DesignABILITY: Framework for the Design of Accessible Interactive Tools to Support Teaching to Children with Disabilities

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ABSTRACT

Developing educational tools aimed at children with disabilities is a challenging process for designers and developers because existing methodologies or frameworks do not provide any pedagogical information and/or do not take into account the particular needs of users with some type of impairment. In this study, we propose a framework for the design of tools to support teaching to children with disabilities. The framework provides the necessary stages for the development of tools (hardware-based or software-based) and must be adapted for a specific disability and educational goal. For this study, the framework was adapted to support literacy teaching and 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. The experts' evaluation of the framework shows that it is well structured and may be adapted for other types of disabilities.

CCS CONCEPTS

• Human-centered computing~Accessibility design and evaluation methods • Human-centered computing~HCI design and evaluation methods • Human-centered computing~Accessibility design and evaluation methods

KEYWORDS: Design; Disability; Storytelling; Collaborative Learning; Deaf Children; Literacy

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1 INTRODUCTION

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 [1].

From an HCI perspective, some methodologies and models have been proposed to improve accessibility and usability of systems [1][2] while others involve children in the design/development process through a User-Centred Design approach [3].

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 [4]. 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 [5][6]. 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.

To solve these problems, a framework is proposed for the design of accessible interactive tools aimed to support teaching to children with disabilities. The proposal can be adapted for different impairments and teaching strategies. In this paper, 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 [7], 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 [8].

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 [9]. 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) [10].

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 tools aimed at children with disabilities. To close this gap, the proposed framework is being adapted to focus on one particular (but extensive) learning goal and by engaging two well-known strategies in literacy learning: Interactive Storytelling [11][12][13] and Collaborative Learning [14][15]. Since gathering a group of children to work together in a common task does not guarantee an effective collaborative work [16], it is necessary to structure activities that lead to a 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 the way to promote collaboration among deaf students.

By providing this framework, designers and developers will have a guide through the design process of any technological tool (hardware-based or software-based) targeting at helping to support education of children with disabilities and for this particular case to develop reading and writing skills for deaf children. A prototype is being developed following the stages of the framework and will be evaluated by teachers from different institutions for Deaf children in Colombia.

2 RELATED WORK

2.1 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 [17] 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: Identity, Immersion, Interactivity, Increasing Complexity, Informed Teaching, 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 [18] 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 [19] which presents a very large development life-cycle (13 stages) and even so, it lacks of 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 [4] 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. [20] 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.

2.2 Designing for People with Disabilities

As seen in the previous section, some approaches for 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 [1] 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 scope and feasibility of the system is 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 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. [2] also developed a process model called Process Model of Usability and Accessibility Engineering (MPIu+a for its acronym in Spanish). This approach adds to software engineering model a set of well-organized activities: analyse 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 main goal of the tool.

A more narrowed approach was developed by Guimarães et al. [21] to inform 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. [22] states that approaches like User-Centred 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 a real empathy with their user groups (including those with disabilities). Something similar is proposed by Ladner [23] with his *Design for User Empowerment* approach where users develop the project, design the requirements and features, develop the prototypes, test the prototypes, and analyse 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. [24] 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.

3 DESIGNABILITY 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.

This is the result of 4 years of research with children with auditory, visual and cognitive disabilities.

As can be seen in Figure 1, the proposal is divided into four stages:

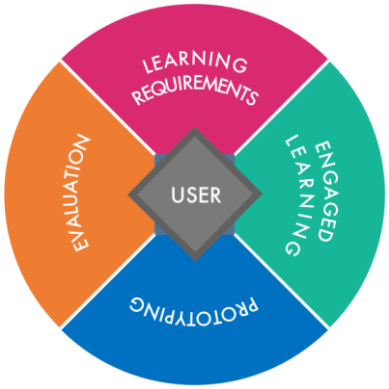

Figure 1: Framework for the Design of Accessible Interactive Collaborative Tools to Support Teaching

3.1 Learning Requirements

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.

3.2 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.

3.3 Prototyping

A 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.

3.4 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.

4 USING THE DESIGNABILITY FRAMEWORK

In order to show how the framework can be used, we decided to focus our work on deafness and the development of one particular but extensive skill like literacy. Reading and writing is considered the second language of deaf people who use sign language as their main way of communication[25]. Poor literacy skills affect the development of new knowledge in areas like math and sciences [26]. 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 [10][27]. A collaborative learning approach could enhance the construction of new knowledge by working with peers [28].

4.1 Background

4.1.1 Literacy in Deaf Children's Education. One of the main reasons Deaf people do not finish higher education is due to poor literacy skills [29]. 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 [30][21]; 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 in order to acquire a second language (L2) in a written form (for instance, English or Spanish) [31] which will give them the opportunity 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 [32].

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 [33], while deaf children cannot do the same with sign language as it has a completely different structure from a written language.

4.2 Methodology

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 [5][34][13]. The resulting framework can be seen in the next section.

4.3 DesignABILITY (Deafness + Literacy)

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

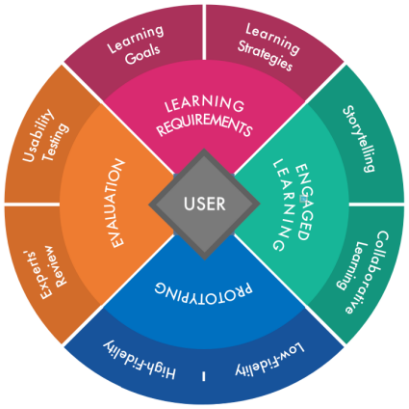

Figure 2: Framework for the Design of Interactive Collaborative Tools to Support Literacy Teaching to Deaf Children

4.3.1 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 analysed 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.

We mapped the LG for the first year of education of all five curricula and found similarities in all of them, 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 from memory simple sentences dictated by the teacher.

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).
- 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.

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).

4.3.2 Learning Strategies. Different literacy teaching strategies or methods can be used to achieve these goals. During our research, two particular strategies designed for Deaf children's literacy are being studied: the Fitzgerald Key [35] and Logogenia [36]. The former helps to understand the structure of grammar by assigning a different colour 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 colour.

This colour code can be different depending on the educational institution (EI), which is why it is very important to know the colour 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 colour 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).

4.3.3 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 [37]. This strategy has been used in the education of Deaf children to develop or strengthen skills in literacy or sign language [10][27][38][39]. 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 research we have been carrying out 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 analysed 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.

4.3.3.1 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. We evidenced this 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. We mention 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.

4.3.3.2 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 our 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.

4.3.3.3 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.

4.3.4 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 [40]. 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 [7]. 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 [41]. 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 [41], a model was proposed for the design of collaborative strategies in serious games for children with hearing impairments.

4.3.4.1 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.

4.3.4.2 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.

1. *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.).
2. *Nature of collaborators:* Specify the type of interaction (peer-to-peer, teacher-student, student-computer).
3. *Group heterogeneity:* Define variables such as size of the group, gender or academic level.
4. *Positive Interdependences (PI), Game Mechanics (GM) and 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.
5. *Setting of collaboration:* Define the place where the collaborative activity should take place (e.g. classroom, home, virtual environment).
6. *Conditions of collaboration:* Define how the collaboration will be mediated (physically, computer-mediated).
7. *Period of collaboration:* Time that will be invested by children during the activity.

As part of this research, we have mapped positive interdependences (PI) with game mechanics (GM), collaborative game mechanics (CGM) and learning mechanics (LM) to make it easier to define these features [42]. This mapping is based on the LM-GM framework proposed by Arnab et al. [43].

PI is what makes an activity to be actually collaborative, where the success of one student is dependent on the success of the group [7]. GM and CGM are the rules and procedures that provide interaction with a game [43] and for CGM, these rules promote collaboration among players. Finally, LM are pedagogical practices that support learning [43].

Table 1: PI-GM-CGM-LM Mapping (short version)

(PI)	(GM)	(CGM)	(LM)
-Task	-Game turns		-Repetition
- Reward	-Status -Reward/Penalty	-Common stimuli	-Responsibility -Incentive

The PI-GM-CGM-LM mapping is a great way to communicate ideas between educators, designers and developers. For instance, if an educator suggests that the activities should provide a LM such as incentive or a CGM like common stimuli, this can be translated to a game designer language as a GM like reward/penalty which is present in all games. This can also be mapped as a PI (celebration/reward), which guarantees that the activity promotes some kind of collaboration. The full version of the PI-GM-CGM-LM mapping can be seen in [42].

4.3.4.3 Structure Collaboration. Finally, the collaboration must be structured by defining four elements.

1. Activities: Workflow of individual and collaborative tasks that must be performed by the group of children, who form a team to fulfil the goal of the activity. The rules of each task should also be defined, so the regulations, norms and conventions that constraint actions and interactions with the tool are clear to the students. The activity must have a main goal that will be achieved by the team and may have a set of partial goals that can be reached individually by each member of the group (aiming to achieve the main goal).
2. Roles: Each member of the group should be assigned a role during the activity. Each role has its own responsibilities and every member should have the opportunity to play a different role to balance work load of the activity and promote the same learning benefits among students.
3. 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).
4. Shared Resources: Every member of the group should be provided with the necessary resources to achieve the partial and main goals. These resources will be shared with the rest of the group and represent the knowledge each member has to contribute to the purpose of the activity and the success of the whole group.

4.3.5 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 a 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.

4.3.5.1 UI Design. During the research we have been carrying out in the last years, we created a Graphical User

Interface Design Guide (GUI-DG) 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, we analysed the profile of the children and evaluated our prototypes and existing applications developed for deaf children with the help of teachers, experts and students. The final guide can be found in [44] and is divided into the following categories and sub-categories:

1. Style: Colour, icons, animations and video, typography, writing, labels
2. Components: Buttons, dialogs, menus, lists, progress and activity
3. Patterns: Navigation patterns, search, errors, confirmation
4. Learning: Intro to application, future discovery
5. Content: Content, interaction, stimuli and rewards
6. Other aspects

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

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

1. Useful. The tool should fulfil a need, and this is exactly what we want by developing a system to support literacy teaching, so this factor is by default present in the tool that is being designed.
2. 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.
3. 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.
4. Findable. All the content or elements of the tool must be easy to find and well organized.
5. 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.
6. 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" [45]. 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.

4.3.6 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.

4.3.6.1 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 [46] and principles by Tognazzini [47] 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.

1. Principles

- 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).

The designer/developer team of the tool may add more heuristics and principles depending on what they think should be reviewed. The GUI-DG we 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.

4.3.6.2 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 users are enough (preferably real users 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 [5][48][49]:

1. Direct observation: This method does not require the child to express their opinions or feelings in a direct way, instead, their actions are analysed. 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 in order to have permission to do so).
2. 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.
3. 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.

4.3.6.3 Collaborative Learning Evaluation. The evaluation of CL is essential to guarantee that the tool actually promotes learning among peers. In section 4.3.4, we showed how positive interdependences can be mapped with game/learning mechanics, so, based on the work done by Tondello et al. [50] and our experience in previous studies with deaf users, the following heuristics are defined for CL evaluation:

1. Purpose and meaning: Users identify a meaningful goal that will be achieved through the system and can benefit the team.
2. Completeness and mastery: Users satisfy their intrinsic need of competence by completing series of tasks or collecting virtual achievements.
3. Autonomy and creativity: The team find meaningful choices and opportunities for self-expression.
4. Relatedness: Users satisfy their intrinsic need of relatedness through social interaction with team members and teacher.
5. Immersion: Users are immersed into the activities through the story behind them.
6. Ownership and rewards: The team is motivated through extrinsic rewards or possession of real or virtual goods.
7. Feedback: Users receive feedback from peers, teachers or the system.
8. Identity and role-playing: Each member of the team sticks to their role.

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

5 EVALUATION OF THE DESIGNABILITY FRAMEWORK

To evaluate this first version of the framework, a survey was conducted to evaluate each stage of the framework and get some feedback on how it can be improved. 26 researchers 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. The following section shows the results of every question that was asked per stage:

6 RESULTS

For the first evaluation of the framework, the answers show the following results:

1. Learning Requirements (Learning Goals and Learning Strategies)

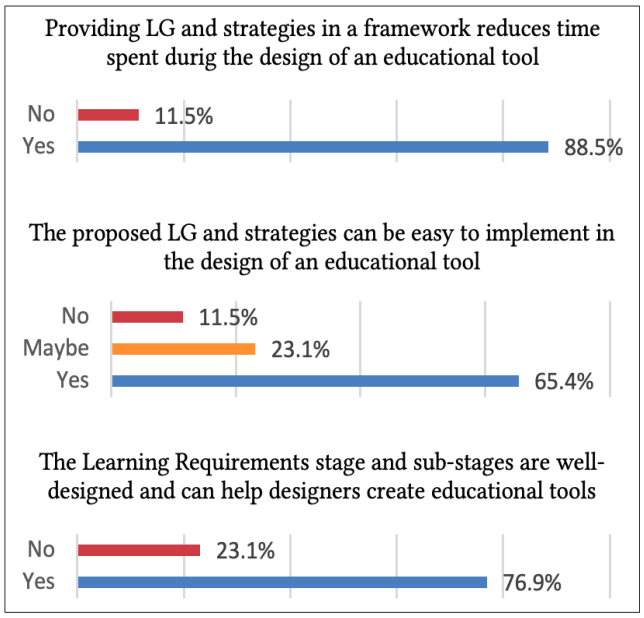

Figure 3: Evaluation of the Learning Requirements stage

From a 5 Likert-scale rating (where 1 is 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.

2. Design for Engaged Learning (Storytelling and Collaborative Learning)

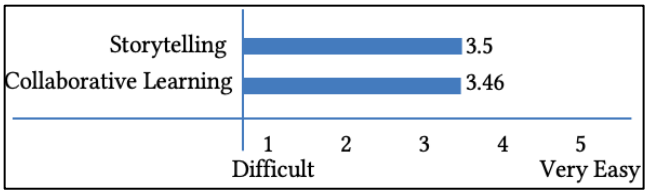

Figure 4: How easy a Storytelling and CL activity can be implemented by following the Design for Engaged Learning stage

- 80.8% think the PI-GM-GCM-LM mapping is easy to understand.
- From a 5 Likert-scale rating (where 1 is 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.

3. Prototyping (UI/UX Design)

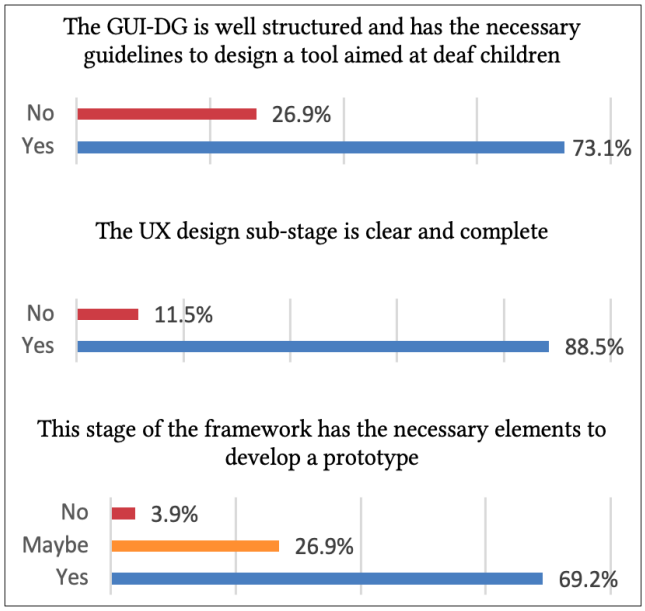

Figure 5: Evaluation of the Prototyping stage

- From a 5 Likert-scale rating (where 1 is 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.

4. Evaluation (Experts' Review and Usability Testing)

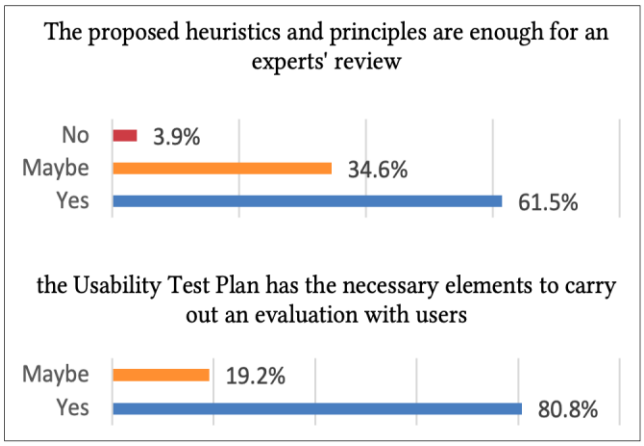

Figure 6: Evaluation of the heuristics, principles and usability test plan proposed in the Evaluation stage

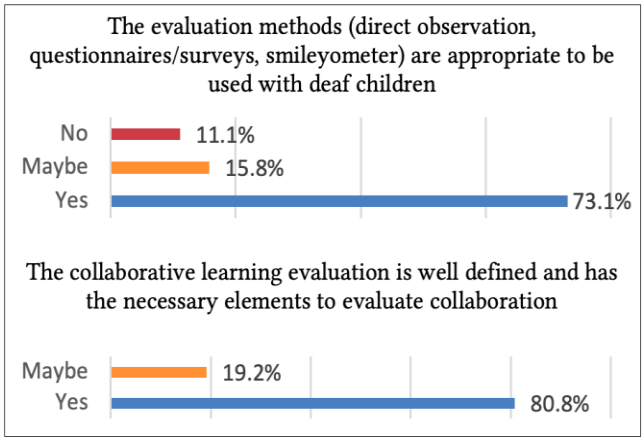

Figure 7: Evaluation methods and Collaborative Learning evaluation proposed in the final stage

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

5. Overall Framework

- 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. Average is 4.04.
- 73.1% think the framework can be adapted for other disabilities and learning goals. 26.9% answered *maybe*.

7 DISCUSSION

Based on the evaluation of the framework, the results show that it has been well accepted by researchers 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 a first evaluation. The researchers who took the survey had the opportunity to express their opinions and give suggestions when an answer was not positive, this additional information will help us improve every stage of the framework. Some of their concerns are mainly on 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 example shown in this study is not a fixed solution, instead, it is a solution tailored to the needs of the teachers 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. They think both approaches need more simplified information in order 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. Both sub-stages will be reviewed to address these concerns and make the framework easier to use. 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. We proposed some of these based on our previous studies, and more will be added as this research continues. The information shown in this study aims to provide a theoretical background of the framework which can make it look difficult or complex to use, but its use will be supported by a software tool (under development) that will guide the whole process and a set of cards that can be used by designers and developers to ease the communication between them and educators.

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.

8 CONCLUSIONS AND FUTURE WORK

The proposed framework makes it easy to break down the activities of every stage and adapt it to other types of disabilities and learning goals/strategies. The adaptation made in this study to support literacy teaching to deaf children 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. A first evaluation of the framework is shown in this paper, 26 researchers from different fields (HCI, design, 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 will be 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 [51].

During the review of the literature on storytelling [13] and collaborative learning (CL) [8] to support literacy teaching, we 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 [10][11][12] [14] [41][52].

Two prototypes are under development following the stages of the DesignABILITY framework adapted for literacy teaching to deaf children. These prototypes will be tested by deaf children in institutions from Colombia and Scotland. The process is being supported by teachers of deaf pupils in both countries with high expectations from educators.

The new framework proposed in this study, 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, our 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.

For future work, the DesignABILITY framework will be adapted to support teaching to children with other disabilities like blindness, autism or with cognitive impairments.

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