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An Accessible Serious Game-Based Platform for Process Learning of People with Intellectual Disabilities

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Abstract: This research presents the "LudoMinga" platform based on serious games designed to facilitate the learning process of people with intellectual disabilities. The platform is focused on providing an inclusive and accessible learning environment. Serious Games combines educational content with video game mechanics, and the platform aims to enhance the learning experience and promote active participation. Through an iterative development process, including user feedback and evaluations, the platform was developed using the iPlus methodology to align with the specific requirements of the target audience. Preliminary user test results indicate positive results in terms of user engagement, learning, and satisfaction. This accessible platform based on serious games promises to improve educational opportunities and outcomes for people with intellectual disabilities, ultimately fostering their personal and cognitive development. The success of the "LudoMinga" platform lies in the combination of interactive games, personalized support, and accessibility features, ultimately creating an engaging and effective learning environment. Continued advances in this area have the potential to unlock barriers for people with intellectual disabilities, fostering their growth, independence, and active participation in society.

Keywords: serious games; learning; cognitive abilities; education; LudoMinga; disability; software engineering; accessibility; usability

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1. Introduction

Over the past decade, constitutional and legal changes in Ecuador have significantly increased the relevance of studying and addressing disabilities. This heightened attention to researching and treating disabilities has brought to light the societal issue of limited responsibility and exclusivity at all levels. While there have been gradual improvements, the situation still remains inadequate despite efforts to promote inclusion and address disabilities through initiatives such as public policies, educational programs, academic research, and context-specific product design tailored to the Ecuadorian context.

The ubiquitous presence of Information and Communication Technologies (ICT) presents opportunities and challenges for society. It is imperative to harness the potential of ICT to develop more democratic and inclusive societies. ICT plays a crucial role in realizing Sustainable Development Goal 4 (SDG 4) of the 2030 Agenda, which aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for everyone" [1].

Nevertheless, searching for reasons, causes, and consequences should continue to drive knowledge and understanding, ultimately leading to improved inclusion of people with disabilities.

The World Health Organization (WHO) indicates that 16% [2] of the global population has a disability, representing a significant challenge for universal design and accessibility professionals about serious games. In Ecuador, as reported by the National Council for Disability Equality, 471,250 individuals have a disabling condition, of which 23.12% have been diagnosed with an intellectual disability [3]. For individuals with this type of disability, achieving educational, social, and labor inclusion is often a significant challenge due to society's perception of this population, which requires priority attention.

In the specific context of this project, the research was motivated by a need to support the treatment and improvement of a particular group of individuals with disabilities, to reduce difficulties related to cognitive abilities, focusing on fundamental aspects such as perception, attention, and memory. As the research continued, a learning platform was developed as a valuable tool for the targeted population under investigation. Thus, the area of disability became a convergence point for multiple disciplines, where research experts from education, psychology, and engineering contributed to a scientific search and proposal process.

The learning platform developed and implemented in this project, named "LudoMinga" consists of several mini-games designed to promote the acquisition and development of cognitive skills among the target population. The platform integrates serious games designed based on the "iPlus Methodology", which adopts a participatory, flexible, and user-centered design approach. The platform employs creative techniques that are easily understandable by all users, combining entertainment and serious aspects with the participation of experts. The application targets individuals with mild to moderate intellectual disabilities who do not face physical barriers to regularly using technological devices.

Furthermore, this study intends to evaluate the usability and accessibility of the developed learning platform, taking into account its efficiency, effectiveness, and satisfaction levels, using the CSUQ (Computer System Usability Questionnaire). Similarly, the platform's compliance with the WCAG (Web Content Accessibility Guidelines) 2.1 guidelines will be assessed to ensure its accessibility. The evaluation results will enable us to measure the platform's usability and accessibility for successfully implementing the project entitled "A framework as a support tool to improve socio-cognitive skills within the framework of full inclusion for people with intellectual disabilities regardless of the place of residence".

This article is structured as follows: Section 2 presents a framework providing context on models for addressing disabilities, serious games, the characterization of the target population, and our proposed solution to the problem. Section 3 describes the design of serious games for cognitive disabilities and the implementation of the "LudoMinga" learning platform. Section 3 proposes evaluations of the platform's accessibility and usability. Finally, Sections 4 and 5 present the discussion and conclusions, respectively.

1.1. Background and Framework

1.1.1. Disability

In recent decades, there has been an evolution in the conceptualization of disability and a shift in perception toward people with disabilities. This notable conceptual evolution is observed in several countries as society strives towards a more inclusive and less segregated world [4].

In the 1980s, disability was defined as the objectification of deficiency in the individual with a direct impact on their ability to perform activities that were considered normal for any individual of their characteristics (age, gender, etc.). This was established in the International Classification of Impairments, Disabilities, and Handicaps (ICIDH) published by the World Health Organization in 1980 [5].

In the specific context of this project, the current definition of intellectual disability refers to a limitation in intellectual functioning, which translates to difficulties in under-

standing or reasoning. Furthermore, it can be defined as a limitation in adaptive behavior, such as understanding concepts, social relationships, or practical skills [6].

When discussing adaptive behavior, we refer to the abilities or skills necessary for individuals to function effectively daily, whether at home, work, educational institutions, or in the community they reside in [7]. To achieve adequate adaptive behavior, individuals with intellectual disabilities require the necessary support and resources to strengthen their psychological processes and develop autonomy by the degree of disability they possess. Psychological processes refer to an individual's mental processes, including perception, attention, memory, language, and cognition [8].

To strengthen the psychological processes of individuals with disabilities, it is essential to design and create a web platform consisting of psychoeducational video games that motivate learning processes, allowing people with intellectual disabilities to improve their cognitive and social skills and develop their adaptive behavior for better inclusion. There are several web platform options available that promote this objective, but it is worth noting that our proposal has a language, images, and content type for the Ecuadorian context. Therefore, the serious game proposal is built from an Ecuadorian cultural context intended for Ecuadorian end-users. In this sense, we based our work on the needs and particularities of the beneficiaries, taking the Ecuadorian context as a reference.

1.1.2. Disability Approach Models

Theoretical models of disability are conceptual approaches that allow us to understand and examine the world of people with disabilities from different perspectives [9]. Over time, there has been an evolution in the definition of disability and the associated models of care. These models have adapted to reflect the advances in our understanding of disability and to more effectively address the needs and rights of people with disabilities.

In the past, until the mid-20th century, the prevailing theoretical model for addressing disability was the individualistic model. This approach viewed disability as a divine punishment, a personal tragedy, or an individual deficiency. Under this paradigm, people with disabilities were seen as objects of pity, incapable of fully participating in society. The focus was on "fixing" or "normalizing" the person with a disability, with little emphasis on the role of society in creating barriers and limitations.

However, following the Second World War, advocacy movements for people with disabilities sparked a fundamental shift in perspective. These movements advocated for a social model of disability, which posits that disability is not simply an individual characteristic but is deeply rooted in the social environment and attitudes. According to this approach, disability is constructed and experienced based on the social context in which individuals live.

In the social model of disability, it is emphasized that society is responsible for removing the barriers that limit the full participation of people with disabilities. These barriers can manifest in discrimination, lack of access to necessary services and supports, and negative attitudes and stereotypes perpetuating exclusion. This approach highlights the importance of ensuring equal opportunities, inclusion, and respect for the human rights of people with disabilities.

1.1.3. Serious Games for Cognitive Disabilities

To promote better development in their environment, people with intellectual disabilities need to develop cognitive functions, which refer to the mental processes required to perform any task and facilitate the reception, selection, transformation, storage, processing, and recovery of information.

Serious games for cognitive disabilities are digital games designed with the purpose of promoting cognitive development in individuals with cognitive impairments. Serious games have been identified as effective tools for training and supporting individuals with cognitive disabilities [10–13]. They offer engaging and motivating learning experiences.

The definition of serious games varies among researchers. Clark C. was one of the first to provide a formal definition, stating that serious games should not be solely for personal pleasure but should aim at instructing, informing, and educating [14,15]. Michael Zyda defines serious games as mental contests played with a computer according to specific rules, utilizing entertainment to promote various objectives related to government, corporate training, education, health, public policy, and strategic communication [16].

Carrión-Toro M. presents an updated definition that combines different elements of serious games, emphasizing their use for different purposes and incorporating video game components to enhance user experience and engagement.

> "Computer application used for different purposes, such as the dissemination of messages, training and data exchange in different contexts (education, defense, religion, health, politics), containing elements of video games, such as story, gamification, gameplay, art and software, both of which are used to enhance user experience and engagement" [17–19].

Various components are considered in serious games, including the serious aspect, storytelling, gameplay, and gamification [16,20–25].

Various components are considered in serious games, including the serious aspect, storytelling, gameplay, and gamification:

- Serious Aspect: refers to the pedagogical aspects or content relevant to the specific field addressed in the serious game;
- Storytelling: involves describing the story or narration within the game, incorporating visual art;
- Gameplay: refers to the actions or functionalities players perform in the game scenario;
- Gamification: incorporates elements from video games that motivate and engage the player.

Several studies have investigated the relationship between serious games and cognitive disabilities, highlighting the positive impact of digital games on children's cognitive skill development. In his article [26] Pitaru emphasizes the significance of inclusive game design and underscores the importance of considering individuals with disabilities. This involves ensuring accessibility, providing customization options, and allowing control over game elements such as timing and response. By incorporating these principles, game designers can create engaging experiences that foster enjoyment, facilitate cognitive growth, and offer equal opportunities for players of all abilities.

Maresa-Yee [10] designed a serious game to improve identification and auditory discrimination skills in children with hearing disabilities who use hearing aids or cochlear implants. The project integrates emotional design, serious game development methodologies, and activities applied by teachers to enhance listening skills in these children. Similarly, other researchers [11] developed a playful environment to reinforce motor and cognitive aspects in children with intellectual disabilities, focusing on educational content related to the human body. Using visual and sound elements in digital learning creates multisensory experiences beneficial for different disabilities, strengthening vision, hearing, and motor coordination. These studies highlight the importance of recreational environments in special education for promoting the development and social integration of children with cognitive disabilities.

Designing effective serious games for individuals with cognitive disabilities requires a precise and relevant set of techniques, tools, and guidelines. The APRehab methodology [12] proposes a framework for designing serious games that aid in rehabilitation, particularly for individuals with visual or hearing disabilities. This methodology facilitates the continuous construction and evaluation of prototypes, with the participation of both designers and users.

The iPlus methodology [19] employs a user-centered design approach and has been utilized in the development of serious games for individuals with cognitive disabilities, such as a virtual reality game for recreational therapy involving body movements and

visiting different locations [13]. Additionally, a mobile application has been proposed to facilitate cognitive skill development in individuals with intellectual disabilities, focusing on resolving temporal sequences and reviewing vocabulary associated with specific work scenarios to contribute to their vocational integration processes [27].

To design effective serious games for individuals with cognitive disabilities, the utilization of methodological frameworks such as APRehab and iPlus is recommended. These frameworks provide guidelines and facilitate the continuous construction, evaluation, and participation of designers and users in game development.

Overall, serious games for cognitive disabilities offer a promising avenue for promoting cognitive development, learning, and rehabilitation, thereby contributing to the well-being and inclusion of individuals with cognitive impairments.

A comparative study of platforms designed to acquire and enhance cognitive skills was conducted. All the analyzed platforms were easily accessible online through mobile or desktop devices via a web browser. Furthermore, these platforms aimed to pedagogically reinforce users' cognitive skills through games and playful activities, as shown in Table 1.

It was observed that platforms with a greater diversity of games and tools offered access to most of their content through a paid subscription. On the other hand, user session reports proved to be fundamental indicators for evaluating patients' progress. Some platforms, such as MindMate [28], provided only a record of daily activities, while others such as Rehametrics [29] and Elevate offered timely information on performance. In contrast, LudoMinga, NeuronUP, and Cognifit [30–32] provided detailed reports on progress in games, providing specialists with more information about the users.

An important aspect to consider in this study was the customization of activities and games. In this regard, LudoMinga and NeuronUP allowed for the modification of various factors to adapt work sessions to the pace of each patient. Additionally, these platforms were the only ones to incorporate usability and accessibility standards in developing their games and the platform itself. They also allowed scalable management, encompassing organizations, professionals, and individual users. In contrast, other platforms only allowed for user management.

Based on the comparative study, LudoMinga emerged as the best option. This platform is accessible and free, facilitating user access to the games. Moreover, it offers a high level of customization, allowing for the creation of sessions tailored to individual users' needs.

1.2. Target Population

The target population of this study comprises individuals with intellectual disabilities who receive educational, emotional, and vocational support at a specific center with the ultimate goal of achieving genuine inclusion. A study was conducted to identify the target population to gather information about their characteristics and needs, guiding the design of a web platform tailored specifically to their requirements.

A total of 47 individuals with intellectual disabilities were included in the study. The participants were characterized based on their demographic information, as depicted in Figure 1. Among the participants, 53.19% were female, and 46.81% were male. The age range of the individuals varied from 20 to 62 years, representing a diverse age distribution within the target population.

To characterize the target population further, an analysis was conducted using data obtained from the cards issued by the Ministry of Public Health of Ecuador [33]. The results of this analysis are presented in Figure 2, which provides insights into the degree of disability among evaluated the individuals.

Table 1. Comparative analysis between platforms.

Platform	OS	License	Cognitive Skills	Standards	Custom	Games	Progress Reports	Profiles Management
Ludo Minga	Platform (Windows, Mac, Linux) Multidevice (Web, Mobile, Desktop)	Free	Recognition, memory, perception, emotional recognition	WCAG 2.1.	Time, difficulty, size, speed, stimuli, visual and auditory feedback	22	Reports based on work sessions and time intervals	Organizations, specialists, and users
NeuronUP	Platform (Windows, Mac, Linux) Multidevice (Web, Mobile, Desktop)	Paid	Social cognition, memory, attention	ISO 924111	Number of exercises, speed, time	More than 100	Real-time reports of work sessions	Organizations, specialists, and users
Cognifit	Platform (Windows, Mac, Linux) Multidevice (Web, Mobile)	Paid	Visual memory, planning, monitoring	Unknown	Difficulty and visual and auditory feedback	58	Real-time reports after each work session	Only users
Rehab metrics	Platform (Windows, Mac, Linux) Multidevice (Web, Mobile)	Paid	Attention, memory, perception, language	Unknown	Difficulty and stimuli	160	Detailed information about the conducted sessions	Only users

Table 1. *Cont.*

Platform	OS	License	Cognitive Skills	Standards	Custom	Games	Progress Reports	Profiles Management
Mindmate	Platform (Windows, Mac, Linux) Multidevice (Web, Mobile)	Free	Memory, reasoning, logic	Unknown	Difficulty and sound	6	Activity monitoring	Only users
Elevate	Platform (Windows, Mac, Linux) Multidevice (Web, Mobile)	Paid	Memory, logical thinking, focus	Unknown	Difficulty	40	Performance report	Only users

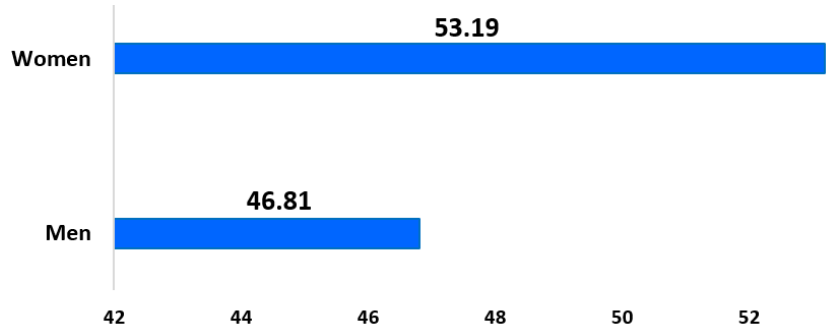


Figure 1. People with disabilities evaluated.

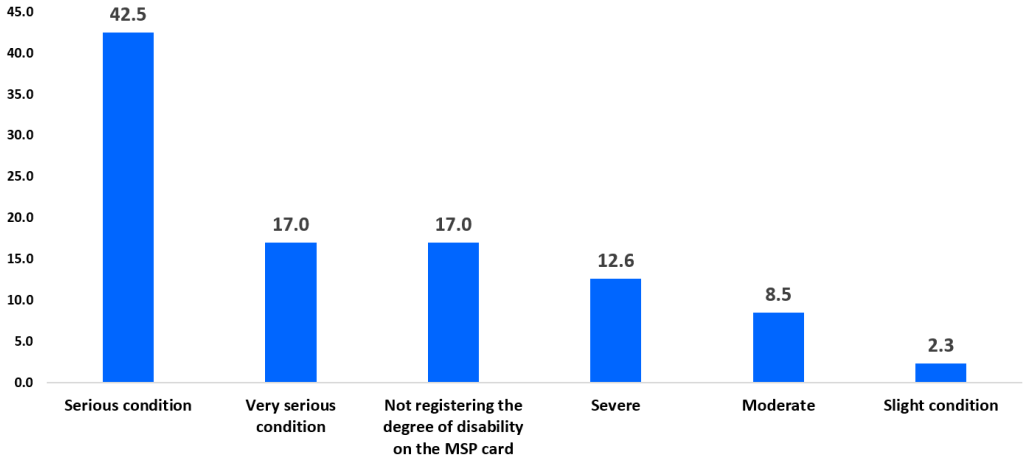


Figure 2. Disability degree.

In addition to the demographic and disability-related information, the study utilized several evaluation instruments to comprehensively understand the target population. The Support Needs Assessment Scale for individuals with intellectual and developmental disabilities (SIS-C) [34] was employed to evaluate the support requirements of the participants. This semi-structured interview-based instrument assessed 57 activities of daily living and facilitated the identification of specific support needs. Furthermore, the Adaptive Behavior Assessment System, Second Edition (ABAS II) [35], was employed to assess specific adaptive abilities, adaptive behavior in conceptual, social, and practical domains, and general adaptive behavior.

Based on the application of the SIS-C Scale, the study concluded that 2% of the sample required intermittent support (supervision), 27.6% required limited support (verbal or gestural encouragement), 48.9% required extensive support (partial physical help), and 21.3% needed generalized support (real physical help).

The ABAS II assesses three types of scores: specific adaptive abilities, adaptive behavior in conceptual, social, and practical domains, and general adaptive behavior.

The results revealed that most participants scored at the 1st percentile in conceptual adaptive behavior, indicating a shallow level of functioning in areas such as communication, functional academic skills, and self-direction. In the social domain, the scores were also in the 1st percentile, with an average index of 64 points. In the practical part, the result was similarly located in the 1st percentile [36].

The general adaptive behavior score for the target population was 56.11%, placing them in the 1st percentile. According to the ABAS II guidelines, this indicates a "very low" level of functioning.

These assessment tools provided an objective evaluation that helped determine the specific needs of individuals with intellectual disabilities who participated in the research study.

1.3. Proposal

Following the characterization of the target population, a team of professionals identified the necessity to design and implement a series of gamified games that would effectively strengthen psychological processes for individuals, specifically those with intellectual disabilities. The goal was to create a platform that fosters meaningful learning experiences.

The developed Serious Games (SG) would be accessible on a freely available platform without registering a user. This resource is a valuable tool for professionals in education and psychology, enabling them to incorporate it within intervention plans for cognitive skill development. Moreover, the platform can function as both an evaluation instrument and an intervention tool, as it allows to track each player's progress. Professionals can utilize this information to adapt and customize activities, select appropriate games, and enhance the development of psychological processes such as attention, concentration, perception, language, and conflict resolution.

The serious games included in the learning platform, named "LudoMinga", were meticulously designed by the principles of Universal Design for Learning (UDL). UDL is a framework that aims to ensure equitable access to learning and equal opportunities for individuals, irrespective of their diverse needs and characteristics [37]. Each game within the "LudoMinga" platform offers various accessibility features, such as text enlargement, audio options, and image zooming, enhancing usability. Notably, considering that not all individuals with intellectual disabilities possess reading and writing skills, including audio options enables this specific group to access and engage with the platform effectively. The ability to enlarge images cater to users with low vision, while careful consideration of colors and imagery prevents visual fatigue or discomfort.

The platform was intentionally designed to be accessible across different devices, including computers, tablets, and mobile phones. This decision was driven by many households in Ecuador lacking access to computers. A research study conducted in public schools in the Sierra region of Ecuador reported that only 33% of students had computer access. Similarly, the study found that merely 11.9% of households in the northern highlands of Ecuador, where the students resided, owned a tablet [38].

The value of our research-driven product lies in its ability to meet the specific needs of our context. While initially developed for individuals with intellectual disabilities, the platform can also be utilized by school children or older adults seeking to enhance and develop skills related to psychological processes. By addressing the target population's unique requirements and adhering to universal design principles, the platform provides an inclusive and effective solution for promoting psychological growth and fostering equal opportunities for all individuals.

2. Materials and Methods

Using educational video games can reduce the impact of disability and open up possibilities to leave behind invisibility, defeatism, learned hopelessness, and discrimination [39]. Therefore, the development of serious games can be an effective training and assistance method for people with intellectual disabilities, as they are tools that facilitate learning and motivate students [10–13].

Serious games for cognitive disabilities must be designed using an adequate methodology and considering the aforementioned components. The lack of correct design can bring negative results; researchers have found that games that are not well-designed lose both their appeal and their essence and no longer serve their serious purpose. The design process requires a multidisciplinary team's involvement and practice to define how to intervene and act effectively.

This section presents the design of the SG using the iPlus methodology, which has enabled the development of an educational application aimed at stimulating the development of cognitive skills. The application consists of a collection of 22 mini-games hosted on the platform. Furthermore, the design and implementation process of the "LudoMinga" platform, which will host the serious mini-games, is explained in detail.

The target population comprises adults with intellectual disabilities eagerly awaiting viable solutions to facilitate their cognitive inclusion and enhance their quality of life. Such solutions must ensure equal opportunities, equity, and non-discrimination, by the principles of Universal Design. To this end, the platform will require a multidisciplinary team's involvement and practice lines (WCAG 2.1) [40] to provide an inclusive and accessible application that can mitigate inequalities. Notably, the games are compatible with multiple types of devices, including computers, tablets, and smartphones, and can also be played offline, thus being particularly advantageous for remote rural areas.

2.1. The Development Process

The development process of our educational platform was based on a comprehensive methodological approach that placed the target population, namely adults with intellectual disabilities using a disability care center, at the core of all activities. The research was conducted through an interdisciplinary lens, involving professionals from psychology, education, computer engineering, game design experts, and programmers, who shared a common vision and worked coherently to integrate various actors, approaches, components, and variables. The process began with a detailed identification of the target population's educational, emotional, and cognitive characteristics and their specific support needs. The chosen pedagogical approach incorporated the multiple intelligences model and the socio-ecological model of disability, providing a solid foundation for planning and designing educational activities within the platform. The design of the serious games followed the iPlus methodology, which played a crucial role in gathering user requirements, formulating pedagogical objectives, and shaping the overall game design. During the implementation phase, agile principles from the SCRUM framework were employed, enabling an iterative and incremental development of the serious games. This approach fostered flexibility, adaptability, and responsiveness to user feedback and needs. The SCRUM framework facilitated effective collaboration among the development team members, ensuring efficiency and timely delivery of the games on the platform. Finally, a thorough evaluation of usability and accessibility was conducted post-platform development, leading to the necessary refinements and adjustments needed to ensure full usability and accessibility for individuals with intellectual disabilities.

Serious Game Design Using the iPlus Methodology

This subsection discusses the application of the iPlus methodology, which incorporates a participatory, flexible, and user-centered design approach. Additionally, creative techniques that are easy to understand by all participants will be used, combining entertainment and serious aspects, as well as involving experts. The SG developed will target people with mild to moderate intellectual disabilities who do not have physical difficulties that prevent the chronic use of technological devices.

The iPlus methodology is utilized to design serious games [13,19,41]. This approach includes a phase for verifying agreed-upon requirements through the participation of various experts. The iPlus design approach is flexible and can be used to design any serious educational game while offering an integrated design approach with other agile methods. Through iPlus, experts can gather and use user stories as input for any software methodology. The methodology consists of a series of steps organized into five phases, as presented in Figure 3.

1. Phase 1: Identification

The first phase of the methodology is the initial stage, initiated by the product owner, who presents specific educational needs and requirements. In this stage, the general problem is defined by the stakeholder, and depending on the situation, the participants of the methodology are identified.

Description:

This case study engaged experts from diverse fields, including a pedagogy expert (responsible for defining the pedagogical objectives), a psychology expert, the product owner, experts in disability treatment, a game designer, and a software developer.

Resulting artifacts: The outcome of this phase is the identification of the experts who will be involved in the conception of the serious game.

2. Phase 2: Pedagogical Objectives

In this phase, the general and specific objectives are defined in a participatory and consensual manner under the guidance of the pedagogical expert. The stage is facilitated by an iPlus facilitator knowledgeable about the methodology and responsible for ensuring the correct execution of each activity without interruption.

Description: The users' needs are understood by interviewing an expert. Next, an iPlus facilitator receives the participants and gives them an overview of the project and guidelines to ensure proper collaborative participation. Finally, the objectives are defined using an affinity diagram.

Resulting artifacts: The general and specific objectives are defined through a participatory and consensus-building process led by the pedagogical expert. Figure 4 illustrates the general objective and provides an example of a specific objective.

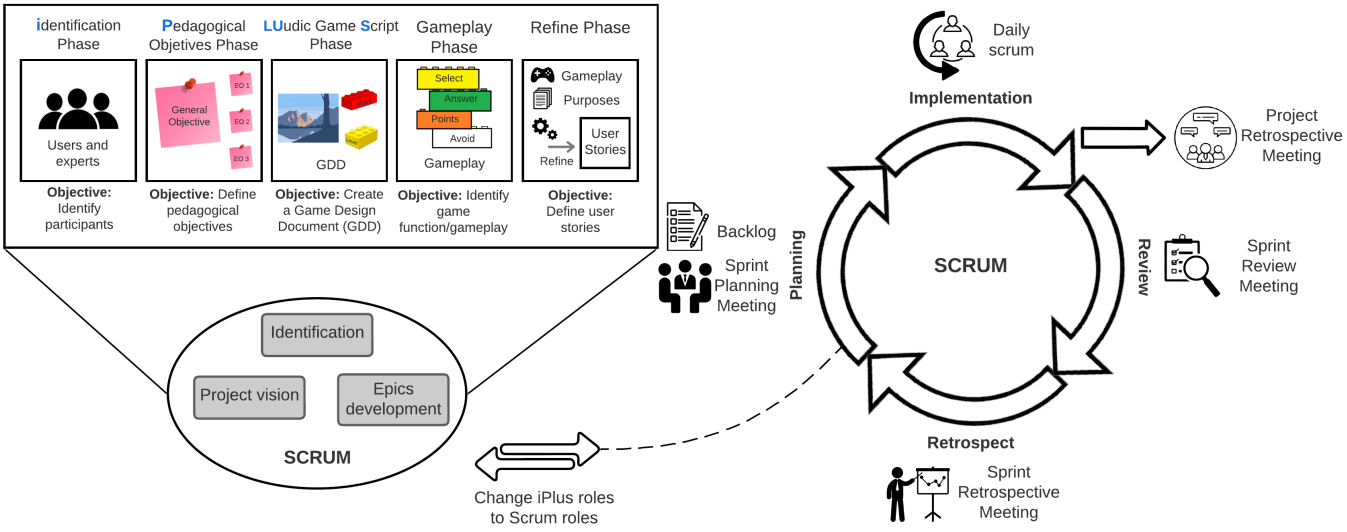


Figure 3. iPlus–Scrum Integration.

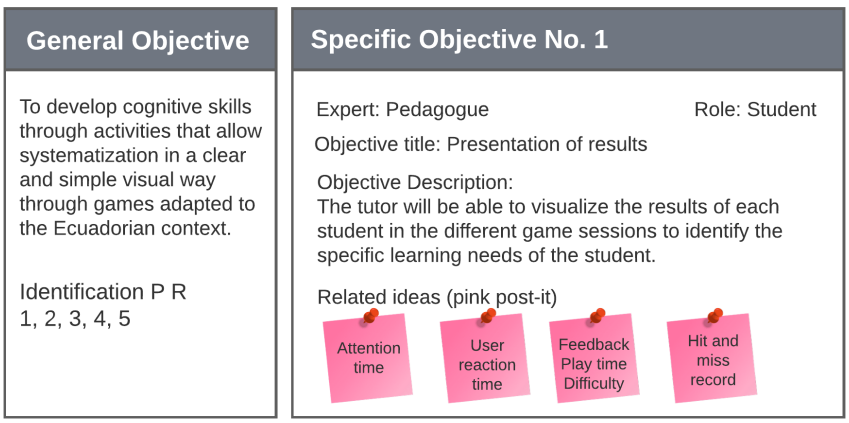


Figure 4. Generaland specific objective.

3. Phase 3: History of the Game

This phase aims to create the "Game Design Document" (GDD), which is based on the product owner's requirements. The participation of experts and users is essential, as they are responsible for envisioning the potential scenarios of the serious game. The participants and the product owner engage in discussions and establish guidelines, and then, with the assistance of the designer, they develop and approve the script.

Description: In this phase, the iPlus facilitator presents the gamification components and elements and explains the activities to be carried out. The participants and the expert in the treatment of disabilities then create the game script, which includes the narrative, characters, and gamification elements such as badges, points, and prizes, among others [42,43].

Resulting artifacts: The serious game design document describes each element that will be included in the scenario. An example from this document is presented in Figure 5.

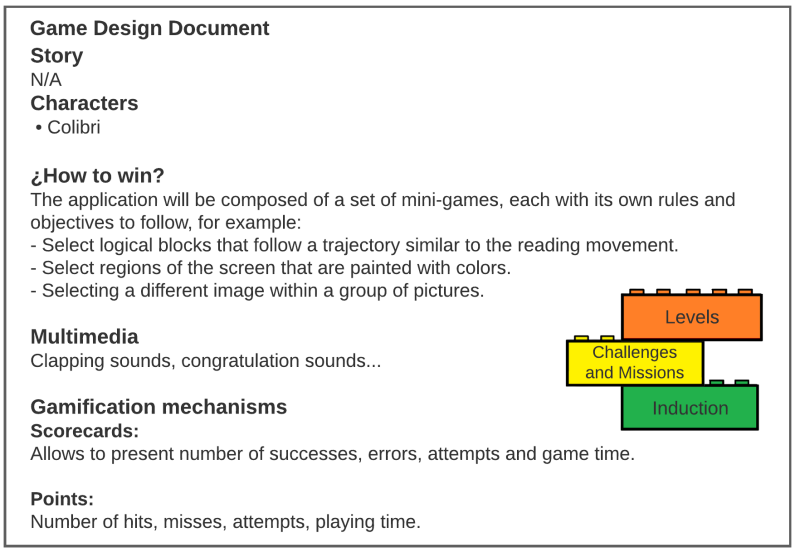


Figure 5. Game script.

4. Phase 4: Gameplay

The GamePlay phase aims to identify the functions and actions to be developed for the game script. Gameplay blocks are used to identify these actions. GamePlay blocks refer to the design of the functions that are part of the system or SG, such as picking up, shooting, managing, creating, etc. This phase also identifies the genre of the game, which can be a role-playing, adventure, simulation, reasoning, strategy, and/or action game. This process is done in collaboration with experts and the game designer. Studies such as Refs. [44–47] provide additional insights into this phase.

Description: In this phase, the experts define the GamePlay blocks, which will be incorporated into the game scenario. These blocks are used to describe the functionality and to identify the serious game genre and key terms [24,44–47].

Resulting artifacts: In this phase, the team defines the actions to be implemented in the SG using the Gameplay blocks. Afterward, the experts and the game designer decide on the genre of the SG. In this case, the serious game was categorized as a reasoning game, as it requires the use of strategies to solve problems. The results of this phase are depicted in Figure 6.

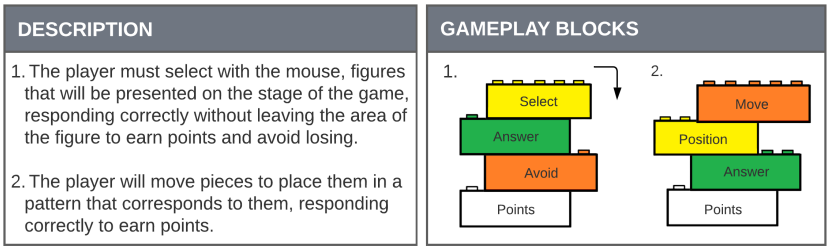


Figure 6. Gameplay card.

5. Phase 5: Refinement

The final phase of iPlus aims to ensure that each requirement satisfies the feasibility criteria. GamePlay documents, objectives, and cards are filtered to remove redundant or unattainable elements by the software developer. To accomplish this, a refinement matrix is used that adheres to the requirements outlined in the ISO [48] standard. These tasks are the responsibility of both the developer and the product owner.

Description: The objectives established in the second phase are reviewed to ensure that they are feasible, along with the GamePlay document to ensure that it can be executed. Furthermore, a meeting with the subject matter expert is conducted to validate that the obtained information is sufficient to implement the serious game. Finally, a user story is developed based on the validated information.

Resulting artifacts: Table 2 presents an example of the result obtained in this phase, which is a user story that includes a description of the activity that the designer must undertake, along with the various related tasks. Additionally, this user story specifies the priority and the role to be played.

Table 2. Resulting user story.

Epic User Story
Id: T01 Role: Tutor Story title: Support in carrying out the game session Priority: High (H) Description: The tutor selects the game and the scenarios to carry out the game session (difficulty, size of the stimuli, number of stimuli, playing time) so that the user develops in the most natural way possible in the application.

2.2. Design and Implementation of the LudoMinga Platform

As mentioned previously, the two main components of the research project, namely ICT and disability, contribute to the achievement of SDG-4, which is to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all".

Based on this premise, the "LudoMinga" platform was designed. It comprises a collection of serious mini-games that promote the development and acquisition of cognitive skills. During the development of this platform, it has been crucial for the research team to maintain a shared vision that guides their actions from a perspective of proximity, horizontality, transversality, and co-responsibility with the target population.

2.2.1. Identity of the LudoMinga Platform

The research team reached a consensus to name the platform "LudoMinga". The term ludo has its etymological origin in the Latin ludus, meaning "game", while minga, derived from the Quechua mink'a, refers to an ancient tradition of community work in Ecuador and Peru, highlighting values such as solidarity, collaboration, camaraderie, teamwork, satisfaction for the common good, and the sum of efforts that contribute to progress. To define and differentiate the platform, the isotype of a hummingbird (guide or hummingbird)

was adopted, as Ecuador is home to 124 of the 320 known species worldwide. The isotype is presented in Figure 7.

Figure 7. Platform logo and isotype.

2.2.2. Architecture of the LudoMinga Platform

"LudoMinga" is a platform that integrates educational video games to facilitate the registration, storage, and management of data related to educational software. It serves as a support tool for individuals with intellectual disabilities (users) as well as for the actors involved in the process of granting access (platform administrator), delegating (organization administrator), and supervising (tutor) their use. The platform allows for efficient user data management, ensuring that only authorized personnel can access sensitive information.

The platform modules are structured into specific subsystems:

- Authentication module: It will be used by users registered in the system and will allow tracking of their interaction with the platform and the games. In turn, this module is divided into the three roles of the system:
  - Platform administrator module: allows you to access the list of video games, the name and type of organizations, and identify the administrators of the organizations with their respective registration forms.
  - Organization administrator module: makes it possible to manage tutors, users, skills to be developed, time (period), intervention plans, reports, daily schedule, and game customization.
  - Tutor module: presents options for accessing the list of users and starting game sessions. In the list of reports, a code for the intervention plan and various formats for each user are recorded. The tutor can raise an observation related to the user's performance.
- Quick game module: allows the user access to the games without registering or authenticating with the platform; in this case, a record of the user's interaction with the system will not be kept.

The software architecture of "LudoMinga" consists of a three-layer programming model, namely the Model-View-Controller (MVC) model. The primary objective is to separate the business logic that delivers valuable information to the user, the presentation layer that allows proper viewing of application results, and the data layer that handles the data for business logic applications [49].

The data model defines the structure of the platform and the interrelationships among its components. It comprises tables with fields required to manage organizations, users, tutors, evaluations, video games, and their corresponding relationships. Figure 8 illustrates a portion of the platform's data model.

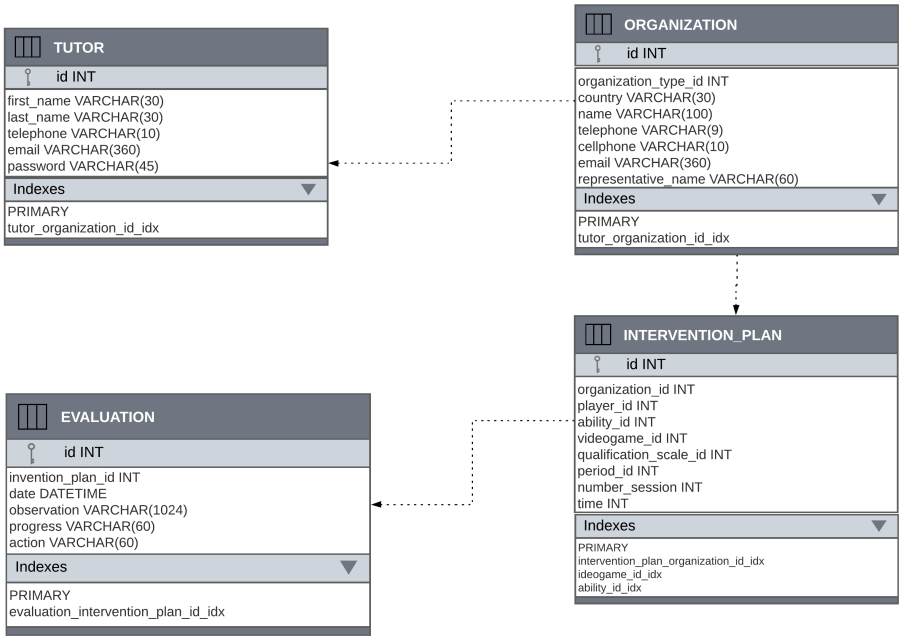


Figure 8. Data model.

2.2.3. Functionality of the LudoMinga Platform

The "LudoMinga" platform offers login options based on the user's role or quick play mode, which allows users to play video games without registering. Users can access the available serious games on the platform through the "Play" option. Figure 9 displays serious game options for developing specific cognitive skills.

Figure 9. Video game selection screen.

LudoMinga's serious games are structured and meet the stimulation needs, as illustrated in Figure 10.

- Games to develop cognitive skills

The games used to develop cognitive skills are divided into four modules that are detailed below:

- LudoExactus: a set of 10 mini-games with various activities that encourage the development of various cognitive abilities simultaneously.
- LudoCheck: a set of 5 mini-games to spot differences and similarities, both internal and external.
- LudoGuesser: a set of 4 mini-games for strategies involving the recognition of objects.
- LudoSpatial: a set of 3 mini-games that promote spatial skills; that is, recognition of symmetrical shapes, balancing models, and free drawing, to stimulate creativity.

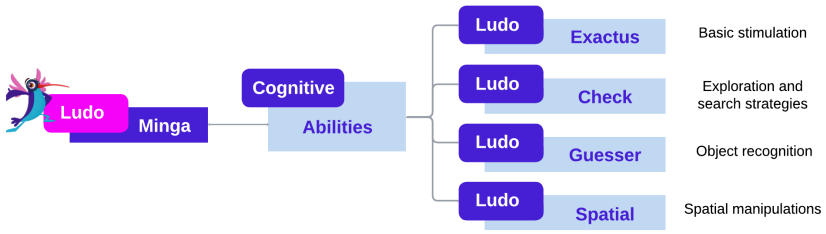


Figure 10. LudoMinga serious games for the development of cognitive skills.

For example, we will examine the game "Igualitos" from the LudoExactus module, designed to enhance visual exploration skills. Figure 11a presents a menu with options to play, adjust settings, read instructions, or quit. The game guides the player by providing specific instructions for each exercise, and the feedback is visually and audibly immediate. The sounds indicating whether the activity was performed correctly or incorrectly are subtle and not disruptive.

Upon completing the game, the results are displayed based on the user's time spent, number of attempts, successes, and failures. The tutor can provide feedback on the work session, as shown in Figure 11b.

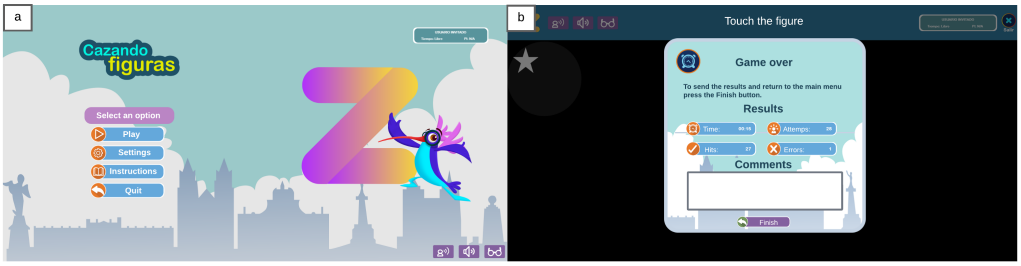


Figure 11. End game screen.

Furthermore, configuration options are available for courses and organizations that allow for generating reports on user performance within the organization and establishing controls for game time and difficulty. Additionally, game settings permit customization of difficulty level, color, stimuli, outline, waiting time, and session duration, as depicted in Figure 12.

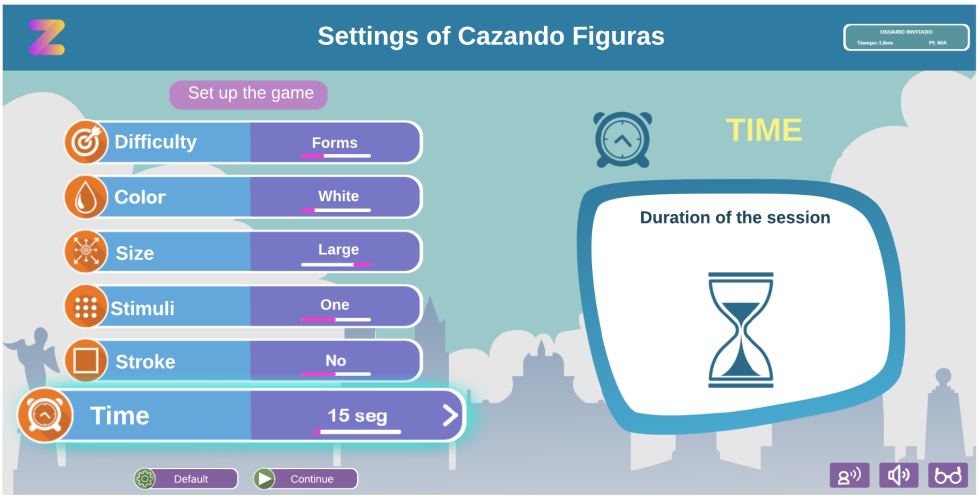


Figure 12. Game options.

3. Evaluation of Accessibility on the LudoMinga Platform

The United Nations (UN) describes universal design as an approach that seeks to create products, environments, programs, and services that all people can use to the greatest extent possible without requiring adaptations or specialized designs.

In this case, accessibility refers to the ease with which individuals with intellectual disabilities can use a software application. The World Wide Web Consortium (W3C) has defined essential guidelines for software design, with accessibility being a crucial criterion at every stage of the development process. These guidelines are based on the Web Content Accessibility Guidelines (WCAG) 2.1 [40]. A mixed approach to assessing accessibility in serious games is suggested, using both an automatic tool and manual evaluation by accessibility experts. This analysis could start future studies linked to the estimation and degree of accessibility in video games for educational and psychological purposes and adapting platforms through digital ramps.

The W3C Accessibility Design Principles are four fundamental pillars used to ensure that web pages are inclusive and accessible to all, including people with disabilities. The first principle focuses on perception through the senses, such as sight, hearing, and touch. The second principle [40] addresses interaction with user interface elements. The third principle focuses on content comprehension and navigation, while the fourth principle addresses the robustness of the interface concerning the various assistive technologies employed by users with disabilities.

3.1. Accessibility Guidelines

The WCAG are guidelines and standards for making web content accessible to people with disabilities. The four main principles of the WCAG are: Perceivable, Operable, Understandable, and Robust.

Guideline 1.1 Text alternative: provide alternative text for non-text content to be transformed into other formats people may need, such as large characters, braille, symbols, or simpler language.
Guideline 1.2 Time-dependent multimedia: provide synchronized alternatives for time-dependent multimedia content.
Guideline 1.3 Adaptable: create content that can be presented differently without losing information or structure.
Guideline 1.4 Distinguishable: make it easy for users to see and hear the content.
Guideline 2.1 Keyboard accessible: allow all functionality to be controlled from the keyboard.
Guideline 2.2 Sufficient time: provide adequate time for users to read and use the content.
Guideline 2.3 Seizures: design content to avoid seizures.
Guideline 2.4 Navigation: help users navigate and find content quickly and appropriately.
Guideline 2.5 Input modalities: facilitate users to operate functionality through various input methods.
Guideline 3.1 Legibility: create readable and understandable text content.
Guideline 3.2 Predictability: create a consistent and predictable layout and use of web pages.
Guideline 3.3 Data input assistance: provide support to prevent users from getting lost or making errors while navigating.
Guideline 4.1 Compatibility: provide compatibility with current and future user agents, including assistive technologies.

3.2. WAVE Accessibility Tool

In this evaluation, the WAVE automatic analysis tool was used as a plug-in for Google Chrome. It is considered one of the best tools for assessing accessibility [50], WebAIM mention WebAIM2023 developed this application to measure the degree of compliance concerning accessibility levels A, AA, and AAA of the WCAG [40]; the errors identified are related to WCAG 2.1. WAVE classifies them into the following categories.

Errors: Errors are fundamental issues that must be addressed to ensure adequate interaction with the "LudoMinga" platform and the serious games being evaluated so that

accessibility is satisfactorily assessed. Each error that occurs is linked to the principles set out in the WCAG 2.1 guidelines.

Contrast errors: The WAVE tool has detected significant accessibility barriers mainly associated with visually impaired users. For example, a contrast error has been identified in an interface using a color scheme with a white background and yellow letters. These errors are considered critical, and it is essential to correct them to achieve an adequate level of accessibility according to the guidelines set out in WCAG 2.1.

Alerts: These are minor accessibility issues that application developers can review and fix.

Features: The parameter set by the WAVE tool corresponds to mild severity and does not significantly impact accessibility.

Structured elements: This parameter has the function of identifying possible accessibility problems that could arise due to the structure of the web page.

ARIA (Accessible Rich Internet Applications): WAVE detects the presence of ARIA attributes in HTML elements, which does not necessarily imply that these are errors. However, it is advisable to check them as inappropriate use of these attributes is common.

3.3. Assistive Technologies or Digital Ramps

Assistive technologies facilitate the use of general software applications by users with disabilities who would otherwise be forced to access only programs specifically designed for them. Software, programs, and assistive products are loaded into the memory of a computer, tablet, or mobile device rather than into the main program. The user may sometimes require some support product or technical assistance to interact with the device.

3.4. Methodology

The accessibility evaluation for the serious games was performed on the "LudoMinga" platform, which can be found at the link: https://juegos.LudoMinga.com/ (accessed on 24 May 2023). A combined method [51] was applied, as shown in Figure 13, consisting of seven phases.

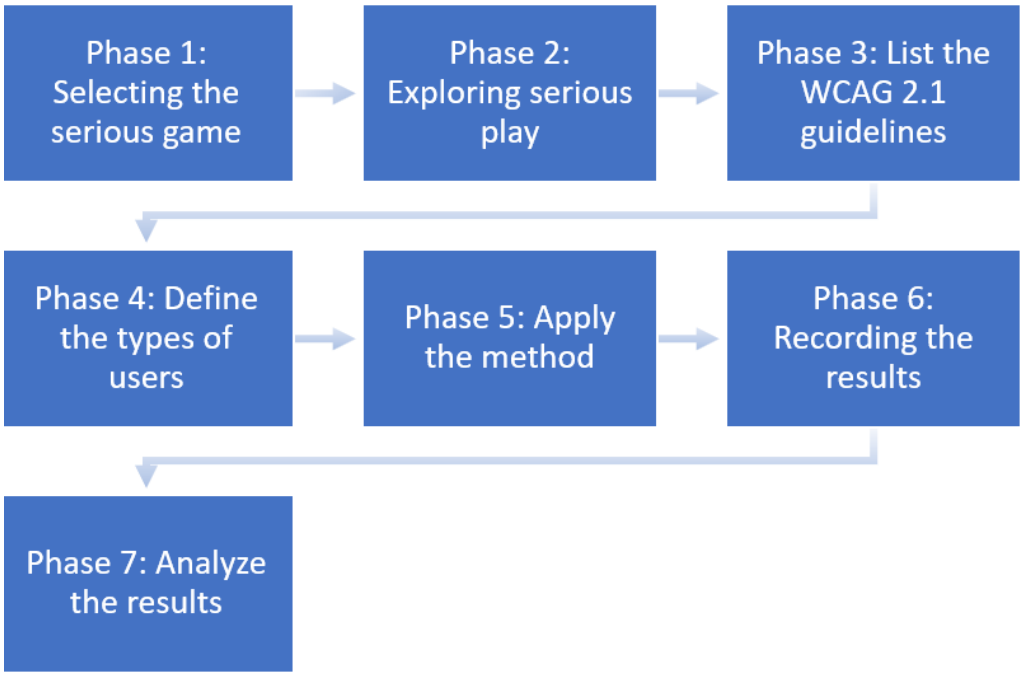


Figure 13. Accessibility evaluation method in serious games.

The expert evaluators in web accessibility evaluated the platform considering all the 22 serious games included in the platform. They applied the 18 guidelines that are presented in Table 3, which contains the ID assigned to each guideline, the name of the guideline, the accessibility principle, success criteria, level of accessibility and compliance; the categories that met the parameters were rated "one (1)" and those that did not meet the parameters were rated "zero (0)". In this case, the games complied with the 18 guidelines considered in this evaluation.

Table 3. Guidelines applied to the evaluation of serious games.

ID	Guidelines	Principles	Success	Level	Complies
G01	Accessible keyboard	Operable	2.1.1	A	1
G02	Luminance flare glitches	Operable	2.3.1	A	1
G03	Animation of interactions	Operable	2.3.3	AAA	1
G04	Easy to read font	Perceptible	1.1.1	A	1
G05	Text alternatives	Perceptible	1.1.1	A	1
G06	Subtitled	Perceptible	1.2.4	AA	1
G07	Information and relationships	Perceptible	1.3.1	A	1
G08	Sensory characteristics	Perceptible	1.3.1	A	1
G09	Adjust display settings	Perceptible	1.3.4	AA	1
G10	Use of color	Perceptible	1.4.1	A	1
G11	Well spaced elements	Perceptible	1.4.12	A	1
G12	Good audio techniques	Perceptible	1.4.2	A	1
G13	Images as sharp as possible	Perceptible	1.4.5	AA	1
G14	Visual presentation	Perceptible	1.4.8	AAA	1
G15	Pause, stop, hide	Perceptible	2.2.2	A	1
G16	Consistent navigation	Robust	4.1.3	AA	1
G17	Labels or instructions	Understandable	3.3.2	A	1
G18	Help	Understandable	3.3.5	AAA	1

In addition, the WAVE automatic inspection tool was used for accessibility evaluation regarding the guidelines related to the contrast of serious games.

Phase 1. Selecting the serious game. Twenty-four serious games were chosen for evaluation.

Phase 2. Exploring serious play. Each option related to the sociocognitive skills of serious games and their functionality was examined. It is observed that there is consistency among the different interfaces, making it redundant to include all the interfaces of all the games.

Phase 3. List the WCAG 2.1 guidelines. The 18 parameters, based on WCAG 2.1, were defined for evaluating accessibility in serious games.

Phase 4. Define the types of users. Previous studies about the population with intellectual disabilities [33] associated with one or more disabilities (hearing, physical, psychosocial, and visual) were considered. Health problems and the combined presence of some conditions and syndromes are observed in the target population users, including language restrictions, cerebral palsy, epilepsy, scoliosis, autism spectrum disorder, positional dorsalgia, behavioral disorders, transient hypotension, muscular dystrophy, Robinow syndrome, and Apert syndrome.

Phase 5. Apply the method. Both accessibility experts evaluated the interfaces of the serious games. When discrepancies arose between them, an invited expert was requested to collaborate. The process applied was a combination between an automatic tool and manual review. In studying the parameters related to contrast and brightness, the automated tool WAVE [52] was used. In the evaluation, categories that met the parameters were scored with one (1) and zero (0) for those that did not. The application developers implemented a screen reader. It reads the instructions and describes the context of the different interfaces. For this reason, it has a rating of one (1) for all games in the "Help" category.

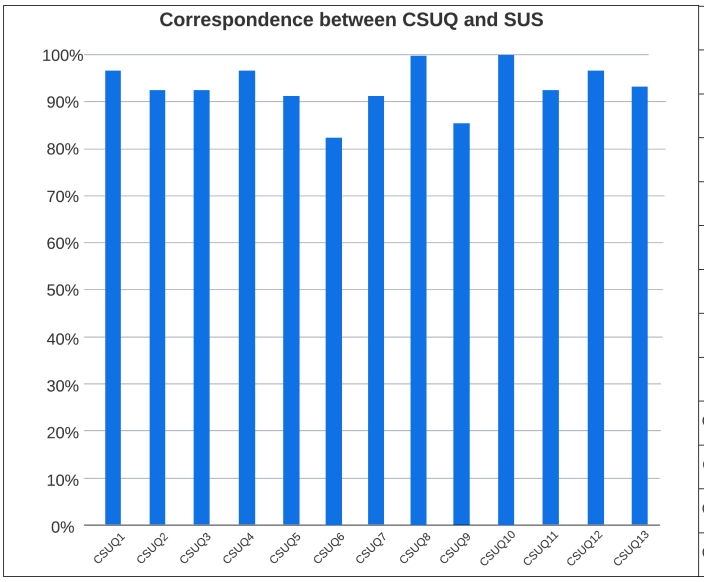
Phase 6: Recording the results. The assessment values were recorded in a spreadsheet, taking into account the 18 specific guidelines related to intellectual disability based on the characterization of the target population users.

Phase 7: Analysis of the results. During this phase, a detailed observation was carried out, and all the games evaluated complied with the 18 previously established guidelines.

3.5. Usability Evaluation

The usability evaluation was conducted to identify potential issues and to determine whether the learning platform is intuitive and user-friendly for its intended audience. To accomplish this, an experimental protocol consisting of four phases was employed, outlined below.

1. Participant Identification Phase: In this phase, participants for the usability tests of the application are identified. According to Nielsen, a maximum of five people performing several small tests is sufficient to identify up to 85% of usability issues. The group of participants must be homogeneous to evaluate the application [53]. Usability tests were conducted with 40 adult individuals who were at least 70 years old and did not have progressive cognitive impairment.
2. Evaluation Phase: This phase commenced with an induction on the protocol and the application's functionality to be followed. Then, the evaluation was conducted with tasks that the user had to perform. Finally, the participants completed the usability survey. The usability survey comprised 13 questions with a rating scale ranging from 1 to 7, where a higher score indicated greater satisfaction. The survey was based on the Computer System Usability Questionnaire (CSUQ) [54], and the questions were adapted to the context of the gamified application.
3. Results Phase: All of the questions in the survey achieved over 80% acceptance, with two achieving a perfect score of 100%: question 8 (regarding voice and text instructions) and question 10 (regarding guidance through instructions). The question with the lowest acceptance rate was question 6 (regarding feedback), which achieved an acceptance rate of 82.86%.
4. Conclusions: The figure presented in Figure 14 indicates that the relative percentage of each CSUQ survey question exceeds 80% satisfaction. The outcomes of the inquiries "Use satisfaction" and "General satisfaction" suggest that the evaluation participants deemed the educational platform "LudoMinga" a usable system.



CSUQ1	Satisfaction of use
CSUQ2	Easy to use
CSUQ3	Ability to complete session
CSUQ4	Comfort to use
CSUQ5	Easy to learn
CSUQ6	Feedback
CSUQ7	Error recovery
CSUQ8	Voice and text instructions
CSUQ9	Understand instructions
CSUQ10	Guidance by instructions
CSUQ11	Interface satisfaction
CSUQ12	Features and training
CSUQ13	Overall satisfaction

Figure 14. Usability results.

4. Discussion

The creation of LudoMinga responds to the scientific interest in providing accessibility solutions for people with disabilities using technology, specifically the special strategy of gamification. Gamification is an area of technology where science and stimulation are combined. Due to its inherently engaging nature, gamification offers a different experience to users, expanding the dimensions of play and contributing to the growth of users. In the design of LudoMinga, the need to improve the skills of the target audience, which is people with intellectual disabilities, was taken into account. It is recognized that a gamification platform offers greater impact and experience due to its characteristics.

To this end, the iPlus methodology incorporated a participatory, flexible, and user-centered approach to designing serious games. The iPlus methodology emphasizes the participation of various actors involved in the design process, such as experts, designers, and representatives of end users. This participatory approach ensures that the platform's design meets the specific needs and preferences of people with intellectual disabilities.

On the other hand, Pitaru's recommendations [26] highlight the need to overcome accessibility barriers, adapt game mechanics, and adjust the gaming experience to the specific needs of people with learning difficulties or intellectual disabilities. By considering Pitaru's considerations, game developers can create inclusive and engaging experiences that promote cognitive development, improve social skills, and provide equal opportunities for people with diverse abilities to actively participate in and benefit from the world of video games.

LudoMinga adequately fulfills several of the recommendations suggested by Pitaru for developing interactive and educational games. This platform effectively incorporates visual elements that stimulate various cognitive abilities, such as visual awareness, fixation, visual focus shifts, spatial awareness, eye tracking, exploration, categorization, facial expression recognition, shape recognition, model balancing, and drawing activities.

Additionally, this platform offers important features such as difficulty adjustment and customization based on the user's skill level. This allows for a personalized gaming experience that adapts to individual needs, which is especially important for users with intellectual disabilities. Including different difficulty levels and learning paces also enhances the game's versatility to accommodate users with different abilities.

As mentioned, gamification is a central element in LudoMinga. Its design incorporates game elements and rewards to motivate users and facilitate cognitive, adaptive, and vocational development. In its construction, the importance of a friendly and intuitive design has been recognized, with the aim of gradually removing supports and promoting user autonomy and independence.

It is also necessary to highlight that this project applied WCAG 2.1-based standards and took into account user feedback to adapt to the target audience's needs. By applying WCAG 2.1, the four principles of accessibility up to AA level are considered. The main goal is to provide an inclusive and accessible learning environment, combining educational content with game mechanics to promote active participation and personal and cognitive development of people with intellectual disabilities.

An important factor in the development, implementation, and evaluation of gamification platforms such as LudoMinga is evaluation. This cross-cutting process ensures that the game is accessible and easy to use for a wide range of users, including those with disabilities. Serious game developers face several challenges when evaluating accessibility and usability, as multiple factors come into play, such as navigation, interface design, compatibility with assistive devices, user feedback, and information presentation.

To successfully carry out accessibility evaluation, automated tools such as WAVE are recommended, as well as a manual review of the interface and game functionalities. It is also essential for developers to work with test groups that represent the diversity of users, including people with disabilities.

Usability is another critical aspect that developers considered throughout the entire game development process. This involved designing the game's interface and interactions

so that users can understand and navigate easily. Usability testing plays a crucial role in evaluating the effectiveness and efficiency of the game's usability aspects. Through usability testing, developers were able to identify potential issues and gather user feedback, allowing them to make necessary changes to improve the overall user experience.

By conducting usability tests with a diverse group of participants, including those with different levels of gaming experience and varying abilities, developers were able to obtain valuable insights into how users interact with the game and make informed design decisions to accommodate their needs.

In addition to evaluation, developers prioritized the application of accessibility and usability guidelines from the early stages of game design and development. Established usability heuristics were considered, and accessibility considerations were integrated from the beginning of the design process. Developers proactively addressed the needs of all users, resulting in the creation of a fully usable and accessible game. Usability heuristics, such as consistency, simplicity, and feedback, can guide developers in designing intuitive and efficient player interfaces. Compliance with recognized standards, such as WCAG 2.1 accessibility guidelines, further enhances the game's accessibility for many users.

It is important to note that accessibility evaluation is an ongoing process that should be part of the game's lifecycle. Developers should conduct periodic accessibility evaluations, even after the game's release, to ensure that it remains accessible as technology and user needs evolve.

There are several challenges posed by accessibility and usability evaluation. For example, the diversity of users entails considering a wide range of individuals with different abilities, needs, and preferences. This process can be challenging due to the variability of capabilities and the difficulty of representing all users in the evaluation process. Subjectivity and individual experience, where each person may have different needs and experiences, make objective evaluation and the identification of common issues challenging. Resource and technical limitations may require specialized teams or specific technical knowledge. These limitations can make conducting comprehensive evaluations difficult, especially for developers or teams with limited resources. Technological advancements pose a challenge in terms of keeping up with and evaluating accessibility and usability in various environments. Standards and guidelines may also change over time, requiring continuous adaptability in the evaluation process. The experience provided by the design of this platform confirms the need to include users in the creative process to determine the most useful strategies for addressing different challenges. In the evaluation process, it is essential to involve real users and individuals with diverse abilities and needs. Direct opinions and experiences can provide valuable insights into the accessibility and usability of a product. Established tools and guidelines provide guidance and objective metrics for identifying issues and measuring accessibility and usability more systematically. Conducting comprehensive testing with people with disabilities and navigation and compatibility testing with different devices and platforms is useful and necessary. Staying informed about the latest accessibility and usability standards and guidelines is crucial. This process involves keeping up with technological advancements, changes in guidelines and best practices, and continually adapting evaluation processes. Collaborating with accessibility and usability experts can provide specialized knowledge and additional guidance. These experts help identify specific issues and recommend accessibility and usability improvements.

5. Conclusions

This research project has addressed the specific needs for improving skills in a group of individuals with intellectual disabilities to build a gaming platform that helps them enhance specific areas of their development. To this end, a structured approach was taken to the living and learning space of the target group, individual characteristics were evaluated, and the degrees of disability were verified.

The collected data was used for designing the LudoMinga platform using the iPlus methodology. Both the developers and the target group actively participated in all phases

of creating this game. This involvement allowed the platform's plan to adapt to the specific needs and preferences of people with intellectual disabilities. This inclusive and collaborative design process ensures a meaningful and engaging experience for the intended population.

Accessibility in serious games is a crucial aspect that should be considered throughout the design and development process. Accessibility barriers, particularly for users with visual or motor disabilities, can limit their ability to interact with games and fully enjoy the experience. It is essential for developers to apply accessibility guidelines, such as those established in WCAG 2.1, and utilize accessibility evaluation tools to identify and address accessibility issues in serious games. Even minor accessibility improvements can significantly enhance the gaming experience for all users.

The results of the CSUQ survey conducted on the LudoMinga platform demonstrate high satisfaction levels among the participants in the evaluation. The results reveal that the relative percentage for each question in the CSUQ survey surpasses 80% satisfaction. Specifically, the questions regarding "Ease of use" and "Overall satisfaction" indicate that the participants consider the educational LudoMinga platform very user-friendly. Similarly, the high satisfaction among the evaluation participants suggests that the LudoMinga platform has achieved its goal of improving usability for people with disabilities.

In the future, there are anticipated opportunities to continue developing and expanding the LudoMinga platform to further support individuals with intellectual disabilities. One area of interest could be the incorporation of personalized learning features. The platform can adapt the learning experience to each user's specific needs and abilities by applying adaptive technologies and intelligent algorithms. This personalized approach can enhance engagement, motivation, and overall learning outcomes.

Furthermore, the LudoMinga platform can benefit from current research and advancements in assistive technologies. Exploring the integration of accessible hardware devices, such as eye-tracking systems or alternative input devices, enables individuals with severe physical disabilities to overcome barriers and fully participate in the gaming experience. Ongoing updates and improvements to accessibility features will ensure that the platform remains inclusive and accessible for users with diverse abilities.

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Institutional Review Board Statement: The development of this platform was approved by the Research Ethics Committee for Human Subjects at the Pontifical Catholic University of Ecuador with approval date of 14 December 2018, under the Approval number 2018-53-OE.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data is unavailable due to privacy or ethical restrictions imposed by the organization conducting the study.

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Conflicts of Interest: The authors declare no conflict of interest.

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