	The first one	Alone
S8	Good because we can help each other	That we can help each other	I liked everything	The second one because it is more fun	With my classmate
S9	Good	No answer	I liked it	The second one	With someone
S10	Happy because we shared	Working with my classmate	Everything ok	Both	With my classmate
S11	Good	No answer	No answer	The second one	With my classmate
S12	I feel good	New vocabulary	No answer	The second one	With someone

Table 10. Results of the collaborative activity (ASORVAL)

Student	Q7	Q8	Q9	Q10	Q11
S13	I feel very good	I liked learning the vocabulary and knowing if I was right	I liked everything	The second one	With my friend
S14	I liked practicing the vocabulary	Signs and new words	I liked it	The one sharing with my classmate	With a classmate
S15	Good, we played, we shared	Typing my name and interchanging the game	I liked it	The second one to play with my classmate	I liked with my friend
S16	I felt good playing with my classmate	I liked working with my classmate	I liked it a lot	Second one	With my classmate
S17	I feel good, I liked the game because the tablet vibrated and told me if I was right	I liked sharing with my classmate and questions about the story	I was very happy	Second one	With classmate
S18	I am very happy because I played with my classmate and we could help each other	I liked the game, like a secret and suspense because I didn't know if I was right	No answer	Playing with my classmate	With a friend
S19	Happy with this game	I liked knowing if the word was right or wrong	I liked everything	I liked sharing with my classmate	With classmate
S20	I felt good because we could share and know if the answer was right or wrong	Sharing with my classmate	I liked everything	I liked more that one was doing something and the other one answered	With my classmate
S21	I feel good, each one could type their name	Practicing words and signs	I liked it	Both	With someone
S22	I liked that we distributed our work	I liked it a lot because I learned new words like "surprise"	I liked the app	Both	With someone
S23	I am happy, I liked typing the names and I helped my classmate	I liked it a lot	I liked it	The first one, my classmate had trouble understanding	Alone
S24	I feel happy, I will tell my mom.	I liked it	No answer	The second one with friends	With someone

Table 11. Results of the collaborative activity (LA PAMBA)