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Empowering Diverse Abilities: A Revised DesignABILITY Framework for Designing Assistive Technologies

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Abstract

This paper presents the revised DesignABILITY framework to improve the development of assistive technology for individuals with severe speech and motor impairments. To concentrate on utilizing user potential rather than just meeting immediate needs, it introduces an "Empowerment Planning" stage. The framework was validated through an innovative system called "MorSpeech," which integrates a multiplatform application and ESP32 hardware using alternative inputs like vegetables and water containers. Due to intricate ethical issues, wide range of etiologies, and the requirement for customized testing procedures based on individual capacities, recruiting for such studies is difficult. As a result, the final prototype was assessed by three individuals with variety of conditions, including cerebral palsy and amyotrophic lateral sclerosis. Two participants had a 100% task completion rate, according to the results. The prototype showed adaptability to severe neurological disabilities, despite the third participant's completion being limited by significant application timing constraints. By prioritizing empathy throughout the design process, this work illustrated the efficacy of the updated framework in developing assistive technologies that empower users with a range of abilities. Additionally, this study emphasizes how iterative design can overcome constraints to enhance overall wellbeing.

Keywords

Assistive technologies; human-computer interaction; motor and speech Impairments; Morse Code.

Registration

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Empoderando capacidades diversas: Marco DesignABILITY modificado para el diseño de tecnologías de asistencia

Resumen

Este artículo presenta el marco DesignABILITY revisado para mejorar el desarrollo de tecnología de asistencia para personas con discapacidades graves del habla y motoras. Para centrarse en aprovechar el potencial del usuario en lugar de simplemente satisfacer las necesidades inmediatas, se introduce una etapa de "Planificación de Empoderamiento". El marco se validó mediante un sistema innovador llamado "MorSpeech", que integra una aplicación multiplataforma y hardware ESP32 utilizando entradas alternativas como verduras y recipientes de agua. Debido a complejas cuestiones éticas, la amplia gama de etiologías y la necesidad de procedimientos de prueba personalizados según las capacidades individuales, el reclutamiento para estos estudios resulta difícil. Como resultado, el prototipo final fue evaluado por tres personas con diversas afecciones, como parálisis cerebral y esclerosis lateral amiotrófica. Dos participantes completaron la tarea al 100 %, según los resultados. El prototipo demostró adaptabilidad a discapacidades neurológicas graves, a pesar de que la finalización del tercer participante se vio limitada por importantes limitaciones de tiempo de la aplicación. Al priorizar la empatía durante todo el proceso de diseño, este trabajo ilustró la eficacia del marco actualizado en el desarrollo de tecnologías de asistencia que empoderan a los usuarios con diversas capacidades. Además, este estudio enfatiza cómo el diseño iterativo puede superar las limitaciones para mejorar el bienestar general.

Palabras clave

Tecnologías de asistencia; interacción humano-computador; discapacidad motriz y del habla; código Morse

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1. Introduction

It is now possible to design assistive technologies (AT) that will improve the quality of life of people with diverse abilities due to the rapid developments in technology. Assistive technologies are devices and systems designed to help individuals with disabilities do things that might be hard or impossible for them (Prabhakar, Indulakshmi, Jeyaram, Stalin, Kasthuri and Ramanathan, 2019). They range from simple aids such as modified utensils and communication boards to sophisticated systems like voice-activated devices, brain-computer interfaces and many more (Millán, et al., 2010).

Several conditions can lead to motor impairment or speech difficulties such as Amyotrophic Lateral Sclerosis (ALS) (Agurto, et al., 2019), cerebral palsy (Fiori, et al., 2022), strokes (Zarifian, Mahnama and Vosoughi, 2017) and other neurological disorders. Such impairments greatly affect a person's ability to communicate, interact with his or her environment, and even accomplish daily activities.

There may also be a solution within advanced technologies like brain-computer interfaces, but they are rarely accessible in developing countries due to their high cost. In this regard, it is necessary to create affordable assistive technologies that can make a real difference for disabled people (Tarek, et al., 2022).

A way forward for inclusive, effective, and possibly low-cost assistive technologies could be through the DesignABILITY framework (Flórez-Aristizábal, et al., 2019) which targets designs that suit various user needs and capacities thereby enabling alternate interfaces and interactions by designers/developers. The study provides an updated representation of the framework demonstrating its application in making MorSpeech system an all-platform app for learning Morse code aimed at helping people who have problems related to motor control or speech.

Morse code is a low-cost form of communication that uses a series of dots and dashes. It is particularly useful for people who are physically unable to speak. When it comes to communication assistance technology devices, its simplicity and adaptability make it perfect (Tarek, et al., 2022). Users can increase their level of interaction with others by learning Morse code, which allows them to create alternative forms of communication that are not based on standard speech or writing.

MorSpeech is an educational system that combines hardware and software to help people learn and use Morse code more effectively. It was created as a Flutter-based mobile application that connects to an ESP32 hardware module to allow users to respond using different inputs like water containers or fruits. It's also an enjoyable way to learn about various physical disabilities. MorSpeech makes learning more approachable and pleasurable for a wide range of people by converting commonplace objects into input mechanisms.

The five primary stages of the redesigned DesignABILITY framework are focused on different aspects of design and development. In order to maintain the design's user-centeredness and ensure that both hardware and software function flawlessly, each phase takes into account feedback from all end users and experts in related fields.

Participant recruitment is one of the special challenges associated with developing and testing assistive technologies for people with severe motor and speech impairments. Factors such as the diversity of conditions, the need for personalized assessments, and the logistical and ethical considerations (see appendices A.1, A.2, A.3 and A.4) in obtaining consent from individuals or their caregivers often limit sample sizes. Nevertheless, in-depth case studies with even a few participants can provide rich insights into the usability and potential impact of such technologies.

This paper's primary contributions are: 1) The presentation and detailed explication of the revised 5-stage DesignABILITY framework, specifically tailored for assistive technology (AT) development for users with severe motor and speech impairments, emphasizing an iterative, user-empowerment focused approach. 2) A practical demonstration of this framework through the design and initial evaluation of the MorSpeech system, an alternative communication tool. The novelty of the DesignABILITY framework lies in its explicit 'Empowerment Planning' stage, which goes beyond traditional user-centered design by systematically strategizing how technology can support users in overcoming specific impairment-related challenges and potentially contribute to their rehabilitation or skill enhancement. Furthermore, its structured yet flexible 5-stage process offers a comprehensive roadmap specifically for the complex domain of AT for diverse and often unique user needs, a gap not fully addressed by more general design frameworks.

2. Background and related work

2.1. Assistive technologies

Assistive Technologies (AT) enable people with disabilities to interact with their environment and improve their lives. In this context, assistive technologies could be defined as simple or complex devices designed for individuals who are impaired in communication.

Augmentative and Alternative Communication Systems (AAC) are useful for people with difficulty speaking. They have been developed including digitized and synthesized speech to facilitate word selections, symbols and pictures that can be used in communicating. AAC technologies have significantly improved the ability of patients with speech and motor impairments to engage in social, educational and vocational activities (Schultz Ascari, Silva and Pereira, 2019).

Cost effective assistive technology solutions are essential for low-income regions. Different low-cost tools and software applications have been developed to help in education support, communication, daily living among persons with disability; frequently these consist of access switches, gesture recognition systems and multilingual AAC devices (Prabhakar, et al., 2019).

2.2. Motor and speech impairments: Causes and challenges

Motor and speech impairments may result from various causes including neurological conditions such as cerebral palsy (CP), amyotrophic lateral sclerosis (ALS), traumatic brain injury, strokes, and brain tumors. Additionally congenital diseases plus other medical conditions contribute towards these impairments which greatly reduce people’s ability to communicate or perform daily activities thus necessitating use of assistive technologies for enhancing quality life.

Neurological disorders often underlie motor impairment or speech disorder being cerebral palsy the most frequently detected disorder causing motor disabilities globally affecting about 2-2.5 per 1000 live births; children living with CP frequently experience communication difficulties related to it (Fiori, et al., 2022). Aphasia is another major issue caused by strokes and affects around 20% of population leading to language disorder and ultimately a hindrance in communication (Zarifian, et al., 2017). Furthermore, the number of individuals with conditions such as ALS and post-stroke aphasia that cause communication challenges is on a fast rise (Garro, Sappia and Costa, 2019). Most of them have severe speech or language disorders which results in its need to be supplemented or replaced by AAC devices (Gaba, 2014).

Motor and speech impairments create complex problems for individuals. Schultz et al. explain how people with motor control issues or paralysis find it difficult in using regular input devices such as keyboards and mouses. Therefore, there is need for alternative means of interactions, which are both non-invasive and personalized (Schultz Ascari, et al., 2019).

In addition to economic barriers arising from high AAC device prices (Gaba, 2014), there are also technical obstacles that hinder the development of AAC systems suitable for real-life implementation. There are devices’ reliability, safety and user-centered design challenges in developing practical AAC systems. As Millán et al. (2010) stated, effective user-machine adaptation algorithms incorporating HCI principles aimed at improving usability are critical for successful AAC integration.

The impact of motor and speech impairments on daily life is overwhelming. Some of the effects include reduced independence among children living with CP who may lose self-care abilities or being even socially isolated due to poor speech intelligibility coupled with motor dysfunction. Their involvement in social activities like education becomes difficult because they have difficulties when communicating (Fiori, et al., 2022).

Assistive technologies must be innovative and accessible to meet these challenges posed by motor and speech impairments.

2.3. Previous research

By the time the DesignABILITY framework was developed in 2019, there was a lack of guidance through frameworks or methodologies in the design and development of accessible tools for people with disabilities.

Accessibility awareness has been growing; however, a recent review of literature shows that this is not translating into practice. Lack of robust tools and frameworks has kept out effective designs of solutions that meet user needs with disability.

In 2021, a lack of inclusive makerspaces was found by researchers from university of Illinois and Pennsylvania State University, hence proposing the SCAFFOLD framework in order to facilitate equity, inclusion and accessibility in these environments. The research objective primarily aimed at developing an encompassing framework which ensures universality and inclusiveness of makerspaces for sociocultural diverse learners including those with diverse abilities (Seo and Richard, 2021). While SCAFFOLD offers valuable principles for inclusive makerspaces, its primary focus is on broader learning environments and may not provide sufficiently granular guidance for the specific iterative design and evaluation cycles required for assistive technologies targeting complex motor and speech disabilities. The DesignABILITY framework, in contrast, offers a dedicated methodology for AT development, including specific stages like 'Empowerment Planning' and iterative user-centered evaluation tailored to this user group.

In a study, Namoun et al. presented an extremely complex framework that uses cutting-edge machine learning techniques to improve the appropriateness and usability of assistive services. In order to guarantee that the right services are chosen for people with disabilities, they introduced an inclusive disability ontology. In essence, this ontology uses an organized method of service selection to classify and comprehend the diversity among user groups with disabilities (Namoun et al., 2022). Context-aware service selection has advanced thanks to this advanced machine learning framework and disability ontology. However, rather than the generative design of the assistive technologies themselves, their work is mainly concerned with service selection. DesignABILITY complements such approaches by providing a framework for the design of tools and systems that users like those in Namoun et al.'s study might eventually select, ensuring these tools are designed with deep user understanding and empowerment from the outset.

In 2023, one study addresses the issue of accessibility in video games, which is a major form of entertainment that often excludes people with disabilities due to different forms of barriers on this matter. The paper highlights development of a framework aimed at enabling game designers create customizable accessibility options thus leading towards inclusivity in gaming. This research mainly focuses on analyzing existing accessibility features across various game genres such as PC, Console, Mobile or Virtual Reality (Sodhi, Girouard and Thue, 2023). Sodhi et al. address the important area of accessibility in gaming. While their aim to create customizable accessibility options is crucial, their framework is specific to the gaming context. The DesignABILITY framework offers a more universal approach applicable to a wider range of assistive technologies beyond entertainment, focusing on fundamental communication and interaction support for daily living.

Lastly, a multidisciplinary framework is proposed towards creating the next-generation human-centered design guidelines specifically tailored for deaf and hard-of-hearing students. The main goal of this study is to formulate a comprehensive framework for developing human-centered design guidelines that will integrate insights from different disciplines such as user experience (UX), instructional design, accessibility and software engineering (Polanco and Liu, 2023). Polanco and Liu's work on a multidisciplinary framework for human-centered design guidelines for DHH students is vital. Their focus is on guideline creation for a specific sensory impairment. DesignABILITY, while also human-centered and multidisciplinary in spirit, provides a process framework for the development of interactive systems for a different primary user group (motor and speech impairments), detailing stages from initial needs assessment through to evaluation of tangible prototypes.

In this study, the new DesignABILITY framework was used during the development of MorSpeech, an accessible interactive morse code learning tool to aid communication for speech and motor impaired individuals. A literature review was done on this matter too, finding that in recent years, some projects have explored Morse code as an accessible communication method for people with disabilities, such as a collaborative effort between Google Creative Lab and Use All Five resulted in Google's Morse code project (Use All Five, Google Creative Lab, n.d.). This was initiated by Tania Finlayson who is both a Morse code user and an advocate for persons with disabilities alongside her husband Ken Finlayson. Their work focused on integrating Gboard with Morse code which allows users to input text using Morse code on mobile devices. The project aimed at bridging communication gaps by providing an alternative input means that can be customized to personal preferences. While innovative in its use of imagery, Google's Morse code project's reliance on English-centric visuals presents a cultural-linguistic limitation for non-native English speakers. Furthermore, its primary focus on learning the code lacks the broader assistive and adaptive interaction features necessary for individuals with severe motor limitations, a gap MorSpeech, developed under the DesignABILITY framework, aims to address through alternative input methods and user empowerment strategies.

One distinctive feature of Google's effort is that they use images to help users match Morse code signals with the letters. Though this technique works well for English speakers because the pictures are based on English terms (e.g., the letter "E" is represented by an 'EYE'), it may be misleading for non-native English speakers since items in question may not correspond with the first letter of the words in different languages. Further, while this project is enjoyable and designed to be easy to follow, it lacks any further interaction like game elements that could motivate and benefit users even more. Despite these restrictions, Google's Morse Code Project has deeply shaped MorSpeech design.

A different and interesting approach was proposed by Kranthi et al. in which researchers offered a new perspective where morse code was used as a medium of communication for people who have multiple disabilities. The system users have several options to translate morse code into speech (touch, gesture and microphone). An S-Morse dictionary converts Morse code pattern read from the touch sensor to voice and speech from microphone to Morse vibration. A gesture recognition model based on SVM algorithm was implemented for selection of user-accessible modes. System modes also send and receive text data from an android application through cloud network (Kranthi, Suhas, Varma and Reddy, 2020). Morse code was also used in another study but this time through an algorithm that detects the code from eye blinks. The proposed algorithm tracks eye landmarks and calculates the eye-opening level using Eye Aspect Ratio (EAR). This low-cost software decodes Morse Code precisely based on the duration of eyes closed or opened and thus translated into English Language (Sushmitha, Kolkar, Suman and Kulkarni, 2021).

Interaction with IoT devices for people living with motor neuron disease (MND) becomes very difficult as severe motion impairments are involved, hence hindering communication with others. Eventually, most patients lose their ability to speak while their voices can no longer be heard as the disease progresses. However, even after losing control over their arms and hands, many patients retain slight finger movements. To tackle this problem, WiMorse was developed by Niu et al (Niu, et al., 2019). Wi-Morse allows inputting text through a single finger using morse codes so that minimal finger control is enough for communicating without attaching sensors to fingers. Using common WiFi devices, WiMorse tracks subtle finger movements contactlessly and translates them into Morse code. This kind of approach was also achieved though the MorSpeech system designed as part of this study where different types of input interfaces were tested to suit users' needs.

3. DesignABILITY framework

3.1. First version

The DesignABILITY framework originally offered a 4-stage approach (see Figure 1) to develop learning tools for children with various needs:

- Learning Requirements: This stage focused on understanding the specific learning goals that the technology should aim to support.
- Design for Engaged Learning: Once the learning requirements were established, this stage focused on creating engaging and motivating learning experiences.
- Prototyping: Here, preliminary interactive prototypes of the learning tool were designed for early testing.
- Evaluation: The final stage involved a thorough evaluation process. This assessment looked at both the technical aspects of the prototype, ensuring it functioned properly, and the user experience for users with special needs.

Building upon this foundation and the work done in the MorSpeech project, the DesignABILITY framework has since been expanded and refined into a more comprehensive 5-stage model.

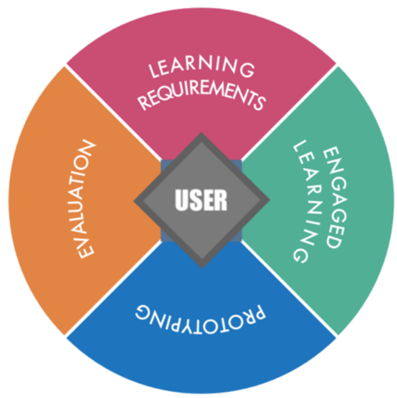

Figure 1. DesignABILITY Framework.
Note: Author's own elaboration from (Flórez-Aristizábal, et al., 2019)

3.2. Revised version

The original version of the framework did not specifically focus on enabling users to exploit their capabilities and overcome limitations. The updated version of the DesignABILITY framework tackles this limitation with a five-step process that highlights understanding of user strengths and empowers them through tailored design, for systematic development of accessible and inclusive interactive systems for users with diverse abilities. The five stages encompass in-depth user research, abilities assessment, empowerment planning, engagement design, and iterative prototyping with evaluation. Figure 2 shows the revised version of the framework.

Figure 2. Revised DesignABILITY Framework.
Note: Author's own elaboration

3.2.1. Abilities assessment

This stage is crucial for comprehending the capabilities of each target group. In order to do this, thorough evaluations are carried out to find different impairments among possible users. Thus, designers can collect such specific data as each user's particular requirements, preferences, and challenges in order to customize technology tools.

3.2.2. Empowerment planning

The goal of this stage is to develop strategies for providing assistance to people with disabilities. In actuality, the developers meticulously outline how the system should assist users in completing tasks that are challenging due to their disabilities during this phase. In doing so, the tools that are created should not only assist the user but also point them in the direction of rehabilitation or recovery, which could enhance their quality of life. It is necessary for designers to work with medical experts and therapists during this phase who will help identify major issues faced by patients and come up with possible solutions. As an example, there might be certain features like adaptive learning modules, motivational feedback mechanisms or step-by-step guidance that would suit a given user.

3.2.3. Engagement design

In order to make the tool more captivating and motivating for its users, the third stage ensures that the system designing process incorporates engaging factors. As a result, the terms "game mechanics," "interactive feedback," and "motivational features" all refer to the Engagement Design component. Therefore, these aspects should be personalized based on different levels of abilities or interests so as not only they are useful but also fun and appealing. For instance, game mechanics may involve rewards or levels so that users remain motivated to advance further in using the tool, while interactive feedback aids them in seeing instant response and comprehending their own progress.

3.2.4. Prototyping and development

In this stage, initial ideas and strategies are turned into tangible prototypes. This stage is important as it brings together all insights and strategies from the previous stages into a single functional design. The process begins with low-fidelity prototypes which are simple, quick and cheap models meant to facilitate quick testing and iteration.

As prototypes mature, they become high fidelity. When compared to simpler prototyping techniques, high-fidelity prototypes resemble final products in terms of functionality and appearance. This prototyping is useful for fully testing the system’s technical aspects such as an application interface and hardware integration.

3.2.5. Evaluation and iteration

This stage ensures that the designed tool is effective and reliable. In this phase, thorough testing is conducted on the prototype to verify its performance as well as user experience. Evaluation process starts with tests done on both technical aspect as well as user interface of the prototype. Testing for technical performance must be done in order to confirm that the tool works properly under different conditions while meeting all specified requirements for it to deliver correctly (by verifying software stability, efficiency, accuracy, etc.).

Among these evaluations is user experience assessment which requires collecting in-depth feedback from end users, especially those affected by targeted disabilities. Their experience can highlight strong points of the designed system versus weak spots on which improvements could be made respectively.

4. Methodology: Design and Development of MorSpeech

MorSpeech is a communication system designed to support people who have motor and speech impairments. By doing so, the tool aims to enhance their quality of life helping them communicate and interact with others. MorSpeech targets individuals with such conditions as amyotrophic lateral sclerosis (ALS), cerebral palsy, and stroke-related impairments to promote independence and social integration.

The development of MorSpeech adopted a Research through Design (RtD) methodology and was guided by the revised DesignABILITY framework (Abilities Assessment, Empowerment Planning, Engagement Design, Prototyping, and Evaluation), which ensures a comprehensive, user-centered approach. The following subsections detail the materials, participants, and procedures applied during each stage to develop and test the aforementioned system.

4.1. Abilities assessment phase

An evaluation of the target user's capabilities and limitations was conducted during the framework's initial phase. It involved a thorough investigation of the many causes of speech and motor impairments, including strokes, ALS, and cerebral palsy. This was justified by the idea that these disorders should be understood holistically in order to identify both potential strengths and weaknesses brought on by them.

Moreover, there was close contact with people suffering from any one of these disorders at this stage. One person who had been diagnosed with ALS actively took part in this process. Her son provided crucial information about her individual needs including photosensitivity, coordination problems and her dependence more on hearing than visual stimuli for most communication purposes. These insights helped in planning for empowering the user in the next stage.

A neurorehabilitation specialist made additional suggestions about what might be required for people with such conditions. This covered, among other things, user interface design, interaction methods, and accessibility specifications. In addition to photosensitivity and limitations in motor and coordination, this initial stage revealed certain abilities, such as the ability to manipulate and reach close objects and the dependence on auditory cues and memory.

4.2. Empowerment planning phase

This step built up on the insights of the abilities assessment and focused on defining the strategies that will support users to overcome their impediments. This was meant to specify how MorSpeech could help people complete tasks they were unable to do due to their disabilities. In addition to being a communication tool, it is designed as a system to improve the general well-being of its users.

Throughout this stage, the involvement of someone with ALS was important. Specific tasks that were difficult for the person were defined by understanding her daily struggles and in turn, targeted strategies that MorSpeech could use to empower such users. Strong auditory feedback was prioritized for this reason because she heavily relied on hearing. The selection of appropriate input methods was guided by data collected in phase one, particularly addressing photosensitivity and coordination limitations. While touchscreen devices with larger visible buttons ensuring minimal motor skill requirements have been put in place for users with touch or tapping capabilities, the participant who has ALS used external elements for interaction instead thus eliminating direct visual attention.

Furthermore, the specialist in neurorehabilitation also gave key insights into how MorSpeech could be beneficial therapeutically. These recommendations helped to shape the system not just as an everyday communication tool but one that would support rehabilitation interventions where users can enhance their speech and motor skills over time.

4.3. Engagement design phase

This stage centers on creating an engaging user experience. It involves employing mechanisms to entice the learner such as game and learning mechanics (Callaghan, et al., 2017), interactive feedback, and motivational elements that make the process of learning enjoyable and compelling. The aim is to maintain interest and involvement of users which enhances effective learning and communication.

Integration of different game and learning mechanics into MorSpeech at this point was aimed at enhancing engagement and learning outcomes. The system begins with a login feature, allowing progress to be saved and accessed across multiple devices. Users will navigate through levels, starting from only the first level that is unlocked and progress is shown visually through an image of a walrus (WALRUS = MORSA in Spanish), indicating the current level on the Morse code learning journey.

Entering each level, users experience Morse code letters using multi-sensory methods that encompass visual clues, pictures, and audio cues. Due to specific needs identified during the first stage, involving photosensitivity and coordination problems; interactions with it might be facilitated via either screen buttons or alternative conductive inputs such as fruits or water.

Immediate feedback is given for each entry where wrong answers are displayed in red with sound alerts while right entries are marked green with positive audio feedback. For the ALS user, this type of feedback system was crucial, as it provided non-visual clear cues that she could use along with her auditory sense. Advanced levels (called TROPHY LEVELS) incorporate evaluation stages where users must recall Morse code without hints, reinforcing their learning.

Moreover, visual rewards like confetti were used when correct inputs were made as well as messages of congratulations after finishing levels to motivate the user. These particular elements have been included because the neurorehabilitation specialist stressed the importance of positive reinforcement in keeping user interest and motivation high. By combining these mechanics, MorSpeech ensures an engaging and inclusive learning experience, aligned with the goals of the DesignABILITY framework. Table 1 and Table 2 show implemented game and learning mechanics.

Table 1.
Implemented Game Mechanics

Feature	Mechanic	Purpose
Login/Progress Saving	Progress saving/synchronization across devices.	Allows users to continue their progress on different devices, ensuring continuity and motivation to return.
Levels and Unlockable Content	Progression through levels/unlocking new content.	Creates a sense of achievement and motivation to advance by unlocking new levels.
Visual Repres. of Progress	Visual indicators to show the current level.	Provides clear feedback on the user's progress, enhancing motivation.
Feedback System	Immediate audio and visual feedback for inputs.	Reinforces learning through immediate correction and positive reinforcement.
Reward System	Visual rewards for earned letters in evaluation levels.	Enhances user satisfaction and provides a fun, celebratory element.
Congratulation Messages	Messages of encouragement upon completing levels.	Provides positive reinforcement and motivates continued engagement.

Note: Author's own elaboration.

Table 2.
Implemented Learning Mechanics

Feature	Mechanic	Purpose
Incremental Learning	Introduction of new letters gradually through levels	Facilitates step-by-step learning, ensuring mastery of previous content before introducing new material.
Multi-Sensory Learning	Use of images, audio, and text	Accommodates different learning styles and supports users with visual impairments.
Practice and Reinforcement	Repetition of letters in subsequent levels and practice sessions	Reinforces learning and aids in long-term retention of Morse code.
Hint System	Visual hints and audio cues	Supports initial learning by providing aids to memorize Morse code.
Alternative Input Methods	Use of conductive objects (i.e. water) for input	Ensures accessibility for users with different motor abilities, making the system inclusive.
Evaluation Levels	Levels designed to assess knowledge without hints	Tests user knowledge and readiness to progress, ensuring they have mastered the content.
Progress Tracking	Display of earned letters and remaining letters to be learned	Provides a clear visual representation of progress, helping users see their achievements and what they still need to learn.

Note: Author's own elaboration.

4.4. Prototyping and development phase

The development of the MorSpeech system heavily relied on an iterative prototyping process. This ensured that insights from previous steps were integrated into a cohesive user-centered design. This involved both technical aspects of mobile application and hardware integration which ensured that the system works correctly, hereby converting theoretical and conceptual components into real models that can be tested continuously during optimization.

4.4.1. Low-Fidelity prototyping: rapid iteration

The initial prototyping stage focused on creating low-fidelity prototypes. These simplified prototypes prioritized basic functionality and interface layout.

4.4.2. Feedback and iteration

Low-fidelity prototypes provided vital information. The project team's insights were integrated with suggestions from a physical therapist with expertise in neurorehabilitation, who offered insightful knowledge on therapeutic and supportive design elements essential for users with speech and motor impairments. Additionally, the son of an ALS participant provided feedback that highlighted users' needs and real-world difficulties, further enhancing the development process.

4.4.3. Medium-Fidelity prototyping: building on the foundation

For medium-fidelity prototyping, the development team took their cues from low-fi prototypes. In this case, there was an addition of extra functionality thus giving a prototype that nearly resembled a finished product. There were changes like user interfaces upgrades, more inclusive accessibility options among other modifications that were influenced by the initial feedback.

4.4.4. High-Fidelity prototyping

During the final phase of prototyping, high fidelity prototypes were created. These working models looked similar to the final product in terms of design, usability and performance. They included all details such as game and learning mechanics, alternative input methods and multi-sensory feedback systems.

4.4.5 Refinement

Constant testing and refinement were highly necessary across all stages of prototyping. Each iteration aimed at addressing identified problems and incorporating new insights from feedback received. This involved technical experts, therapists and end-user representatives who worked in collaboration to undertake holistic design approach.

The final MorSpeech prototype consists of two main parts: a cross-platform Flutter application and ESP32 microcontroller-based hardware device. The purpose of these components is to provide users with motor speech limitations an accessible Morse code learning platform that is both engaging and easy to use.

4.4.6. Multiplatform flutter application

The MorSpeech app is developed using the Flutter framework that allows the development of native applications for multiple platforms (Orlova and Blasco, 2024), including Android and iOS which ensures that the application is accessible to a wide range of users, regardless of the mobile device they own. The progress of the user is saved in the cloud using Firebase services.

4.4.7. ESP32 Hardware device

The hardware component of MorSpeech is based on the ESP32 microcontroller (Zulfiqar, 2024) which is not only a versatile but also a cost-effective platform widely used in IoT applications. This device acts as an interface between the user's alternative input methods and the Flutter app. The final design of the MorSpeech system (see Figure 3) is expected to achieve accessibility and user engagement as well as adaptability to the needs of people with diverse abilities, this is possible through the integration of software and hardware components carefully designed for this purpose. This is important due to the introduction of various alternative methods of interaction with the system, providing and more enjoyable and effective learning experience.

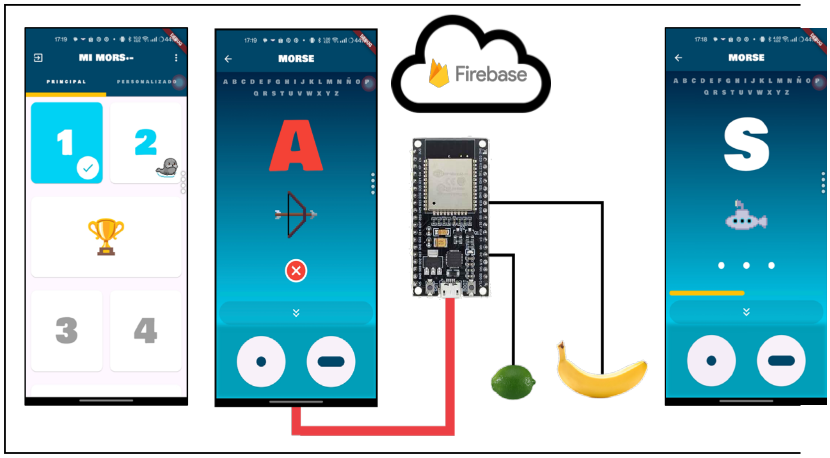

Figure 3. MorSpeech system.
Note: Author's own elaboration

4.5. Evaluation and iteration phase

This is the last phase of the MorSpeech design, which entails a thorough testing and analysis of the features of the prototype in terms of functionality, usability and effectiveness. It is during this phase where the design team makes sure that the system is adequate to the expectations of the target users and identify where the system can be improved.

4.5.1. Ethical Considerations and Participant Protection

All research activities involving human participants were conducted after obtaining ethical approval from the Institución Universitaria Antonio José Camacho Ethics Committee. Given the involvement of individuals with significant disabilities, particular attention was paid to ensuring a sensitive and respectful research process. Informed consent was obtained from all participants or their legal representatives prior to their involvement. The consent process clearly outlined the study's purpose, the nature of participation, data handling procedures, confidentiality measures, and the participants' right to withdraw at any time without consequence. To protect participant privacy, all data were anonymized, and any identifiable information was removed or disguised in reports and publications. The testing environment was designed to be comfortable and accommodating, with researchers ensuring that participants did not experience undue fatigue or distress during the evaluation sessions."

4.5.2. Participant and testing setup

The study involved three subjects including a 47-year-old woman (participant A) diagnosed with Amyotrophic Lateral Sclerosis (ALS). Other drawbacks consist of moderate coordination difficulties and motor limitations, although none of the two are severe for now, in addition to that, photosensitivity is an issue that restricts interaction with visual interfaces. With proper modifications, she can still use the system as required. Another participant is a 43-year-old man (participant B) who was diagnosed with irreversible motor and speech impairments due to perinatal hypoxia, but his condition does not necessarily preclude the person from using regular input devices like keyboards. While the participant was able to effectively express himself using either text or voice, he showed a keen interest in learning about emerging technologies and their potential to improve the communication capabilities of other individuals with the same or even more severe limitations. Finally, a 25-year-old male (participant C) who has a severe neurological deterioration, a traumatic brain injury, and underwent a hemispherectomy as a result of a brain infection. This participant showed significant motor challenges, including a spastic contracture in one hand, making it difficult to open, and fine motor dysfunction in the other hand, impeding precise movements. Despite these profound difficulties, he was able to use the prototype, particularly succeeding in tasks involving water containers which do not require fine motor control. His case underscores the prototype's adaptability to users with very limited motor function.

It is important to note that recruiting participants for studies involving individuals with severe and complex motor and speech impairments is exceptionally challenging. This is due to several factors, including the difficulty in obtaining necessary permissions from legal guardians or caregivers, the wide etiological diversity of these disabilities (meaning each case is unique), and the consequent need for highly personalized testing protocols tailored to individual capabilities. Therefore, while the number of participants is limited, the depth of insight gained from each case is substantial.

All participants (or their legal representatives) signed informed consents indicating their voluntary participation in the test and that there were no restrictions in using the system. In the document of informed consent, tall aspects of the evaluation were described, that is, the objective of the evaluation, the video recording of the entire session, the privacy aspects of the information, and the rights of the subject including the right to be excused during the test at his or her own free will.

The participants experienced levels 1 and 2 of the app before proceeding to the first TROPHY challenge, which was the first test of letters learned letters in the previous levels. After the participants were permitted to take on the 3rd and 4th levels, yet again they faced another new TROPHY challenge which was meant for letters acquired in the first 4 levels. Each level and TROPHY challenge is considered a task, and all together the participants had six such tasks to complete during this usability testing.

The letters to be learned were chosen to let the participants be able to spell in morse code basic words like their names, or the international distress signal in Morse code:

- Level 1 = A, S
- Level 2 = E, O
- Level 3 = R, N, I
- Level 4 = J, H

4.5.3. Evaluation procedure

During the evaluation, the participants interacted with the MorSpeech system using two different sets of input methods. For the first method, fruits (a circular slide of carrot for dot and a celery stick for dash) were used in levels 1, 2 and first TROPHY challenge, and for the second method, two water containers (one circular for dot and one rectangular for dash) were employed (as seen in Figure 4) for levels 3, 4 and second TROPHY challenge. This setup aimed to map the physical inputs to the Morse code representations of dots and dashes. Figure 4 shows tests carried out with different participants and alternative input methods.

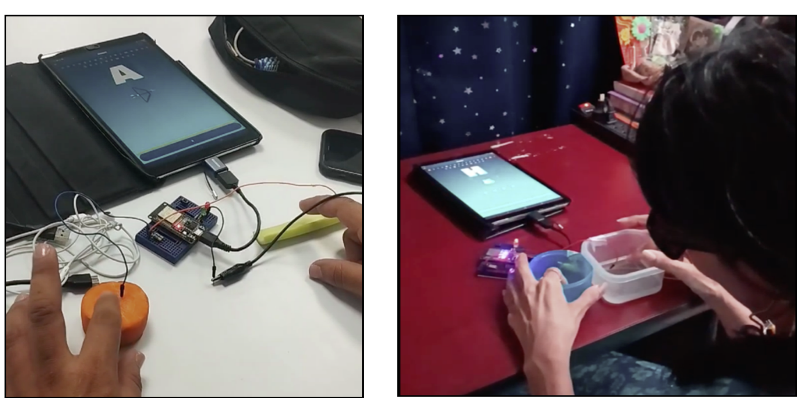

Figure 4. Usability tests with alternative input methods.
Note: Author's own elaboration

4.5.4. Quantitative data

Some metrics such as task completion rate, task time and number of errors per task (Tullis and Albert, 2008) were used during the usability test of the MorSpeech system.

- **Task Completion Rate**: Measures the percentage of levels successfully completed by the user. This metric assesses the overall effectiveness of the MorSpeech system in facilitating learning and progression through the levels.
- **Task Time:** Refers to the amount of time the participant takes to complete each task or level. It helps in understanding the efficiency of the system.
- **Number of Errors Per Task:** Measures how often the user makes mistakes while completing a task. This metric provides insights into the accuracy and clarity of the system's feedback mechanisms.

4.5.5. Qualitative data

Qualitative data was obtained through participant observation during usability testing, think aloud (Nielsen, 2012) if the participant felt it was necessary and a post-test assessment upon completion of the test scenario based on key focal dimensions:

- **General User Experience:** The participants' overall experience with the prototype, including positive and negative aspects.
- **Level and Trophy Structure**: Feedback on the structure and utility of the levels and trophies designed to facilitate Morse code learning.
- **Interaction with External Elements**: Assessment of the effectiveness and preference after using fruits and water containers as input methods.
- **Ease of Use:** The participant's perception of the system's usability, including confusing or difficult parts.
- **Feedback and Learning Mechanics:** The effectiveness of the system's feedback mechanisms and learning mechanics implemented in the app.
- **Improvements:** The participants' suggestions to improve the system.
- **Overall Evaluation:** The participants' overall evaluation of the system.
- **Final Exercise:** Asking the user to spell specific words in Morse code, observing any mistakes made with each letter.

The MorSpeech team endeavors to develop the system in such a way as to be usable and functional by users with motor and speech disabilities through iterative testing of the system against such users and incorporating their views within the development process. Such evaluation and iteration have a significant role in guiding further enhancements and developments of MorSpeech both in terms of user experience and performance.

5. Results

In this section, the evaluation of the MorSpeech prototype is presented which was done with two persons who have motor and speech impairments. During the evaluation, metrics like task completion rate, task time, and the number of errors per task were measured in order to assess the effectiveness of the system. These metrics helped to obtain a detailed picture of the participants experience using the system, what worked well and what did not.

The individuals who took part in the study actively used the system and commented in detail on the usability, methods of interaction, and the experience with the prototype. The results of metrics by participant C were not included in this section because he was not able to complete any task due to time constraints in the app that did not allow him to introduce Morse code at a slower time rate and thus no task was successfully completed by him, so a differentiated evaluation was carried out.

5.1. Task completion rate

The task completion rate for participants A and B was 100%, showing that all levels and tasks were successfully completed. This high completion rate suggests that the MorSpeech system is accessible and effectively designed to facilitate learning and engagement.

5.2. Task time and errors for participant A

Both metrics were measured for participants A and B and the results (see Figure 5 and Figure 6) show differences that will be discussed and explained in section 6.

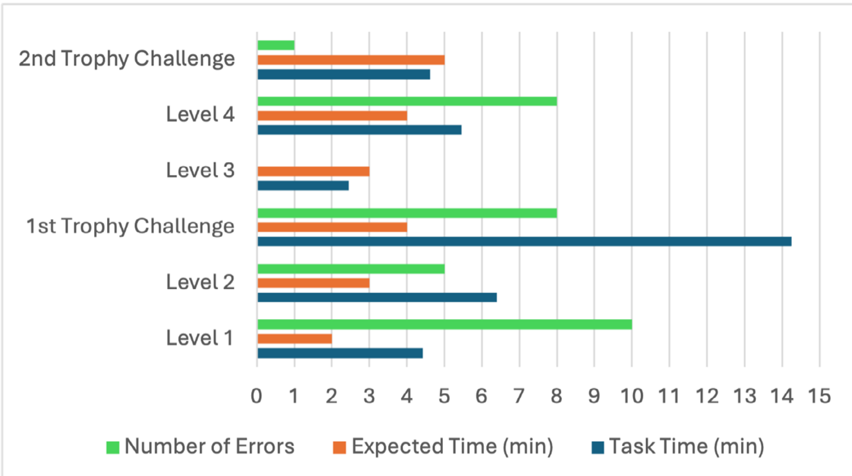

Figure 5. Comparison of Task Times and Errors for participant A.
Note: Author's own elaboration

5.3. Task time and errors for participant B

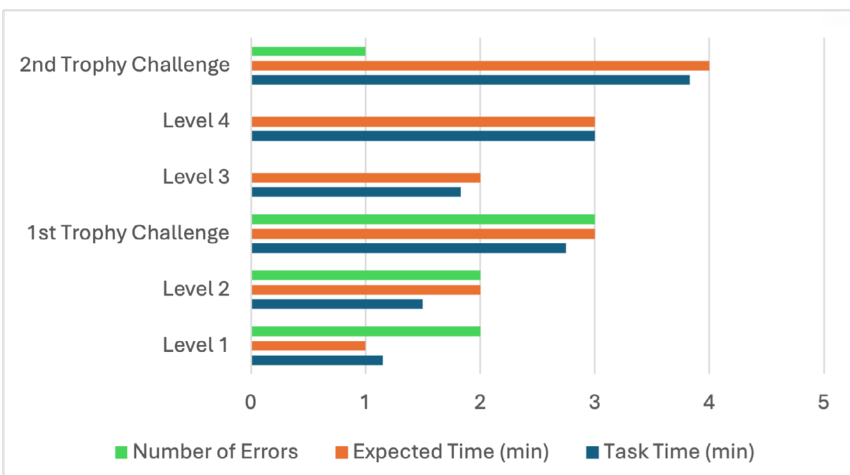

Figure 6. Comparison of Task Times and Errors for participant B.
Note: Author's own elaboration

Overall, the metrics (especially those from the TROPHY challenges) suggest that MorSpeech is able to assist in learning Morse code for users who may have both upper body and speech limitations. With 100% of the tasks completed successfully by the two study participants, this is a good sign that the system is usable and appealing to the users. However, it must also be emphasized that some of the errors which the participants made were not due to the accessibility or usability limitations of the system, but rather on the system's poor interpretation of the input signals.

5.4. Experience of Participant C

The interaction of Participant C, a 25-year-old male with severe neurological and motor impairments (spastic hand contracture, fine motor dysfunction) following a brain infection and hemispherectomy, further underscores the system's adaptability. He managed to use the prototype, particularly finding the water container inputs feasible due to the lack of need for fine motor skills. Unfortunately, this participant did not complete any of the tasks because of the limited time given by the app. This case, while highlighting the difficulties faced by users with such profound disabilities, also demonstrates the prototype's capacity to accommodate a range of severe physical challenges and the need for an even more personalized experience offered by the app, especially in this case where even though all participants have motor and speech impairments, their needs differed depending on the degree of each disability.

5.5. Overall experience

All participants expressed a highly positive overall experience with the Morse code learning prototype, indicating overall enjoyment of the system.

- Positive Aspects: Participant A appreciated the ability to learn at her own pace and found the auditory-based Morse code learning method intuitive, despite occasional confusion arising from both sounds (dot and dash). Also, the level-based structure and the use of trophy levels were particularly appreciated, as they provided a clear progression and sense of achievement. Participants B and C noted that the system effectively aligns with his existing motor and memory skills, a fortunate match that facilitated successful interaction.
- Negative Aspects: Participant A suggested adding more interaction methods to enhance the user experience, catering to diverse preferences and abilities. Participant B indicated that the auditory Morse code cues were a source of distraction, as he primarily relied on visual cues for interaction. Participant C needed more time to successfully finish each task.
- Structure: The level division was found to be very useful for learning Morse code, allowing the participants to progress through the material in manageable steps. Practicing with earned letters in the trophy levels was described by participant A as satisfying and motivational.
- Preference: All participants preferred using water containers over fruits or vegetables, finding them simpler and more effective for inputting Morse code. This preference highlights the importance of offering multiple interaction methods to accommodate user needs.
- Effectiveness: For all participants, the interaction methods were found effective for learning Morse code. Participant A highlighted that the multi-sensory feedback provided by the system helped reinforce learning.
- Difficulties: Participant A faced issues differentiating between the dot and dash sounds was sometimes challenging, particularly for letters 'S' and 'O', while participant B encountered difficulty using the celery stick to input dashes. This was due to insufficient conductivity, which impeded proper signal transmission to the hardware.
- Usability: The prototype was rated as easy to use, with the interface being straightforward and accessible. Despite the overall ease of use, there were some confusing parts, specifically related to distinguishing between the sounds of dots and dashes for participant A.
- System's Feedback: Participant A and C had some difficulties with the Morse code sounds, which sometimes made it hard to differentiate between similar letters. Initial training or tutorials were suggested to help users better distinguish between dot and dash sounds at the beginning of their learning journey.

Participant B recommended offering users the option to deactivate auditory Morse code cues and provide different kinds of sounds for a more personalized experience.

- Improvements: Participant A suggested implementing an initial training phase to better differentiate between the dot and dash sounds. Also, adding more interaction methods was recommended to cater to a broader range of user needs and preferences. In contrast, participant B and C advocated for two user-selectable options: muting auditory feedback and adjusting the validation time for user-inputted Morse code. Additionally, participant B suggested implementing a progress tracking feature that not only displays earned letters and unlocked levels but also incorporates errors made, letters identified as challenging, and time taken per level. This comprehensive progress dashboard would empower users to conduct self-assessment and tailor their learning experience.
- Future Use: The participants indicated a willingness to use the prototype again, especially with further improvements to the system.
- Experience Rating: The overall experience with the prototype was rated as good by both participants.
- Final Exercise: For the final exercise, participants and B successfully spelled the following words in Morse code without mistakes:
    - JOHANNA (This is participant A's first name, spelled as):
        - J(. - - -) O(- - -) H(. . . .) A(. -) N(- .) N(- .) A(. -)
    - JOHN JAIRO (These are participant B's first and middle name, spelled as):
        - J(. - - -) O(- - -) H(. . . .) N(- .) J(. - - -) A(. -) I(. .) R(. - .) O (- - -)
    - S O S (This is the international distress signal in Morse code, spelled as):
        - S(. . .) O(- - -) S(. . .)
    - ROSA (The Spanish word for "rose," spelled as):
        - R(. - .) O(- - -) S(. . .) A(. -)
    - ASEO (The Spanish word for "cleanliness," spelled as):
        - A(. -) S(. . .) E(.) O(- - -)

These words were chosen to test the participant's ability to reproduce Morse code using the letters practiced and learned during the evaluation stage. The successful completion of this final exercise indicates effective learning and retention of Morse code through the prototype using either audio cues, visual cues or both in order to match diverse learning styles. Participant C did not do this part of the evaluation due to the need of more interaction with the prototype, taking into account that even though he was able to interact with the system through the water containers, sometimes the time given by the app to complete the task was not enough for him.

6. Discussion

The evaluation of the MorSpeech prototype offered constructive suggestions which also served to reaffirm its positive features. In this part, the results' implications are considered, in particular how the DesignABILITY framework contributed to its efficiency and importance, and what could be improved or added in the following versions of the system. In order to contextualize the outcomes better from the perspective of the advantages of the DesignABILITY framework, this part is structured around the main themes derived from the evaluation.

- Effectiveness of the DesignABILITY Framework: The generally positive feedback provided by the participants of the Morse code learning prototype indicates the effectiveness of the DesignABILITY framework in designing inclusive and accessible interfaces targeting people with physical and speech impairments. Participant A and B's needs were fully met during the tool's development, as evidenced by the task success rate of 100%. However, participant C's needs were not met, as he required a more customized experience that would have enabled him to complete some of the tasks. Even though the cohort of three participants is small, it is important to consider the enormous difficulties in finding people with such severe and particular disabilities. Long approval processes, reliance on caregivers, and the need to identify people whose unique circumstances and abilities match the study's requirements are all common components of the process. As a result, each participant offers priceless, in-depth insights that could be diluted in larger, more diverse samples.

This effectiveness of the DesignABILITY framework validates the need for specific methodologies for complex disabilities, distinguishing it from more general frameworks such as SCAFFOLD (Seo and Richard, 2021). While SCAFFOLD focuses on inclusion in broad learning environments, our results demonstrate that DesignABILITY's granular focus and 'Empowerment Planning' stages are crucial for addressing the specific technical and personal barriers of users with severe motor impairments. Likewise, unlike the model by (Namoun, et al., 2022), which specializes in service selection through machine learning, this study shows that an empowerment-centered generative design process allows for the creation of tools from scratch that adapt to the user's etiological diversity.

- Engagement and Motivation through Gamification: MorSpeech's level-based system was crucial in maintaining participant engagement as a result of the gamification implementation in the DesignABILITY framework. Progressing from level to level and obtaining letters in TROPHY challenges as rewards created an atmosphere of success and fulfillment, which is important for continuous participation. Even though the tasks took longer than expected and included a fair number of errors (by first levels of experience), the participants' continued interest in them shows how well the framework integrates elements of motivation that help the user overcome the initial challenges. These findings regarding motivation through levels and trophies reinforce the utility of Morse code as a low-cost, highly effective medium described by Tarek et al. (2022). Nonetheless, MorSpeech overcomes a key limitation of Google's Morse project (Use All Five, Google Creative Lab, n.d.), which relies on English-centric visual aids that can be confusing for non-native speakers. By integrating multisensory feedback and game mechanics that do not depend on visual linguistic cues, this system achieves a 100% success rate in learning fundamental letters among Spanish-speaking users.

  This study shows high engagement levels that align with the findings of Sodhi et al. (2023), who emphasize the importance of gamification for inclusivity in digital environments (video games). The DesignABILITY framework applies these game mechanics to a fundamental communication tool. These results suggest that gamification is not only vital for leisure but is a powerful driver for the intensive practice required to master assistive communication systems.

- Diverse Interaction Methods: The validity of the principle put forward by the framework of having as many interaction methods as possible was covered by the actual emerging users' overweighted preference for water containers instead of fruits or vegetables, pointing out the need for ease and perceived accuracy. This feedback justifies the framework's stance of incorporating multiple interaction possibilities to meet the demands and the preferences of the users. The participants' preference for water containers over fruits aligns with the need for personalized, non-invasive interfaces noted by Schultz Ascari et al. (2019). However, MorSpeech expands interaction possibilities compared to more restrictive systems, such as the eye-blink system by Sushmitha et al. (2021), the finger tracking of WiMorse (Niu, et al., 2019) or the one proposed by Kranthi et al. (2020) that relies on touch, gestures, and microphones for input. The results with Participant C demonstrate that MorSpeech is viable even for users with profound fine motor dysfunction and spastic contractures, thanks to the use of low-precision alternative inputs like water containers.

  Refinement of Input Mechanisms: The study's participants encountered the difficulty of unexpected input activation when utilizing the prototype, which underscored the significance of the DesignABILITY framework's iterative approach. Problems caused by the system misinterpreting inputs show that input detection needs to be improved. This mirrors the principle of the framework where enhance capabilities are developed in response to user needs received from feedback as the assistive technologies keep advancing and becoming more usable and accessible.

- Feedback and Sensory Considerations: The difficulty faced by Participant A in differentiating between the sounds of dots and dashes revealed a critical area for improvement in the prototype's feedback mechanisms. The framework's emphasis on multisensory feedback was validated, but the need for initial training sessions to help users distinguish these sounds effectively was also highlighted.

  Statistical Evaluation: Regarding the quantitative metrics such as task time and error rates, these are presented descriptively for each participant. Given the small and heterogeneous nature of the participant sample (N=3) -a common characteristic in exploratory research with populations experiencing severe and diverse impairments- a formal inferential statistical analysis was not performed. Such analyses would lack statistical power and could yield misleading conclusions with this sample size. Instead, the quantitative data are intended to provide an exploratory overview of individual performance patterns and are interpreted in conjunction with the rich qualitative data gathered, which offers deeper insights into the usability and effectiveness of the MorSpeech prototype for each user's unique context. The challenges experienced in recruitment (N=3) and the heterogeneity of the sample are not isolated weaknesses, but rather an intrinsic characteristic of research with populations with profound disabilities, as indicated by Millán et al. (2010) when referring to the complexity of user-machine adaptation. As in the case studies by Garro et al. (2019), the depth of the qualitative data obtained from each participant in this study offers a clinical and functional validity that massive statistical analyses could not capture in this context of individual-centered design.

- Limitations of the Study and Prototype: Several limitations should be acknowledged in this study. Firstly, the MorSpeech prototype, while demonstrating feasibility, has inherent hardware considerations. Its reliance on the ESP32 microcontroller and specific conductive materials (fruits, water) for alternative input introduces potential variability and may require further refinement for robustness and everyday usability. As noted in the results, some errors were attributed to the system's interpretation of input signals, indicating a need for improved sensor calibration and input detection algorithms.

  Secondly, the participant sample, while providing deep qualitative insights, is small (N=3). Recruiting for studies with individuals experiencing severe and heterogeneous motor and speech impairments is exceptionally challenging, as previously discussed. This small sample size limits the generalizability of the quantitative findings and means that the variability in user feedback, while valuable, reflects a narrow range of the diverse experiences within this population. For instance, Participant A's photosensitivity and reliance on auditory cues differed significantly from Participant B's preferences and Participant C's profound motor challenges, highlighting that a 'one-size-fits-all' AT solution is rarely optimal.

  Thirdly, the evaluation may have been subject to a novelty effect, where participants' engagement or performance could be influenced by the newness of the technology. While feedback was largely positive, prolonged longitudinal studies would be needed to assess sustained usability and effectiveness. Researcher presence during testing, although intended to be supportive, might also have subtly influenced participant interaction.

- Future Enhancements: Recommendations provided by participants for additional input methods during interaction, better first training, ability to turn off sound and increased accuracy for the user's input in some interaction techniques are the improvements that will be incorporated for the next usability test. By integrating these recommendations, the system can become more versatile and usable, which is in line with the framework's goal to develop assistive and inclusive technologies.

  Future work will focus on enhancing MorSpeech by integrating Artificial Intelligence (AI) for features such as predictive text, adaptive error correction, and more natural text-to-speech conversion. The DesignABILITY framework will continue to guide this development. For example, the 'Abilities Assessment' of users with varying communication speeds and error patterns will inform the training and personalization of AI models. The 'Empowerment Planning' stage will help define how AI can proactively assist users, perhaps by learning their common phrases or adapting to their unique Morse input styles to reduce physical and cognitive load. The 'Prototyping' stage will involve developing and iteratively refining these AI-driven features, and the 'Evaluation' stage will be critical in assessing not only the technical performance of the AI but also its impact on user communication efficiency, perceived effort, and overall satisfaction. This will involve further usability tests with a broader range of participants to ensure the AI enhancements genuinely empower users in alignment with the framework's core principles.

7. Conclusions and future work

This paper has presented the revised DesignABILITY framework, a 5-stage user-centered methodology for developing assistive technologies and demonstrated its practical application in the creation and initial evaluation of the MorSpeech system for individuals with motor and speech impairments. The study underscores the framework's value in guiding the development of functional, engaging, and accessible tools by systematically addressing user abilities, empowerment, engagement, and iterative refinement.

The evaluation of the MorSpeech prototype has demonstrated the significant benefits of using the DesignABILITY framework in the development of assistive technologies. The framework was found valuable to be effective in guiding designers through the development of a functional, engaging, and accessible tool for people with motor and speech impairments by focusing first on identifying users' abilities, then empowering them through carefully defining how the system will assist them in performing tasks that are challenging due to impairments, followed by determining the right engagement elements and finally taking these features to a user-centered prototype that was evaluated through an iterative process that led to iterative enhancements.

One of the advantages of the DesignABILITY framework is that it advocates for a more systematic collection of data to profile the problems in a way that better serves the users. The first step involved literature review of health problems that alter motor and or speech abilities, which made this preliminary study necessary in identifying the needs of the users and challenges they experience while interacting with other people. It offered a good appreciation of the disorders, enabling the design team to modify the MorSpeech system for the targeted audience with speech and motor impairments. During the early stages of development, insights from a person with ALS and a specialist in neurorehabilitation informed the subsequent design phases.

The incorporation of game mechanics in the third stage of the framework, such as rewards, level progression, and learning mechanics like practice and evaluation, significantly enhanced user engagement and motivation. This approach was necessary in maintaining the participants' interest and commitment to learning Morse code. The positive feedback on the structured levels and trophy stages underscores that users found this strategy effective in educational tools for people with disabilities.

Iterative prototyping allowed for continuous improvements during the fourth stage of development because all participants provided feedback that highlighted areas for improvement in terms of interaction strategies and feedback procedures. By making these changes, the MorSpeech system was able to adapt to the needs and preferences of its users, increasing its usability and efficacy.

The final phase of the framework involved a thorough evaluation of the MorSpeech prototype. The system's performance was quantified by the task completion rate, task time, and number of errors, which also revealed certain usability issues. Data gathered through direct observation and post-test evaluation provided insights on how the user system interaction could be enhanced. High task completion rate and a general positive user experience confirmed that the DesignABILITY framework is an effective approach for developing assistive technologies that are impactful.

The DesignABILITY framework has demonstrated its value in every stage of the design process for MorSpeech. From initial research to prototyping and final evaluation, each stage contributed to creating a user-centered, inclusive, and effective assistive technology that not only meets the needs of individuals with motor and speech impairments but also enhances their learning experience and may be helpful for users to overcome their disabilities, thanks to the framework's emphasis on user needs, iterative design, gamification, and rigorous evaluation.

After a series of usability tests with potential users that can benefit from the use of the MorSpeech system, a new module will be developed for the mobile app for Morse-to-text and text-to-speech conversion, this way, the system will be able to support communication of targeted users. Also, the integration of Artificial Intelligence (AI) will enhance the user experience as the system will be able to correct mistakes made by the user, suggest and predict sentences to make this communication process easier.

The challenges encountered in recruiting a larger sample size also underscore the need for collaborative research networks and potentially multi-site studies to gather more extensive data on assistive technologies for these populations. Furthermore, the unique presentation of each individual with severe motor and speech impairments (as exemplified by our three participants with differing etiologies and capabilities) reinforces the necessity for personalized approaches and highly adaptable systems, a core tenet of the revised DesignABILITY framework.

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Data availability

The authors declare that the article contains all the data necessary and sufficient for understanding the research.

Disclosure statement

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee of Institución Universitaria Antonio José Camacho (ING-001-22-01 march 4th 2022)."

Informed Consent Statement

Informed consent was obtained from all subjects (or their representatives) involved in the study.

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The manuscript was originally drafted in English by the authors. Assistance with language editing was subsequently provided by Google's Gemini to refine sentence structure and ensure grammatical accuracy. The tool was used exclusively for proofreading, not for translation. All intellectual contributions, including the research ideas, data analysis, and conclusions, are solely the work of the authors, who bear full responsibility for the content of this paper.

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APPENDICES

A. Ethical Considerations

A.1. University ethics committee endorsement – Spanish

DECANATO ASOCIADO DE INVESTIGACIONES
COMITÉ DE ÉTICA DE LA INVESTIGACIÓN

CONCEPTO ÉTICO A PROTOCOLOS DE INVESTIGACIÓN

El Comité de Ética de la Investigación de la [redacted] en adelante CEI-UNIAJC es *"un organismo colegiado e interdisciplinar y tiene como función principal velar por el respeto de la dignidad, bienestar e integridad de todos los participantes en los procesos de investigación adelantados por la* [redacted]*- o de aquellos en los que participe en cualquier forma la institución. Igualmente, será un organismo asesor para la discusión y conceptualización sobre los diferentes problemas éticos que surgen en torno a los procesos de investigación"* (Artículo 3, Resolución No. 466 de 2018)

El CEI-UNIAJC tiene competencia de acción sobre todos los "trabajos de grado, tesis de maestría y doctorado, las investigaciones de los profesores y las investigaciones de otras instituciones en las que participa la UNIAJC" (Cf. Literal b, Artículo 5, Resolución No. 466 de 2018) en la que el ser humano y/o cualquier forma de vida sean sujetos de estudio, prevaleciendo el criterio del respeto a su dignidad y la protección de sus derechos y su bienestar (Cf. Artículo 5 de la Resolución 0008430 de 1993)

I. INFORMACIÓN GENERAL DEL PROTOCOLO DE INVESTIGACIÓN

Título del protocolo de investigación evaluado	Adaptation of the DesignABILITY Framework for the Design of an Interactive Tool to Support Communication for People with Physical and Speech Impairments	
Objetivo	Adaptar el framework DesignABILITY para el diseño de herramientas interactivas que apoyen la comunicación para personas con discapacidades motrices y del habla a través de código morse	
Investigador principal	[redacted]	Código ING-001-22-01

II. CONCEPTO DEL COMITÉ

Proyecto con Aprobación Expedita	
Proyecto Aprobado	X
Proyecto Pendiente	
Proyecto no Aprobado	

III. CLASIFICACIÓN DEL RIESGO

Partiendo de los expuesto en el artículo 11 de la Resolución No. 0008430 de 1993, el aval ético que se emite al protocolo de investigación referenciado en el numeral I, se cataloga como:

Proyecto Sin Riesgo	
Proyecto con Riesgo Mínimo	
Proyecto con riesgo mayor que el mínimo	X

DECANATO ASOCIADO DE INVESTIGACIONES
COMITÉ DE ÉTICA DE LA INVESTIGACIÓN

CONCEPTO ÉTICO A PROTOCOLOS DE INVESTIGACIÓN

IV. OBSERVACIONES

Las siguientes observaciones deben ser atendidas por el Investigador Principal y ser entregadas al CEI-UNIAJC en los tiempos que este designe:

- Durante la ejecución del proyecto informar al CEI-Uniajc los cambios y/o ajustes que se puedan presentar.
- Garantizar la anonimización de los datos obtenidos, especialmente en la presentación de los resultados de la investigación.

Vigencia: El presente Aval tiene vigencia de dieciocho (18) meses de acuerdo con el cronograma presentado por los investigadores, a partir de la firma del acta de inicio. Si una vez cumplido este tiempo, los investigadores solicitan prorroga al DAI para la culminación del proyecto, deben notificar al Comité de Ética de la Investigación.

Firma del Presidente del CEI-UNIAJC [redacted]	**Fecha** Marzo 04 de 2022
Nombres y apellidos [redacted]	**Capacidad de representación** Presidente Comité de Ética de la Investigación
Contacto: Decanatura Asociada de Investigaciones, Casa Docente, Avenida 6N No 28N-102 Teléfono: 6652828, Ext. 3305 Correo electrónico: conitedeetica@[redacted]	

Note: Copy from Research Ethics Committee

A.2. University ethics committee endorsement - English

ASSOCIATE DEAN OF RESEARCH
RESEARCH ETHICS COMMITTEE

ETHICAL CONCEPT FOR RESEARCH PROTOCOLS

*The Research Ethics Committee of the [redacted], hereinafter CEI-UNIAJC, is *"a collegiate and interdisciplinary body whose main function is to ensure respect for the dignity, well-being, and integrity of all participants in the research processes carried out by the [redacted]– or those in which the institution participates in any way. Likewise, it will be an advisory body for the discussion and conceptualization of ethical problems that arise around research processes"* (Article 3, Resolution No. 466 of 2018)

*The CEI-UNIAJC has jurisdiction over all *"graduate papers, master's and doctoral theses, research by professors, and research by other institutions in which UNIAJC participates"* (Cf. Literal b, Article 5, Resolution No. 466 of 2018) in which the human being and/or any form of life are subjects of study, prevailing the criterion of respect for their dignity and the protection of their rights and well-being (Cf. Article 5 of Resolution 0008430 of 1993)*

I. GENERAL INFORMATION ON THE RESEARCH PROTOCOL

Title of the research protocol evaluated	Adaptation of the DesignABILITY Framework for the Design of an Interactive Tool to Support Communication for People with Physical and Speech Impairments	
Objective	**To adapt the DesignABILITY framework for the design of interactive tools that support communication for people with physical and speech impairments through Morse code**	
Main researcher	[redacted]	Code ING-001-22-01

II. COMMITTEE'S CONCEPT

- Project with Expedited Approval [ ]
- Approved Project [X]
- Pending Project [ ]
- Project not Approved [ ]

III. RISK CLASSIFICATION

Based on the provisions of article 11 of Resolution No. 0008430 of 1993, the ethical endorsement issued to the research protocol referenced in numeral I, is cataloged as:

- No Risk Project [ ]
- Project with Minimum Risk [ ]
- Project with risk greater than minimum [X]

ASSOCIATE DEAN'S OFFICE FOR RESEARCH
RESEARCH ETHICS COMMITTEE

ETHICAL CONCEPT FOR RESEARCH PROTOCOLS

IV. OBSERVATIONS

The following observations must be addressed by the Principal Investigator and delivered to the CEI-UNIAJC within the times it designates:

- During the execution of the project inform the CEI-Uniajc of changes and/or adjustments that may occur.
- Guarantee the anonymization of the data obtained, especially in the presentation of the research results.

Validity: This Endorsement is valid for eighteen (18) months in accordance with the schedule presented by the researchers, starting from the signing of the start-up act. If once this time has elapsed, the researchers request an extension to the DAI for the culmination of the project, they must notify the Research Ethics Committee.

Signature of the President of the CEI-UNIAJC [redacted]	**Date:** March 04, 2022
Names and surnames: Juan Carlos Cruz Ardila	**Capacity of representation:** President of the Research Ethics Committee
Contact: Associate Dean's Office for Research, Casa Docente, Avenida 6N No 28N-102 Telephone: 6652828, Ext. 3305 Email: conitedeetica@admon.uniajc.edu.co	

Note: Copy from Research Ethics Committee

A.3 Consent Form (Signed) – Spanish

Consentimiento para Participar en la Prueba de Prototipo

Proyecto: Sistema de Aprendizaje de Código Morse para Apoyar la Comunicación de Personas con Dificultad del Habla y/o Motriz

Investigador Principal: [redacted]

Fecha: Mayo 11 de 2024

Yo, ______________________, comprendo y acepto que estoy participando en la prueba de un prototipo para el proyecto mencionado anteriormente. Entiendo que el propósito de esta prueba es evaluar la funcionalidad y usabilidad del prototipo.

Entiendo que:

Se me pedirá que utilice el prototipo y proporcione retroalimentación sobre mi experiencia.

Entiendo que la información recopilada durante esta prueba será utilizada únicamente con fines de investigación y desarrollo del prototipo, se mantendrá confidencial y ningún dato sensible que me identifique será revelado.

Tengo derecho a retirarme de la prueba en cualquier momento si así lo decido.

Si experimento cualquier malestar o incomodidad durante la prueba, tengo derecho a interrumpirla inmediatamente.

Confirmo que no tengo restricciones para usar o estar cerca de dispositivos como teléfonos inteligentes o Tablets y que el equipo de investigación hará todo lo posible para garantizar mi comodidad y seguridad durante la prueba.

Acepto la grabación de video o la toma de fotografías de espaldas a la cámara.

Firmo este consentimiento de manera voluntaria, demostrando que he entendido completamente la información proporcionada y que estoy de acuerdo en participar en esta prueba.

Firma del Participante: ______________________

Note: Author's own elaboration from signed consent form

A.3 Consent Form (Signed) – English

Consent to Participate in the Prototype Test

Project: Morse Code Learning System to Support the Communication of People with Speech and/or Motor Disabilities

Principal Investigator: [redacted]

Date: May 11, 2024

I, ______________________, understand and accept that I am participating in the testing of a prototype for the aforementioned project. I understand that the purpose of this test is to evaluate the functionality and usability of the prototype.

I understand that:

I will be asked to use the prototype and provide feedback on my experience.

I understand that the information collected during this test will be used solely for research and prototype development purposes, will be kept confidential, and no sensitive data that identifies me will be disclosed.

I have the right to withdraw from the test at any time if I so decide.

If I experience any discomfort or unease during the test, I have the right to interrupt it immediately.

I confirm that I have no restrictions on using or being near devices such as smartphones or Tablets and that the research team will do everything possible to guarantee my comfort and safety during the test.

I accept video recording or taking photographs with my back to the camera.

I sign this consent voluntarily, demonstrating that I have completely understood the information provided and that I agree to participate in this test.

Participant's Signature: ______________________

Note: Author's own elaboration from signed consent form