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en la Era de la Inteligencia Artificial
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COMITÉ EDITORIAL

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ACTAS DE LAS JORNADAS

Las memorias de las 11 Jornadas Iberoamericanas de Interacción Humano-Computadora (11JIHC´25) reúnen una selección de los trabajos aceptados y presentados en modalidad de artículos cortos *(short papers)* y artículos largos *(full papers)* durante el evento realizado en la ciudad de Zacatecas, México, del 7 al 9 de mayo de 2025, bajo un formato híbrido. Las Jornadas fueron organizadas por la Universidad Autónoma de Zacatecas "Francisco García Salinas", en colaboración con el Consejo Zacatecano de Ciencia, Tecnología e Innovación (COZCYT) y la Red Iberoamericana HCI-COLLAB.

El eje temático "Interacción Humano-Tecnología en la Era de la Inteligencia Artificial" orientó esta edición hacia el análisis crítico de cómo las tecnologías emergentes modifican y amplifican las experiencias humanas y sociales, fomentando la accesibilidad, la inclusión y la colaboración en ámbitos como la educación, la salud, la industria y el entretenimiento. En este marco, los artículos enviados corresponden al *track principal* de las 11 JIHC'25, lo que garantiza la pertinencia temática y la alineación con las discusiones contemporáneas de la comunidad IHC en torno al impacto de la inteligencia artificial en los sistemas interactivos.

En atención a los lineamientos editoriales, los trabajos distinguidos como mejores contribuciones no se incluyen en estas memorias, dado que serán publicados en la serie Communications in Computer and Information Science (CCIS) de Springer.

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SESIÓN PRINCIPAL

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Adaptability of Homomorphic Caching Schemes in Quantum Computing Environments

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Abstract. Homomorphic caching schemes integrating fully homomorphic encryption (FHE) with quantum cryptographic (PQC) primitives are examined through the lens of adaptability. This study introduces the idea of dynamic responsiveness concerning latency control, workload endurance, and security flexibility. The case studies indicate latency reductions as high as 30-45%, as well as improvement to resource allocation. hybrid PQC-FHE approaches with caching schemes demonstrate scaling defenses and adaptability to user-centered or AIdriven requests. Moreover, results revealed the importance of flexibility when adjusting to quantum secure infrastructures dynamic bootstrapping or caching logic. This paper recommends evaluation criteria for adaptability, contributing to the development of secure systems that respond fluidly to computational shifts in intelligent, quantum systems.

Keywords: Quantum Cryptography, Fully Homomorphic Encryption, Lattice, Homomorphic Caching schemes, Secure Distributed Systems.

1 Introduction

Quantum cryptography introduces secure communication protocols founded on quantum mechanics, wherein quantum key distribution (QKD) prevents eavesdropping through immutable physical properties of particles [1][16]. Meanwhile, quantum algorithms such as Shor's and Grover's have exposed critical vulnerabilities in classical cryptographic constructs, rendering traditional security parameters insufficient against quantum adversaries [2][3][17]. In response, quantum cryptography (PQC) organizes mathematically robust schemes primarily lattice-based, code-based, and hash-based structures designed to ensure resistance against quantum attacks [7][18].

Gentry's theoretical work on homomorphic encryption (HE), particularly fully homomorphic encryption (FHE), has led to practical schemes such as BGV, BFV and CKKS, which have proven important in machine learning and bioinformatics [4][9]. The challenges still remain with continued attention to, but not limited to, noise, circuit depth, and integration with quantum-resilient protocols [21].

In distributed intelligent systems, caching approaches are crucial to performance, typically approached through content-, tag-, or hybrid based [22][23] methods. These approaches have previously relied on the existence of cryptographic primitives; however, with quantum computing, these primitives are no longer sufficient, compromising data confidentiality, integrity, and availability [11]. For this reason, moving forward, we must support cache designs determined to address these threats, and redesign them as adaptable, using quantum-secure primitives and protocols [14][27]. Homomorphic caching in PQC settings introduces potential for enhanced adaptability—manifested in dynamic reconfiguration, resilience, and workload-aware behavior [24][28]. However, such adaptability imposes a computational overhead that must be mitigated through efficient bootstrapping and hybrid PQC-FHE designs to achieve robust and scalable encryption mechanisms [13][29].

Based on the above, this paper seeks mechanisms that quantify and enhance the adaptability of homomorphic caching systems under quantum conditions. It offers a comprehensive review, analyzes integrative techniques, and proposes evaluation metrics aligned with evolving requirements in AI ecosystems and human-centric technology infrastructures.

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2 Methodology

A systematic mapping methodology was subsequently applied to identify and synthesize the available evidence on the adaptability of homomorphic caching schemes in quantum computing systems [25]. In detail, studies were selected from extensive searches in specialized scientific databases addressing aspects like resistance to quantum attacks, efficiency of the schemes, and their applicability in different scenarios. The selected studies were analyzed deep down to extract information regarding the techniques employed, the results obtained, and the indicated limitations.

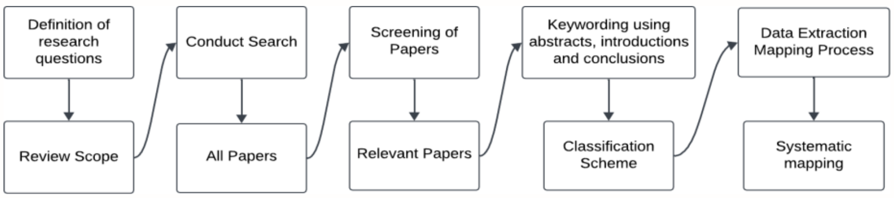

Fig. 1. Systematic mapping process.

2.1 Research question

General question leading to the objective of the systematic mapping:

How can adaptability be systematically optimized in homomorphic caching schemes to enhance both efficiency and quantum data security in intelligent and interactive environments?

2.2 Research questions and methods directly related to subject matter

Table 1. Research questions.

Research questions	Motivation
Which homomorphic caching schemes demonstrate the highest adaptability against quantum-level threats?	Identifying schemes that are not only secure but also adaptable is key to their implementation in dynamic environments, especially those affected by emerging quantum threats.
How does operational latency affect the adaptive behavior of homomorphic caching in quantum intelligent systems?	Latency is a critical bottleneck in AI applications and distributed systems. Understanding its impact on operational adaptability enables real-time efficiency improvements.
What are the main constraints limiting adaptability in quantum homomorphic caching schemes?	Knowing the factors that restrict adaptability allows prioritizing architectural and methodological improvements in secure cryptographic systems.
Which optimization strategies enhance scalability and adaptability in quantum homomorphic caching systems?	Optimization strategies are essential for adaptive systems to scale efficiently, especially under heavy usage conditions such as in AI or big data.
What evaluation frameworks and metrics can objectively assess adaptability in quantum caching schemes?	Establishing clear metrics for assessing adaptability ensure transparency, reproducibility and scientific validation in critical environments.
What sector-specific impacts do adaptive post-quantum caching schemes have on privacy and system reliability?	Analyzing the effects in real contexts (health, finance, government) allows aligning technological development with specific needs for privacy and operational robustness.

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2.3 Search strings

In this research, the following terms were used to conduct a systematic search regarding homomorphic caching schemes and their adaptation to quantum computing environments: "Quantum homomorphic encryption", "Homomorphic caching schemes security", "Quantum-resistant cryptographic caching", "Distributed cache security quantum", "Homomorphic encryption optimization techniques", "Quantum cryptography cache systems", "Quantum-safe homomorphic schemes", "Cache efficiency quantum systems", "Lattice-based homomorphic encryption", "Homomorphic encryption performance metrics", and "Quantum cache adaptation methods". The following table shows the terms as search strings.

Table 2. Search strings.

Research terms	Research strings
Quantum homomorphic encryption	Homomorphic encryption AND quantum AND security
Homomorphic caching schemes security	Homomorphic caching schemes OR cryptographic security
Quantum-resistant cryptographic caching	Cryptographic caching AND quantum resistance NOT classical

The following table shows the scientific databases used for the search of the selected articles:

Table 3. Description of digital libraries.

Database	Descriptions	Url	Area	Search
Scopus	A comprehensive and professionally designed database of citations and abstracts.	https://www.scopus.com/	interdisciplinary	Yes
IEEE Xplore	A research database for articles describing fields related to electrical, electronic or software engineering.	https://ieeexplore.ieee.org/	engineering	Yes
ScienceDirect	One of the largest sources of information on science, technology, research and medicine.	https://www.sciencedirect.com/	interdisciplinary	Yes
Springer	A global publisher of books, e-books and peer-reviewed scientific journals related to science, technology and medicine.	https://link.springer.com/	interdisciplinary	Yes
arXiv	A database of open access academic preprints covering subjects such as physics, mathematics, computer science and biology.	https://arxiv.org/	Science and technology	Yes

Once the search strings and scientific databases have been defined, the inclusion and exclusion criteria are defined for the selection of papers.

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Table 4. Inclusion and exclusion criteria.

Type of criteria	Criteria	Type
Time period	Papers between 1994 2024	Inclusion
Language	English	Inclusion
Source type	Conference papers, experimental papers, books, papers	Inclusion
Accessibility	Papers for free use or accessed by agreement with the university	Inclusion
	not accessible	Exclusion
Sections reviewed	Abstract, introduction, conclusions	Inclusion
Relevance to the research question	Not relevant to one or more of the research questions	Exclusion

2.4 Results

The following table shows the results obtained by applying the inclusion and exclusion criteria:

Table 5. Number of papers found.

Search strings	Number of papers found	Selected paper
1	7	5
2	6	4
3	5	3
4	8	4
5	4	3
6	10	5
7	12	6
8	9	5
9	11	6
10	6	2
11	9	3

The following graph shows the number of publications per year. It is determined that most of the publications have a greater relevance in the year 2023. With this we can say that the topic is of great interest today.

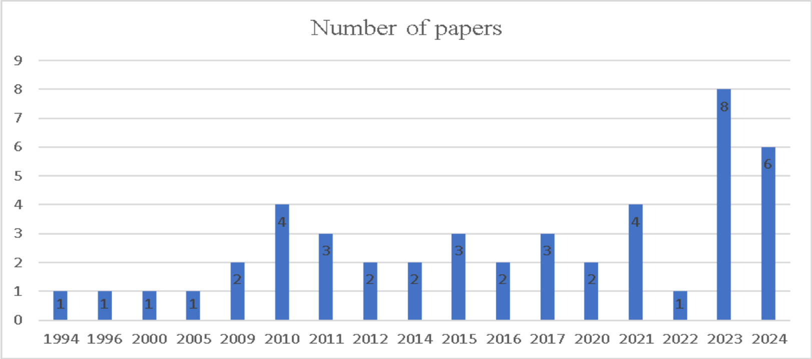

Fig. 2. Number of papers per year.

The selection of references within this study was made with diligence so that they were relevant, done with credibility and directly in line with the research focus.

Because of that reason, in addition to generic quantum computing literature, this work only concentrated on references that specifically address the issues of homomorphic encryption, quantum cryptography, and caching mechanisms. Preference was accorded to peer-reviewed journals, conference proceedings, and technical reports

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presented by leading cryptographic research groups. Although we can find relatively many scientific works on quantum security, their empirical evaluation or structured methodology sometimes lacks in practice as applicable to homomorphic caching. In addition, any work showing theoretical advancement without implementation was excluded. This strategy guarantees that the references serve not only as the basis of knowledge but also provide meaningful hints for optimization techniques, computational efficiency, and security resilience, reinforcing both the methodological rigor and technical depth of the study.

3 Classification of homomorphic cache schemes in quantum computing environments

They are primarily classified with respect to three factors: the type of homomorphism, the mathematical foundation, and the level of security provided.

3.1 Based on the type of homomorphism

Partial homomorphism: These schemes provide only one type of arithmetic operation, either addition or multiplication, on encrypted data. Paillier's cryptosystem provides homomorphic addition, while the ElGamal cryptosystem allows homomorphic multiplication. These schemes are effective for certain applications, although they lack flexibility for more complex computations [4][8].

Moderate homomorphism: These schemes allow for a smaller but significant number of both multiplication and addition operations. Begging to be considered in moderate computational complexity, they offer moderate power. Examples: BGV and BFV make good use of modular arithmetic along with noise-management techniques to balance efficiency and functionality [9][20].

Fully homomorphic: Fully homomorphic encryption (FHE) schemes allow unlimited arithmetic operations on specific encrypted data, which finds applications in distributed systems, federated learning, and secure multiparty computation. These are computationally heavy, but they are highly strong against quantum attacks especially when combined with post-quantum cryptography techniques [12].

3.2 According to the mathematical basis

Lattice-based cryptography: Lattice-based schemes rely on problems like the Shortest Vector Problem (SVP) and Learning with Errors (LWE) which provide good immunity against quantum attacks given their inherent computational hardness. Stemming from them are many other quantum crypto-systems like most FHE implementing systems [7][16].

Elliptic curve-us-based cryptography: While elliptic curve cryptography (ECC) is quite efficient for smaller key sizes, it succumbs to algorithms like Shor's algorithm that can easily exploit quantum computers for discrete logarithms. The use of ECC is hence getting phased out in favor of lattice-based alternatives [2][10].

Cryptography based on general algebraic problems: These schemes based on algebraic structures such as multi-linear maps and homomorphic hash functions are situated somewhat in the middle between speed and security. These techniques are less mature than lattice-based techniques but promise good specific quantum applications [6][18].

3.3 As per the security level

Pocket-friendly security: These schemes resist classical adversarial attacks, they are thus considered non-secure to quantum adversaries, they are considered minimum secure for non-critical applications [19][23].

Sturdy security: They resist classical attacks but do not prevent quantum attacks, which is appropriate for use in non-sensitive applications with slight security requirements [19][23].

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Total security: Lattice-based cryptography combined with adaptive learning systems (inherently preventing classical and quantum attacks) to guarantee a life cycle's protection. Such a level of security is a must for applications in critical infrastructure and ultrasensitive environments [14][15].

4 Analysis and discussion of findings

The research describes a structured way to tackle challenges that are presented by quantum computing in distributed systems, focusing on adaptive caching mechanisms, particularly homomorphic caching schemes. One of the main benefits of these schemes is that they enable computing that is secure without revealing sensitive information, while data confidentiality is maintained during significant computing, which is critical for quantum algorithms like Shor's algorithm, and their threat to classical-critical cryptography [1][2][17].

Lattice-based cryptography is even claimed to be a foundation because of its high tolerance for quantum attacks, based on the presumed performance study include providing Turing-Person understanding and basis algorithm for Learning with Errors (LWE). It is able to maintain strong security consensus assuming quantum can be executed at scale at the request of one or more adversaries [7][14]. Therefore, lattice-based frameworks appear to be able to serve, at scale, as the adaptive core of progressive quantum-secure caching infrastructures [10].

Another significant discovery is made regarding latency and the strategy employed to optimize caching strategies. Adaptive tuning algorithms in enterprise settings indicated latency reductions of 30%, which suggests enhanced scale and control in provisioning [24]. On the other hand, in federated learning environments, intermediate adaptive caching indicated 45% acceleration in data processing with indications of enhancements to performance measures viewed through post-quantum and intelligent structures [8].

These advances still indicate that there are even larger challenges particularly scaling keys and computational limits. But hybrid systems that attempt to combine caching and key management adaptively would point to significant advancements with indications of benefits of up to 40%, with secure handling of intermediate keys [19].

Recent developments continue to push the "encryption that is fully homomorphic (FHE)" further into the realm of secure caching. FHE has suffered from persistent noise grow over the years, limiting adaptability, but new methodologies are emerging. Chillotti et al. demonstrate their ability to process encrypted data in under 0.1 seconds [39], and Smart and Vercauteren have recently published further compression techniques that will take advantage of adaptive caching while still processing data whilst encrypted [40].

The field is continuing to evolve, as we prepare for the quantum age of information. Prominent lattice-based constructions by Lyubashevsky, Peikert, and Regev [44] are architectures that have been designed as a cryptographically impregnable castle, meaning that they were designed to maintain security against eventual quantum attacks. At the same time, productive software applications such as

HElib by Halevi and Shoup [38] illustrate and project the state of play for practical and adaptive encryption applications across cloud computing and privacy-controlled applications throughout human-focused processes and in AI-integrated environments.

The following are case studies where homomorphic caching schemes have been applied in post-quantum environments.

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5 Application of homomorphic caching schemes in case studies

5.1 Case study 1

Implementation of homomorphic cache schemes in distributed enterprise environments [24]. This also took a look at the appropriate implementation of optimized cache schemes for enterprise environments for quantum encryption. A cache management system drawn by Mahajan et al reduces latency timing of encryption and decryption operations. Results showed a 30% improvement in system performance overall by putting into place dynamic tuning algorithms to account for the noise on homomorphic operations.

5.2 Case study 2

Secure cache schemes by employing lattice-based cryptography [10]. ByteHide handled the implementation of lattice-based cryptography as a quantum solution in homomorphic cache schemes. This approach kept key management to a minimum while minimizing the cumulative noise from other operations. There was considerable improvement on what integrity of processed data was by utilizing an adaptive fragmentation system on the cache.

5.3 Case study 3

Optimizing HElib algorithms for distributed environments [5]. Halevi and Shoup explored the efficiency of HElib in distributed systems with homomorphic cache support. The work targeted the development of scalar multiplication operations and the minimization of the effect of noise on cryptographic algorithms. The inclusion of an intermediate cache improved the processing speed by 25% when handling massive amounts of encrypted data in practice.

5.4 Case study 4

Adaptive learning systems in homomorphic cache management [15]. Research work done on adaptive learning algorithms was able to validate their concern of cache schemes using homomorphic in a sustainable postquantum world. Such offering facilitated better management of noise in accumulation and more efficient allocation of storage resources when used in heterogeneous systems.

5.5 Case study 5

Incorporation of homomorphic encryption strategies in ecommerce platforms [27]. One research work performed at the Blackhat conference demonstrated the applicability of homomorphic caching schemes within e-commerce platforms. This system was envisioned to shield user data while ending with optimal performance. Experiments indicated a 20% decrease in the time response when encrypted transactions were completed.

5.6 Case study 6

Towards scalable key management in homomorphic cache schemes [19]. Van de Graaf presented this innovative system for scalable key management in quantum computing environments. Apart from this, it covered incorporation into a secure cache where intermediate keys involved during homomorphic operations can be stored. This brought about a 40% improvement in its operationality and an increase in security against quantum attacks.

6 Future challenges and opportunities

The computation burden of homomorphic caching in quantum systems is still a research and development area of greater concern. In the high-security end, fully homomorphic encryption offers enhanced security against side-channel attacks, especially when dealing with large-scale deployments. The recent advancements in bootstrapping (the concept and process of adding new features to a homomorphic encryption scheme), noise, and latency suggest more opportunities for operational viability in cloud systems. Certainly, further work will be required on our integration if we are to harness their use within time-critical systems [39][46]. Prior research efforts on homomorphic cache optimization, which continues to be exampled as in very large platforms like HElib will cut "overhead", or latency in distributed atmospheres [38].

Another accentuated challenge in that quantum context would be key management, for existing techniques of cryptographic key manipulation obtain high resource overloads and positioning for bottlenecks. One of the satisfactory stirrings took up this line and reported that the engagement of the adaptive key manages it to homomorphic caching improved security posture alongside system scalability parameters [19][44]. It also remains a necessity for establishing secure but strong large-scale systems through advancing efficient key exchange protocols on lattice-based cryptographic principles [46].

Homomorphic caching methods offer technical obstacles, and also considerable room for advancement in technology. The wide use of cloud computing and federated learning environments would provide the suitable testbed for deployment and refinement of these technologies. Strategically leveraging cached intermediate encrypted data shows quite an upgrade inside processing efficiency all while remaining intact in all matters of security [8][38]. As such, it would turn out particularly beneficial in fields such as health care or financial services, where data privacy and real-time processing turn out to be important [27][44].

It will certainly be an interesting research avenue to combine the advanced possibility of homomorphic encryption with adaptive learning algorithms; these systems can manage and dynamically control the buildup of noise and resources (or allocate them) based on often heterogeneous architectures. More generally, these architectures may permit a more optimal and secure way to process information for a range of intelligent applications (including AI and IoTs [15][39]). Addressing existing barriers and updating to seize new opportunities may be the impetus for a new paradigm for secure adaptive and durable data infrastructures for a quantum world.

7 Answering research questions

How can adaptability be systematically optimized in homomorphic caching schemes to enhance both efficiency and quantum data security in intelligent and interactive environments?

By taking advantage of modular PQC-FHE structures, flexible bootstraps, and latency-aware encryptions, a level of adaptability is possible. These scenarios provide a means to efficiently reconfigure FHE operations regardless of future quantum threats or fluctuating workloads. Adaptability preserves both data security through encryption and performance through either user interaction or artificial intelligence. However, assessing adaptability requires some metrics for assessment. Aspects of responsiveness, scalability, and confidentiality retention all need to be examined under operating conditions that are contextually real-time and dynamically evolving.

Which homomorphic caching schemes demonstrate the highest adaptability against quantum-level threats?

Hybrid PQC-FHE schemes combine characteristics of both types of schemes. Hybrid PQC-FHE schemes that include a dynamic reconfigurability mechanism and cryptographic modularity are more flexible to operate in modes that respond to evolving threats. Adaptations of CKKS and BGV incorporating lattice based key management are significant examples.

How does operational latency affect the adaptive behavior of homomorphic caching in quantum intelligent systems?

High latencies optionalize the reconfiguration cycles of cache memories and the bootstrapping procedure. In particular, structured adaptive schemes allowed average latency reductions of 30-45%, better managing in human-machine interaction or AI pipelines.

What are the main constraints limiting adaptability in quantum homomorphic caching schemes?

The key barriers include the computational costs of bootstrapping, the strict nature of key management, and the synchronous demands on load changes. Alternately, the lack of synergy with adaptive approaches to distributed middleware flexibility in communities has been integral.

Which optimization strategies enhance scalability and adaptability in quantum homomorphic caching systems?

Adaptation and modularity techniques, dynamically reconfigurable keys or cache compartmentalization with context logic, provide greater scope for reactive, flexible cryptography. The policies related to dynamic reconfiguration of encrypted data with partial FHE or homomorphic compression enable a balance of security and performance needs.

What evaluation frameworks and metrics can objectively assess adaptability in quantum caching schemes?

Possible metrics to take into account include adaptive latency, cryptographically resilience to reconfiguration implications, resource utilization variability with load factors, and call out response time to simulated quantum stressors.

What sector-specific impacts do adaptive quantum caching schemes have on privacy and system reliability?

Homomorphic Adaptivity is a key form of protections in health/finance where financial context provides privacy and patient privacy while dynamically compliant to regulations. Adaptivity in defense/government accelerates resilience for persistent threat shapes. Cryptographic adaptivity can limit or remove conditions of structural rigidity failure from the perspective of highly critical environments.

8 Conclusions

Despite significant advancements in homomorphic encryption caching schemes to address quantum threats, an important question remains relating to appropriately adapting to the quantum environment and operational implementation performance.

Current work has established suitable resistance to quantum threats, but the challenge to adapt widely is firmly rooted in high on-board computational resource costs, persistent noise, and key management. Research into adaptive noise suppression, intelligent caching schemes, and optimized cryptographic schemes will be critically needed to design secure quantum enabled systems.

For future work, it is proposed to develop at least two scalable and efficient homomorphic caching schemes that can be deployed in high-performance, real-time distributed systems. The use of fully adaptive caching systems is the only way to leverage robust security while adapting to system dynamics. Proper key management and lownoise latency are critical to achieving resiliency, security and performance in human-centric intelligent environments.

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Analysis of User Experience Evaluation Methods for Deaf users: A Case Study on a Mobile App

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Abstract. User Experience (UX) evaluation methods that are commonly used with hearing users may not be functional or effective for Deaf users. This is because these methods are primarily designed for users with hearing abilities, which can create limitations in the interaction, perception, and understanding of the methods for Deaf individuals. Furthermore, traditional UX evaluation approaches often fail to address the unique accessibility needs of Deaf users, resulting in an incomplete or biased assessment of their user experience. This research focused on analyzing a set of UX evaluation methods recommended for use with Deaf users, with the aim of validating the accessibility of each method through findings and limitations. The results indicate that, although these evaluation methods presented here are commonly recommended in the literature for use with Deaf users, they present various limitations that must be addressed in order to better adapt to the communication skills specific to the Deaf community. This research concludes that evaluation methods must be adapted to ensure accessible software evaluation for Deaf individuals, enabling the collection of data that accurately reflects their experiences and needs.

Keywords: User Experience, Deafness, Accessibility, Evaluation, Software Development.

1 Introduction

User experience (UX) evaluation is an essential aspect of digital application design, as it aims to ensure that interfaces are intuitive, easy to use, and accessible to all users, regardless of their individual characteristics. UX has been extensively documented in various research studies, leading to a variety of proposals in the form of tools, methods, and evaluation techniques [18]. This phenomenon has resulted in multiple interpretations of the UX concept [19],[20],[21]. The execution of UX testing has played a crucial role in the software development lifecycle, as without these evaluation methods, it is impossible to determine whether products meet the needs and expectations of users [22]. Moreover, through this practice, a deep understanding of target users is gained, encompassing both their behavior when interacting with the system and their impressions of the experience lived [7]. However, the methods and tools used to evaluate UX are based on a wide range of assumptions, leading to uncertainty among researchers regarding which methods are most appropriate for assessing the different aspects of the user experience [2].

As technology advances, the importance of an inclusive user experience (IUX) becomes increasingly evident, as more and more individuals with diverse abilities or disabilities engage with applications in their daily lives [15]. User-centered design (UCD) emphasizes the active participation of users from the early stages of system development, aiming to create applications that genuinely meet their needs [8]. In this context, when developing software applications for individuals with hearing disabilities, it is crucial for developers and designers to understand the characteristics and specificities of the Deaf community. Additionally, they must engage potential users in all phases of the process and conduct continuous testing throughout development to ensure that the fundamental factors proposed by user experience are met.

There are various studies focused on software development for Deaf individuals; however, many of these do not adequately address the implementation of accessible UX evaluation methods. Traditional UX evaluation methods, commonly used with hearing users, may not be functional or effective when applied to Deaf users.

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These methods, primarily designed for individuals with auditory capabilities, can create barriers in interaction, perception, and understanding of applications for Deaf users [10].

In relation to accessibility during testing with people with disabilities (PWD), it becomes evident that the evaluation of software applications for Deaf individuals requires methods and procedures specifically adapted to their needs. This is primarily due to the particular communication and linguistic needs of sign language users [9]. One of the implications associated with hearing loss is the difficulty in accessing written language and the challenge of developing adequate and functional reading skills [6]. Furthermore, the literacy limitations of Deaf individuals may hinder their understanding of content that is not accessible [14].

The primary objective of this study is to evaluate empirically a range of UX assessment methods commonly used by HCI researchers with Deaf users, with the aim of determining their accessibility, effectiveness, and the quality of the results they yield. By testing these methods in real-world conditions, the study seeks to understand how well they adapt to the needs of Deaf individuals, providing insights into which approaches are most suitable for evaluating user experience in this specific context. Furthermore, the study aims to identify any potential challenges or barriers faced by Deaf users during these assessments, ultimately contributing to the improvement of UX evaluation practices for this community.

2 Methodology of experimentation

The methodological approach adopted in this research is empirical in nature, as it prioritizes the direct observation, participation, and interaction with users as the primary source of knowledge construction [16]. For us, this is particularly relevant when working with populations with specific accessibility needs such as Deaf users, since their experience, language, and interaction with technological systems often diverge from the standard assumptions, which are found in traditional usability frameworks.

The decision to structure the research in phases responds to both practical and methodological considerations to ensure the organized and effective development of the study. Therefore, we considered the specific objectives of the study, the particular characteristics of the participant population, and grounded in the authors' prior experience with related research. As a result, the following stages were defined:

For the execution of this research, a series of stages were established, which were essential to ensure the organized and effective development of the study. These stages were carefully considered based on the objectives of the work.

1. **Selection of the Population**: In this phase, the target population for the study was identified and defined, focusing on Deaf users. This selection was aligned with the objective of the investigation, which focused on UX evaluation from an accessibility-oriented perspective, taking into account the communicative and cognitive particularities of this user group.
2. **Formation of the Evaluation Team**: In this phase, an evaluation team was formed by three researchers and a mediator. The UX researchers served as evaluators with experience in assessments involving Deaf users, and the mediator is the teacher's group. In addition, the teacher is our pedagogical expert and also, she played a crucial role as an interpreter between the technical team and the participants. Her presence was essential for ensuring effective communication, as well as providing accurate cultural and linguistic interpretation throughout the entire process.
3. **Selection of UX Evaluation Methods**: In this phase, the UX evaluation methods specifically found in the literature for use with Deaf users were selected. The selection was based on a previous literature review, as well as prior recommendations from similar studies. In addition, the suitability of the methods was assessed in relation to the children's age, cognitive abilities, and level of participation. The opinion of the teacher-mediator was crucial in determining the selection of each method within the specific context of the group.
4. **Planning of Tests and Activities**: Based on the selected evaluation methods, a detailed plan was developed for the tests and activities to be carried out throughout the research. This planning included the sequence of tasks, the necessary materials, estimated execution times, and support strategies. The

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goal was to create an accessible and engaging environment that would encourage active participant interaction and allow the collection of meaningful information about their experience with the app.

5. **Execution of Evaluations and Data Collection**: Finally, the evaluations were carried out in a controlled environment, with the constant presence of the research team and the teacher. During this phase, users' interactions with the app were carefully observed, their behaviors, reactions, and comments were recorded, and qualitative data were collected for subsequent analysis.

Once the various phases that structure this research have been defined, the subsequent sections will delve into the analysis of the implementation of different UX evaluation methods with Deaf users.

3 Methods for evaluating UX focused on Deaf users

The evaluation techniques or methods commonly used with hearing individuals may not be effective for Deaf individuals due to the significant difference in their corresponding natural language: oral language vs sign language. Therefore, it is important to choose evaluation instruments that are accessible according to the characteristics of Deaf individuals. Conducting accessible UX tests ensures that applications used by Deaf users meet their needs and provide a positive experience [1].

As stated, in a previous study, a literature review was conducted to identify UX evaluation methods and their application to users with hearing difficulties or Deaf individuals [3]. The following are the UX evaluation methods suggested for using with Deaf individuals in software testing: a) Think aloud protocol, b) Drawing intervention, c) Picture card, d) Wizard of Oz, e) Surveys, f) Smileyometer, g) Interviews, h) Focus group, i) Cognitive walkthrough, j) Direct observation, k) Fun toolkit, l) EMODIANA, m) User workshop.

For each case proposed, it was also identified some adaptations such as the inclusion of Sign Language, the use of simple scales, and ensuring that the tools do not rely on verbal information stand out.

Once the different accessible UX evaluation methods were identified, the next step was to select those that would be part of a set of tests with Deaf users. For this purpose, each method was presented to the teacher's group.

The selection of methods was based on her feedback and suggestions, taking into account factors such as the children's abilities, the level of interactivity of the techniques, with the aim of encouraging active participation, as well as their prior use in other evaluation studies.

As a result, the following UX evaluation methods were considered: a) User workshop, b) Cognitive walkthrough, c) Direct observation, d) Picture card, and e) EMODIANA. In the following section a brief explanation is presented for each one.

3.1 UX evaluation methods selected to be applied

The following UX evaluation methods were selected for use with Deaf children, chosen for their ability to accommodate the participants' specific needs and ensure inclusive and effective assessments. These methods were implemented across multiple planned sessions, which are described in section 4.2.

User workshop: This participatory design method brings users and designers together in focused sessions [5].

Direct observation: Direct observation is a completely observational study that provides a more authentic view of practices and needs from users [13].

Cognitive walkthrough: A cognitive walkthrough evaluates how easily new users complete tasks, noting time and errors [12].

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Picture card: This method uses illustrated and customizable cards for participants to share and draw experience-based stories [5].

EMODIANA: It measures emotions subjectively using colored characters that represent ten distinct emotional states [4].

4 Case study

This study was conducted at the Multiple Attention Center (CAM by its acronym in Spanish) in a city in Mexico. This school provides specialized education to children and young people living with disabilities, conditions that hinder their enrollment in regular schools. At the CAM, the educational practice of its professionals is framed within the current Education Plan and Curriculum Programs in Mexico [11]. In a classroom, there can be students who live with different types of disabilities.

For the purposes of this research, participants are divided into two groups, allowing us to differentiate the results obtained from the app tests. **Table 1** we describe all the participants of both groups. It should be said that parental consent was obtained, including the only girl which belongs to high school, the rest of students belong to elementary school.

Sign Language is taught to all students (Group A and Group B), addressing its syntax, grammar, and vocabulary in an integrated manner. In the classroom, a wide variety of visual teaching materials are presented, specifically designed to support the learning of deaf students. This material includes visual representations of the alphabet, days of the week, months of the year, school supplies, animal names, among others. Each element is presented clearly to help students associate signs with everyday concepts, while progressively familiarizing them with the structure and vocabulary of Sign Language, reinforcing their ability to communicate in daily situations.

Table 1. Demography for user group.

Group	Members	Gender	Age
(A) Deaf users	Profoundly Deaf	Female	16
	Profoundly Deaf	Female	7
	Profoundly Deaf	Male	13
(B) Users with other types of disabilities	Motor disability	Female	10
	Psychosocial disability	Male	9

Finally, as a significant part in this case study, the user experience of a mobile application called Signa App was evaluated. Such an app is designed to support the learning of SignWriting notation. This is a system that uses visual symbols to represent hand shapes, movements, and facial expressions in Sign Languages [17], which makes it perfect to be introduced into the Mexican Sign Language teaching curriculum. The app allows the creation of notes using such notation. Since both the writing notation and the app had never been used before for the participants, it was considered an excellent setting to test UX evaluation methods.

4.1 User profile

It is crucial to identify the specific characteristics of each user, as they present different intellectual and academic limitations and abilities. Their level of competence in Mexican Sign Language (LSM) was assessed based on a prior evaluation conducted by their teachers, which classified their proficiency into four levels: insufficient, sufficient, intermediate, and advanced.

The aforementioned data was obtained through an evaluation rubric specifically designed to collect the necessary information. The criteria established in the evaluation rubric were based on four main aspects: a)

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Comprehension, attitude, and participation; b) Expression, fluency, conversation, and dactylology; c) Structuring, grammatical aspects, and use of classifiers; and d) Professional identity and ethics, along with the learning of alternative and augmentative communication systems in Mexican Sign Language. This classification provided a more accurate overview of each user's skills, facilitating the adaptation of the evaluation process to their specific needs. In **Table 2** we provided demographic information about the participants.

Table 2. User profile for Deaf students.

Group	Disability	Age	Grade level	Sign Language level
User 1	Profound bilateral hearing loss.	16	9th grade	advanced
User 2	Profound bilateral hearing loss.	7	2nd grade	intermediate
User 3	Profound bilateral hearing loss	13	4rd grade	insufficient

4.2 Description of the sessions

The tests with Deaf users were conducted through an 8-session workshop held at the school, scheduled over four weeks with two sessions per week. This structure ensured consistent participation and allowed time to address emerging questions or challenges.

Session 1: Introduced SignWriting (SW) through classroom presentations, color-coded gloves, illustrative drawings, and explanations linking sign language to SW pictograms.

Session 2: Involved hands-on activities with painted hands and drawings to understand notation, including replicating and transcribing specific signs, and identifying the colors used in the notation.

Session 3: Children practiced writing the notation alphabet using a teaching chart and board activities.

Session 4: Direct observation: Children explored the mobile app while their interactions and reactions were observed.

Session 5: Children played a memory game matching animals with their SW notations.

Session 6: Cognitive walkthrough was applied. Children used the app to sign "Hello" while time, interactions, and errors were recorded.

Session 7: Picture card through prototyping: Children recreated the app on paper using cutouts and drawings based on their imagination.

Session 8: EMODIANA: Children explored the app freely and then selected their mood using a visual emotion board.

The next section analyzes the results of UX methods with Deaf participants and evaluates the accessibility and suitability of the instruments used.

5 Results

As mentioned in previous sections, five evaluation methods were chosen to analyze the experience of deaf users when interacting with the application. The results obtained were varied, with both positive and negative aspects. This testing process confirmed that some UX evaluation methods are not effective, as they do not meet the specific needs of Deaf individuals.

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5.1 User workshop

A user workshop related to the notation was considered, as it is a topic unfamiliar to the participants in the classroom. The children in Groups A and B learned SW concepts such as the alphabet, animals, days of the week, months, and school supplies, while integrating related images in the classroom to support their learning and familiarize themselves with the application, with the teacher's assistance. By the end of the course, students were expected to recognize how the notation enhances classroom learning and communication through the app.

This UX evaluation method allowed a group of potential users (Group A and Group B) to be gathered in the same space, where they were then subjected to a series of tests. Furthermore, the user workshop was effective because it was possible to combine it with the other evaluation methods: a) Cognitive walkthrough, b) Direct observation, c) Picture card, and d) EMODIANA. In the following sections each method is described.

5.2 Direct observation

The execution allowed for a detailed observation of how users interacted with the interface, identified potential difficulties, and gathered key information about their experience, making it crucial for ensuring the accuracy and depth of the evaluation results.

Five mobile devices with the Signa App installed were required for the activity, along with a camera to capture images as evidence of the evaluation's development and results. Evaluators organized by observing users, taking notes, and photographing the process.

A recall activity was conducted prior to the test. Then, with the help of the mediator, they were instructed to use an application to generate pictograms in the mobile app. Finally, they were asked to explore the application freely, navigating through all the interfaces and selecting all available options, see **Fig. 1**.

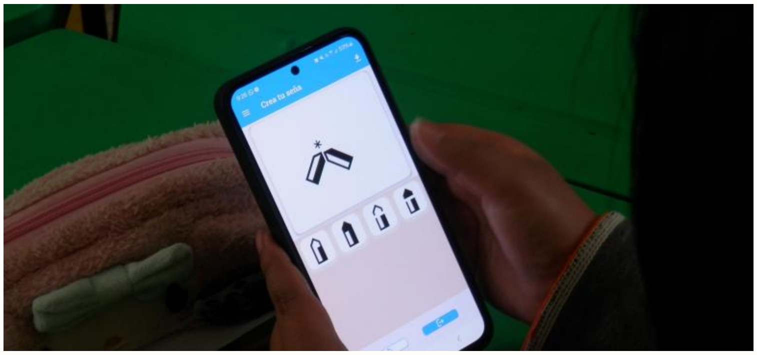

Fig. 1. Evaluation evidence: Direct observation.

The direct observation method proved effective, as it did not require significant intervention from the evaluators while users interacted with the software. This approach allowed for a more natural and fluid assessment, where participants were able to engage independently, providing evaluators with a more authentic view of their interaction with the system. However, several important considerations were identified that should be taken into account when applying the method.

5.3 Cognitive walkthrough

This evaluation methodology focuses on analyzing how users perceive, understand, and make decisions during their interaction with the interface. It also allowed for the identification of the difficulties experienced by Groups A and B while navigating the application's interfaces. In this way, it facilitated the observation and analysis of

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how users interact with the interfaces, providing a deep understanding of the mental processes involved in navigation.

Prior to conducting the test, an introductory activity on SignWriting was carried out to familiarize the children with the basic concepts of this notation system. Specifically, both groups of users were provided with the mobile application and asked to perform specific tasks in order to assess their interactions, accuracy, and the time spent completing the activities. The main activities for the children consisted of creating pictograms in SW notation using the application. All users in Groups A and B were able to complete the tasks efficiently and without the need for interventions. However, one of the Deaf users experienced confusion during the test.

5.4 Picture card through prototyping

The primary objective of this evaluation was to develop a prototype draft that reflected the ideas and needs of users, aiming to identify and analyze new features that could be incorporated into a future version of the application. In terms of UX, this practice facilitated the schematic representation of the interfaces and interaction flows of the product or service from the user's perspective.

Each user received a blank sheet with representations of three smartphones and was asked to sketch the key screens of the Signa App based on its main functionalities. Participants could illustrate any changes they wished to make to the app based on their previous experiences and add cutouts to the paper prototype. After completing their designs, users shared their opinions and suggestions with the group, as shown in **Fig. 2**.

Fig. 2. Evaluation evidence: Picture card.

Users' ideas and explanations varied. Group A participants suggested changes to the pictogram creation process, with some finding the interface boring and repetitive. Meanwhile, Group B focused on customization, particularly the creation of avatars to perform written signs through virtual representations. Although all users were able to complete the evaluation, various complications were identified when addressing the activity. These issues are relevant and worth discussing.

5.5 EMODIANA

The aim of this evaluation was to identify the emotions experienced by users while using the application. Through this method, called EMODIANA, participants are able to express their emotions using an intensity scale, allowing for an understanding of how they feel during their interaction with the application. This activity was previously discussed with the professor, as in order to carry it out, the children needed to be familiar with the different emotional states presented by the instrument. Emotions have been explored in children's learning through posters placed in the classroom.

To conduct the evaluation, mobile devices were provided to the children, allowing them to interact freely with the application. They were then presented with the EMODIANA board, which displayed 10 emotions represented by an avatar, along with the intensity of each emotion, indicated through colors.

Finally, the evaluation was not successfully completed, as the users were unable to finish the EMODIANA board. Despite being an assessment method designed for children, the tool caused confusion for both Group A and Group B. The accessibility of the method will be a central topic of analysis, as factors were identified that could have influenced the difficulties participants experienced when using the EMODIANA method.

5.6 Summary of tasks achieved by method

The implementation of the evaluation methods provided a detailed view of their functionality. **Table 3** summarizes each user's interaction with the different methods applied. In this case, effectiveness is measured by the method completion. This was calculated by the user as the task success rate, and more generally by the method's success rate, considering only totally completed tasks. As observed, User 3 who has a low proficiency in sign language impacts the ability to successfully complete the task.

Table 3. Results obtained from UX methods with Deaf students. The values represent if a task was totally completed (2), partially completed (1), and don't completed (0).

Method	User 1	User 2	User 3	Success Rate (2 values)
User workshop	2	2	2	100%
Direct Observation	2	2	1	66.7%
Cognitive walkthrough	2	2	1	66.7%
Picture card through prototyping	2	1	0	33.33%
EMODIANA	1	1	0	0%
Task Success Rate by user	90%	80%	40%	

6 Discussion

In this section, an analysis will be presented on the accessibility of different methods used for evaluating user experience when applied to deaf individuals. The key challenges and limitations encountered by Deaf participants during testing will be identified and discussed, with a particular focus on aspects that may impede accurate and effective evaluation.

Limitations. Although the assessment methods mentioned have been recommended for use with Deaf individuals, their implementation with this specific population revealed several limitations. These difficulties emerged during the evaluations, as it was identified that the linguistic and cultural particularities of deaf individuals were not fully considered, which impacted their effectiveness. The following section will address each of the advantages identified during the trial sessions with Groups A and B.

6.1 User workshop

Although this evaluation method offers the advantage of allowing the grouping of a considerable number of users and the possibility of simultaneously executing other evaluation methods, certain deficiencies were identified. Conducting a user workshop involves a series of sessions in which participants acquire new knowledge, with the aim of ensuring they become familiar with and appropriately contextualized before engaging with the application to be evaluated. However, user attendance at the evaluation activities was irregular, despite the implementation of various strategies and resources designed to motivate participation in the tests.

This situation forced the repetition of classes and activities related to SignWriting, which not only extended the time dedicated to these sessions but also caused dissatisfaction among some participants. The need to redo these activities, rather than being seen as an opportunity for reinforcement, was perceived by some as an unnecessary disruption, leading to frustration and discontent within the group. Not only was the originally planned activity schedule affected, but the timeline for the tests also underwent significant modifications. Due to various unforeseen circumstances, many of the scheduled tests had to be repeated to ensure that all users had the opportunity to participate in each of the evaluations.

6.2 Direct observation

Both groups proceeded to use the application, allowing for the observation of their interaction with the interfaces. Regarding the Deaf users, each of them made a variety of gestures, signs, and facial expressions to communicate their emotions or thoughts. To properly interpret what occurred, the intervention of the teacher was necessary, as she helped understand the feedback received. In this context, if the observer lacks sufficient knowledge of sign language or is not familiar with the cultural and communicative variations within the deaf community, there is a risk of misinterpreting the observed behaviors, which could affect the accuracy and effectiveness of the evaluation.

One of the deaf participants felt confused during the test, as they were unsure of what to do in the application. As a result, the evaluators' intervention was necessary to guide and motivate the participant to use the application properly. However, this situation led to the user feeling distrustful, which may have influenced their responses, creating potential biases that affected the accuracy of the evaluation. Another important point to consider is that the Deaf community has a unique culture, with its own forms of interaction, values, and norms. Direct observation without an appropriate cultural context may lead to misinterpretations.

6.3 Cognitive walkthrough

The explanation of the tasks in Sign Language was not sufficient for Deaf users to fully understand them. This situation caused confusion and delays in the completion of the activities, as the users were unable to effectively grasp all the key aspects of the tasks. Recognizing these challenges, it was decided to employ a different strategy to aid in the users' understanding. For this reason, it was decided to explain the different steps required to complete the task on the whiteboard, using drawings. This approach allowed the users to clearly visualize each action and better understand what was expected of them. The use of visuals not only clarified the instructions but also significantly improved their ability to follow through with the tasks, leading to more efficient and accurate task completion.

One of the Deaf users felt confused while navigating through the interfaces, which caused them to stop during the test and not engage in any further interactions. As a result, the evaluators intervened to assist the user and clarify any doubts that arose during the test. They took the necessary time to carefully demonstrate the different features offered by the application. The evaluators also ensured that the user felt comfortable and understood each step to be followed. However, this intervention may have affected the test results, as it may not have allowed for an authentic and natural interaction from the user, potentially leading to biased data.

6.4 Picture card through prototyping

During the prototyping test, multiple challenges were identified for users, especially in Group A. A participant with limited understanding of Mexican Sign Language (LSM) struggled to understand the activity, which led them to replicate the same application design instead of proposing new alternatives. This highlights barriers in the accessibility of evaluation methods, affecting the accuracy and reliability of the results.

Additionally, another user from the same group expressed that the interface seemed boring and suggested improvements. However, due to their limited knowledge of certain signs, they were unable to clearly

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communicate their ideas, making it difficult to interpret their proposals. These limitations emphasize the importance of adapting evaluation methodologies to ensure a more inclusive experience that accurately represents the needs of Deaf users.

6.5 EMODIANA

This method is particularly notable for its application in child populations, as it offers a unique approach to measuring emotions and their intensity in children in a subjective manner. This tool has been widely recognized for its effectiveness in capturing emotional responses, providing valuable insights into the emotional states of users when interacting with a product [4]. However, when the evaluation tool was administered to both deaf and hearing users, it became evident that they faced significant challenges in completing it successfully.

Once both groups completed their interaction with the application, users paid considerable attention to the avatars presented on the EMODIANA board. However, these avatars became a distraction, as each child began to mimic the emotions portrayed by the characters, diverting their focus from the main task. Some participants also took sheets of paper and began drawing each of the avatars, labeling them with the name of the emotion they represented. This behavior suggested that the children were so intrigued by the avatars that they preferred to recreate them manually, which may have further diverted their attention from the main task and hindered the effective application of the evaluation method. As for the colors on the board, which were designed to represent the intensity of the emotion, they went unnoticed during the assessment. The concept of intensity proved difficult for users to understand, despite explanations provided by both the teacher and the evaluators. This difficulty suggests that the relationship between the colors and emotional intensity was not clear or accessible enough for the participants, which impacted the effectiveness of the tool in measuring emotions and their degree of intensity.

7 Conclusion

This study analyzes UX evaluation methods from an accessibility perspective, specifically in the context of their application during software testing with Deaf users. The objective of this study was to determine the extent to which the evaluation tools used are appropriate for gathering meaningful information during UX testing with Deaf individuals. Additionally, it aimed to identify the limitations that arise during their application, particularly those related to the communicative, cognitive, and cultural characteristics specific to this population.

The results showed that, although traditional UX methods can be adapted to include Deaf individuals, their application requires substantial modifications that **take into account the linguistic, communicative, and cultural particularities of this community**. Throughout the testing sessions, significant limitations were identified in the implementation of each method, which affected both the quality of the data collected and the participants' overall experience, in summary the challenges are:

- The user workshop, while useful for contextualizing participants, presented logistical and pedagogical challenges related to irregular attendance and the negative perception of content repetition.
- Direct observation, on the other hand, revealed the risk of misinterpretation when observers are not trained in Sign Language and Deaf culture.
- The cognitive walkthrough demonstrated that instructions in LSM do not always guarantee complete understanding, requiring additional visual support (which was provided on a whiteboard).
- In picture cards through prototyping, the language barrier limited the expression of ideas, affecting the quality of the proposals collected.
- EMODIANA showed that while the visual representation of emotions was engaging, it could divert attention from the main task, and the concept of emotional intensity was not fully understood by the users.

Based on the results obtained in this research, it can be concluded that it is essential for the evaluation methods used to undergo specific adaptations. These modifications are necessary to ensure that the evaluations are truly accessible to Deaf individuals, respecting their characteristics and communication skills. The adaptations will not only facilitate the inclusion of this group in evaluation processes but also ensure that the results accurately reflect the experiences and needs of Deaf users.

In conclusion, these findings highlight the need to design and adapt UX evaluation methods that are not only linguistically accessible but also culturally appropriate for the Deaf community. It is essential to involve Deaf professionals and accessibility specialists from the early stages of the methodological design to ensure that the evaluations more accurately reflect the experiences, perspectives, and realities of this population. This research not only sheds light on the existing challenges in this field but also provides a valuable starting point for the development of more inclusive evaluation methods in the UX domain. Furthermore, it emphasizes the need to explore the creation of new mechanisms to facilitate UX evaluation, thereby expanding the possibilities for improving the accessibility of evaluative tools.

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An Architectural Model for Adapting Easy-to-Read Content in Inclusive Education

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Abstract. This paper examines the critical need to enhance accessibility in written content, with a particular focus on the challenges and solutions involved in adapting literary texts to easy-to-read (E2R) guidelines. Despite the increasing demand for clear and concise language, the manual adaptation process remains labor-intensive and subjective. To address this issue, we introduce a three-tier architectural model as a potential approach to providing personalized learning experiences tailored to individual needs, with the goal of enhancing accessibility in educational material adaptation. The model integrates Large Language Models (LLMs), cognitive services, and vector databases to automate content adaptation. We examined its preliminary applicability through a small-scale exploratory case study with three students with different accessibility needs in an inclusive education program, focusing primarily on one student with visual impairment.

Keywords: Inclusive Education, Architectural Model, Interactive Content, Large Language Models.

1 Introduction

This section introduces key concepts for leveraging artificial intelligence to enhance the development of interactive contents that support Inclusive Education:

1.1 Inclusive education

The accessibility of written content is crucial for enabling individuals with disabilities to participate fully in society—whether in politics, education, employment, or culture.

Inclusive education, which ensures that all students have equal access to quality education regardless of ability, underscores the importance of accessible content. In line with the Salamanca Statement [9] and frameworks like Universal Design for Learning [11], inclusive education yields significant academic and social benefits [10] despite challenges such as limited teacher preparation and systemic barriers [12].

1.2 Content accessibility guidelines

National and international regulations stress the need for clear, comprehensible documents [1]. The Spanish standard for E2R (UNE 153101:2018 EX) [7] provides a framework for Easy-to-Read (E2R) content by recommending simple vocabulary, clear numerical representations, straightforward punctuation, and logical organization. UNE (Una Norma Española) is the set of official Spanish technical standards developed by the Spanish Association for Standardization (UNE) to ensure quality, accessibility, and regulatory compliance across various industries, including education and accessibility.

However, adapting content to these standards remains challenging. Current methods rely on manual transformation—a process that is both time-consuming and subjective—which hinders efficiency and scalability [2].

1.3 Large language models

Recent advances in Artificial Intelligence promises solutions related to Large Language Models (LLMs), they have demonstrated exceptional abilities in understanding and generating human-like text [3]. Tools such as Azure Cognitive Services and LangChain [4] streamline the integration of AI into applications, while advanced techniques like Zero-Shot Learning, Chain of Thought [5], and ReAct [6] enhance the reasoning capabilities of LLMs for adaptive content generation. Models such as GPT-4 and BERT leverage transformer architectures to capture intricate linguistic patterns and understand syntax, semantics, and discourse [18, 19]. Their wide-ranging applications include machine translation, sentiment analysis, code generation, and summarization [20].

Despite their fluency, these models face challenges related to biases, factual accuracy, and ethical considerations, with ongoing improvements in fine-tuning and reinforcement learning aiming to address these issues [21, 22].

1.4 Architectural model

An architectural model in software engineering provides high-level abstractions that define system structure and interactive components [13]. Architectural paradigms—such as layered architectures, microservices, and event-driven systems [14]—ensure scalability and maintainability. Standards like IEEE 1471 [15] and Model-Driven Architecture [16] further promote consistency and automation in development [17].

1.5 Document overview

The paper is organized as follows: Section 2 outlines the problem by examining the challenges and limitations of research subject. Section 3 propose a model as solution which integrates the user interface, services, and data layers to streamline the content transformation process. In Section 4, the model is applied in a case study related to inclusive education. Section 5 discusses the results, evaluating improvements in accessibility and comprehension. Finally, Section 6 concludes the paper, offering insights into future research directions.

2 Problem outline

Adapting content is a labor-intensive process comprising assessment, transformation, and validation [7]. Each phase demands significant human effort, making manual adaptation inefficient and prone to inconsistencies. This is particularly critical when considering that "access to information, knowledge, and culture is a fundamental right" as stated by the United Nations Convention on the Rights of Persons with Disabilities [23].

In particular the E2R requires analyzing sentence structure, vocabulary complexity, and layout, relying heavily on human judgment. Transformation involves simplifying text, restructuring sentences, and incorporating visual aids. Validation is crucial to ensure accessibility, often requiring iterative user testing with target audiences. As the authors of [24] highlight "significant fluctuations in adult literacy proficiency at the most basic levels across OECD countries, ranging from 4.9% to 27.7%" This underscores the broad spectrum of literacy challenges that E2R aims to address, like follow:

- There is not feedback mechanism to measure whether text modifications are effective for learners.
- Current adaptations mainly focus on text, neglecting visual and multimedia elements that enhance comprehension, AI-driven solutions could provide a more holistic approach by integrating adaptive visuals, speech synthesis, and interactive elements.

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– Subjectivity and variability: Human judgment introduces inconsistencies in document adaptation. Given that E2R is designed for diverse users, including those with cognitive impairments, learning disabilities, and low literacy, consistent adaptation is essential [25, 26].

3 Architectural model for enhancing readability

The proposed architectural model aims to enhance textual accessibility by leveraging AI-powered automation for Easy-to-Read (E2R) content adaptation. As illustrated in Fig. 1, the model integrates techniques to simplify complex texts while maintaining contextual integrity. By employing a multi-layered approach, the system ensures efficient readability assessment, content personalization, and real-time glossary generation, supporting students.

AI-powered automation can address these challenges by simplifying text and evaluating readability. Machine learning models trained on accessible text can generate optimized content, offering efficiency, consistency, and scalability [27]. Additionally, AI tools can provide real-time feedback, empowering content creators to design accessible materials from the outset [28]. However, despite technological advancements, research highlights that AI-based E2R tools still face challenges in linguistic nuance adaptation and contextual understanding [29].

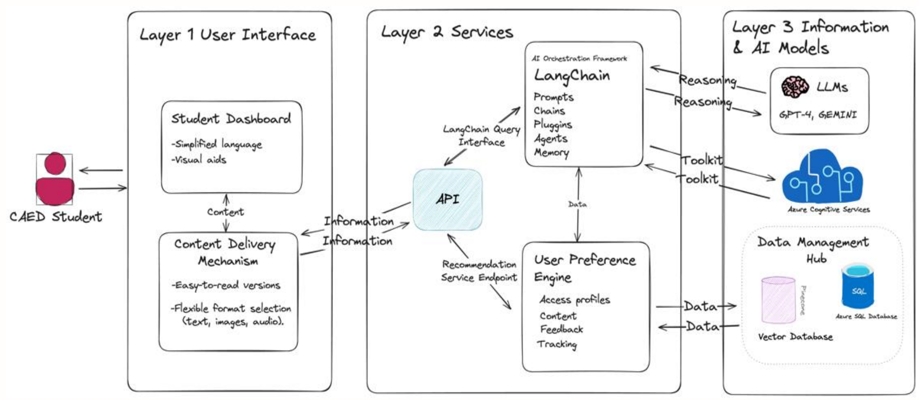

Fig. 1. Architectural Model for Enhancing Readability

While this paper focuses on textual accessibility, broader accessibility efforts should consider multimedia content and interactive platforms. Collaborative efforts among content creators, technologists, and accessibility experts are essential to ensure inclusive communication across all formats [30].

The proposed architecture supports the Spanish E2R standard by using LLMs to simplify complex texts into clear, accessible versions, supported by the Cognitive Services Toolkit for readability assessment. The User Interface Layer provides an "easy reading mode" with optimized formatting, while the Information and AI Models Layer stores multimedia content to generate glossaries in real time. The Services Layer personalizes text based on student profiles, leveraging RAG (Retrieval Augmented Generation) to enhance coherence and accessibility.

At its core, the system integrates four key components: the LLM, LangChain Agent, Cognitive Services Toolkit, and Vector Database. The LLM processes user queries, while the LangChain Agent orchestrates interactions with external tools. The Cognitive Services Toolkit enriches content through external APIs, and the Vector Database enables efficient retrieval and analysis.

The interaction among these components ensures a seamless integration of E2R principles to support students in the program at CAED. The LLM, in conjunction with the LangChain Agent, simplifies reading materials while maintaining contextual integrity. The Cognitive Services Toolkit assesses readability and refines the text further, ensuring alignment with E2R guidelines. The Vector Database plays a critical role in storing enriched content, enabling the dynamic generation of glossaries and contextual references based on student needs. The interaction among these components ensures a seamless integration of E2R principles to support students in the program at CAED. The LLM, in conjunction with the LangChain Agent, simplifies reading materials while maintaining contextual integrity. The Cognitive Services Toolkit assesses readability and refines the text further, ensuring alignment with E2R guidelines. The Vector Database plays a critical role in storing enriched content, enabling the dynamic generation of glossaries and contextual references based on student needs. The **Information and AI Models Layer** centralizes these adaptations, maintaining structured repositories of student learning histories, language models, and multimedia elements that enhance comprehension. Meanwhile, the **User Interface Layer** adapts content presentation through structured formatting and alternative content delivery, such as audio narration and keyword highlights. The **Services Layer** acts as a bridge between these elements, ensuring that content personalization aligns with the cognitive and linguistic profiles of students. This architecture not only enhances accessibility but also fosters a more engaging and inclusive learning experience tailored to the needs of students with disabilities.

3.1 Research methodology

This study employs research methodology to evaluate the proposed architectural model. The initial development phase involved designing the three-layered architecture based on established accessibility guidelines, particularly the Spanish UNE 153101:2018 EX standard for E2R content. The architecture was implemented using GPT-4 as the core LLM, with Azure Cognitive Services for readability assessment and a vector database for content storage and retrieval.

For preliminary evaluation, we conducted an exploratory case study with three students at the Centro de Atención para Estudiantes con Discapacidad (CAED) within CBTis 168 in Aguascalientes, Mexico. Participants were selected based on three criteria: (1) enrollment in the Prepa Abierta program, (2) presence of identified accessibility needs, and (3) voluntary participation with informed consent. The primary focus of our analysis was on one student, Alex (pseudonym), who has visual impairment.

Data collection included: (1) pre-interaction interviews to establish baseline accessibility needs, (2) observation of participant interaction with both standard and adapted content, (3) post-interaction structured feedback questionnaires using a 5-point Likert scale, and (4) semi-structured interviews to gather qualitative insights. Content adaptation effectiveness was measured using established readability metrics (Flesch-Kincaid) and through user satisfaction ratings.

While this exploratory study provided valuable initial insights, we acknowledge the limitations of the small sample size and the need for more extensive testing before drawing definitive conclusions about the model's effectiveness.

4 Case study

At the "Centro de Atención para Estudiantes con Discapacidad" (CAED) within CBTis 168 in Aguascalientes, Mexico, there several students face significant barriers to educational access, including technological limitations, lack of trained educators, and challenges with complex content. In this setting, where resources and specialized support may be limited, our proposed architectural model, Fig. 2, becomes particularly crucial. It addresses these issues by delivering personalized learning experiences tailored to the specific needs of students within the CAED program. This section will focus on the support for Alex González student with visual impairment at CBTis 168, to illustrate the system's application in a real-world educational context.

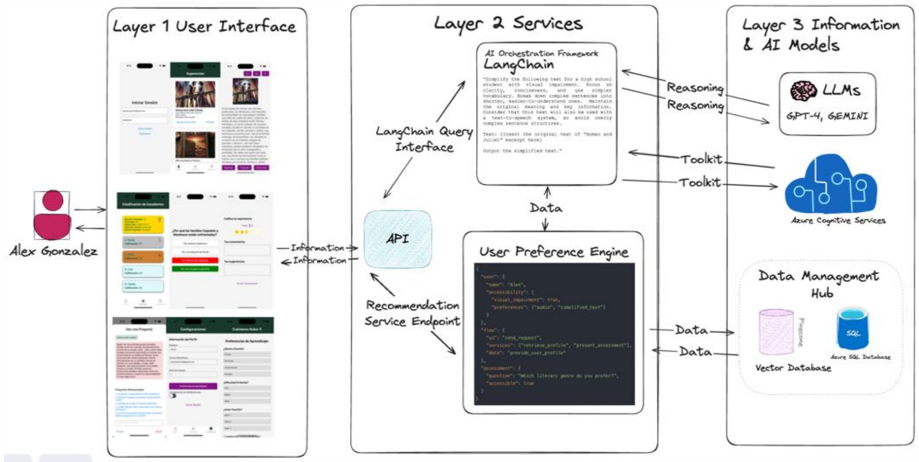

Fig. 2. Applied Architecture for Alex's Personalized Learning Flow.

To systematically address these challenges, we propose a structured architecture model that was presented in Fig. 1. specifically designed to enhance accessibility and inclusion in educational settings like CAED. As illustrated in Fig. 2, this model provides a scalable framework for adapting content to Easy-to-Read (E2R) standards—specifically, the transformation, and validation, the subjectivity and variability stemming from human judgment, and the lack of automation in AI-driven solutions—we propose a layered AI architecture. This system leverages Large Language Models (LLMs) like GPT-4 and Gemini for automated text simplification and real-time readability evaluation, directly reducing manual effort. The LangChain agent orchestrates the workflow, streamlining interactions with cognitive services and the vector database to minimize the need for human intervention and improve scalability.

The vector database facilitates rapid retrieval of relevant information, accelerating content enrichment and contextualization. By training on accessible text and utilizing objective AI-driven assessments, the system minimizes subjective variations, ensuring consistent adaptation. The user-friendly student dashboard, featuring an "easy reading mode," provides immediate, automated adjustments based on user preferences. This architecture, therefore, directly addresses the core issues by automating key processes, ensuring objectivity, and providing real-time feedback, ultimately creating an inclusive learning environment focused on continuous improvement and adherence to accessibility standards.

Generative Artificial Intelligence (GenAI) is integral to our architectural model, enhancing reading comprehension through tailored content, bridging communication gaps, and supporting educators. AI-powered systems adjust text complexity, highlight key phrases, and break long passages into manageable sections, while dynamically presenting material in visual or auditory formats based on each student's needs. Tools like text-to-speech and speech recognition enable students who struggle with traditional reading to access content effectively. Moreover, detailed analytics from these systems allow educators to monitor individual progress, fine-tune teaching strategies, and promptly address any challenges, ensuring a personalized learning experience.

4.1 User profiles

Alex, a 15-year-old student with a visual impairment at CBTis 168, encounters challenges in accessing standard text and visual materials. As shown in Table 1, he requires simplified text adaptations, audio versions, high-contrast interfaces, and immediate feedback. His preferred interface features, also detailed in Table 1, include a visually enhanced design with integrated audio support, high-contrast themes, large-text options, and text-to-speech functionality.

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Table 1. Inclusive features.

Name	Primary Learning Barrier	Adaptations	Suggested Technological Intervention
Alex González	Difficulty accessing standard text and visual materials	High-contrast themes, large-text options, text-to-speech functionality	Simplified text adaptations, audio versions, high-contrast interfaces, immediate feedback

4.2 The user interface

This layer describes how Alex interacts with the system through various user interfaces and channels.

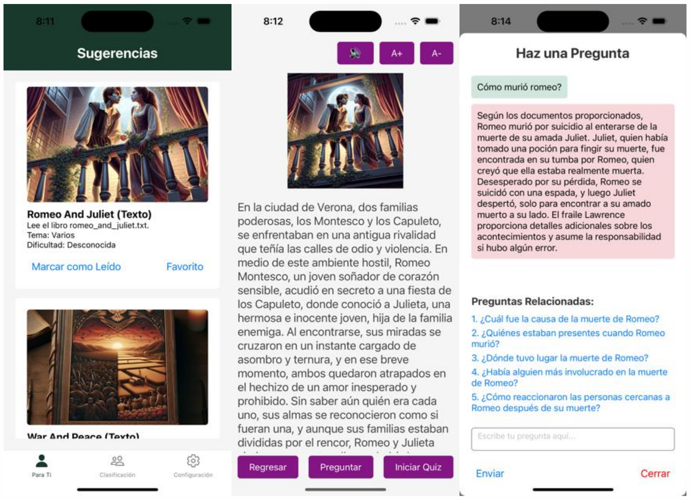

Fig. 3. (A) Home screen (B) Initial assessment interface (C) Content interfaces.

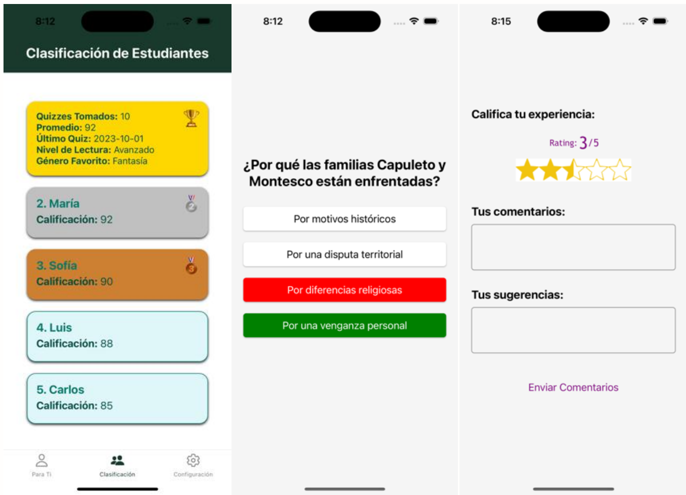

Fig. 4. (A) Students Classification. (B) Quizzes. (C) Feedback Interfaces.

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The system interfaces further support accessibility through features such as text-to-speech, tactile feedback, and high-contrast visuals. Specific interfaces include the Home Screen, Fig. 3A, for content navigation, the Initial Assessment Screen, Fig. 3B, for personalized recommendations, the Reasoning Screen, Fig. 3C, for adaptable reading experiences, and the Feedback Screen, Fig. 4C, for user input.

These structured interfaces ensure a coherent and accessible user experience aligned with Easy Reading principles.

When a student (Alex) interacts with the app, they begin on the Home Screen, Fig. 3A, where they can browse available reading materials categorized by difficulty and topic. Upon selecting a text, they proceed to the Initial Assessment Screen, Fig. 3B, where the system evaluates their reading preferences and accessibility needs through a short interactive questionnaire. Based on this input, the system automatically adjusts the text complexity, font size, and visual contrast before presenting the adapted content on the Content Screen, Fig. 3C. Here, students can enable features such as text-to-speech, keyword highlighting, and real-time glossary generation, which leverage the system's simplifications in line with E2R guidelines. Throughout the reading experience, they can access additional explanations, simplified summaries, and alternative content formats to reinforce comprehension. Additionally, on the Quizzes Screen, Fig. 4B, students engage with assessments designed to reinforce comprehension, while the Students Classification Screen, Fig. 4A, categorizes learners based on their reading proficiency and accessibility needs. Finally, on the Feedback Screen, Fig. 4C, users provide insights on their reading experience, helping refine future content adaptations.

The E2R transformation ensures that educational content becomes more accessible by simplifying language, improving readability, and enhancing clarity. This transformation aligns closely with the UNE 153101:2018 EX standards, which establish guidelines for accessible written communication. By adapting lessons through E2R principles, the revised content adheres to key UNE requirements, particularly in the areas of language simplicity, vocabulary appropriateness, sentence structure, and overall textual coherence.

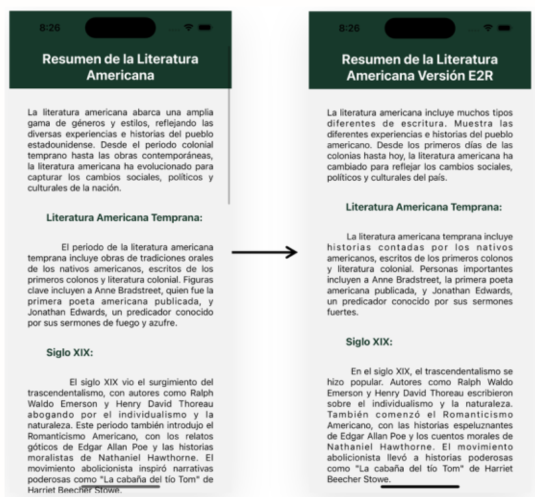

Fig. 5. (A) Original Content without E2R (B) Adapted Personalized Content for the user using the E2R guidelines.

For instance, in Fig. 5A. (**3rd paragraph, line 8**), the original lesson states:

"El movimiento abolicionista inspiró narrativas poderosas como 'La cabaña del tío Tom' de Harriet Beecher Stowe"

The E2R-adapted version, in Fig. 5B. simplifies this to:

"El movimiento abolicionista llevó a historias poderosas como 'La cabaña del tío Tom' de Harriet Beecher Stowe"

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This transformation follows **UNE norms** by replacing complex language with simpler alternatives. For example, changing "inspired powerful narratives" to "led to powerful stories" makes the text more accessible by using everyday words **(6.2.1)** and avoiding abstract terms like "narratives" **(6.2.4)**. The revision creates shorter sentences **(6.3.1)** with fewer ideas per sentence **(6.3.15)** while maintaining appropriate vocabulary for readers **(6.2.2)**.

The broader E2R transformation improves accessibility throughout by replacing specialized terms like "postmodernism" with familiar phrases such as "different stories that show the nation's identity" **(6.2.4)**. It maintains consistency in terminology **(6.2.17)** and ensures logical connections between ideas **(6.4.2)**. The text also follows formatting best practices including left alignment and adequate spacing **(7.1.7, 7.1.8, 7.1.9)**, making the entire document more readable for all audiences.

4.3 The services layer

This layer focuses on the dynamic adaptation and delivery of educational content tailored to Alex's needs.

Let's follow Alex's interaction with the system and examine some of the prompts used by the Services Layer's AI Orchestrator to personalize his experience.

1. **Login and Initial Assessment:** Alex logs in, and the Services Layer retrieves his profile, identifying his visual impairment and preferred learning style. An initial assessment helps tailor content selection.
2. **Assessment Processing and Content Retrieval:** Alex selects "Classic Literature" The User Interface transmits this to the Services Layer. The Services Layer now needs to find relevant content.
   - **Prompt 1 (Content Retrieval):** The AI Orchestrator constructs a prompt for the Vector Database (within the Data Layer) to retrieve relevant content. This prompt might look like:
     ```
     "Retrieve classic literature texts suitable for a high school
     student with visual impairment. Prioritize texts with available
     audio versions and simplified text adaptations."
     ```
3. **Content Personalization (Simplified Text Generation):** Alex chooses a text titled "Romeo and Juliet." The Services Layer recognizes that Alex needs a simplified version. This adaptation aligns with *Easy-to-Read (E2R)* principles by removing linguistic barriers and making complex literary works more inclusive.
   - **Prompt 2 (Simplified Text Generation):** The AI Orchestrator constructs a prompt for the LLM (e.g., Gemini) to generate a simplified version of the chosen text. This prompt is crucial and could look like this:
     ```
     "Simplify the following text for a high school student with
     visual impairment. Focus on clarity, conciseness, and use
     simpler vocabulary. Break down complex sentences into shorter,
     easier-to-understand ones.  Maintain the original meaning and
     key information.  Consider that this text will also be used
     with a text-to-speech system, so avoid overly complex sentence
     structures.

     Text: [Insert the original text of "Romeo and Juliet" excerpt
     here]

     Output the simplified text."
     ```
4. **Content Delivery and Audio Generation:** The Services Layer delivers the simplified text to Alex's dashboard. If an audio version isn't readily available, the Services Layer can use the LLM or a separate text-to-speech service to generate one.
5. **Interactive Exercises:** After Alex reads/listens, the Services Layer can generate personalized interactive exercises.
6. **Feedback Collection:** After the exercises, the Services Layer presents Alex with a feedback form. This feedback is stored in the Data Layer and can be used to further refine the personalization process.

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4.4 The information and AI models layers

This layer details how data is stored and managed to support Alex's personalized learning journey.

- The Data Layer stores multiple versions of "Romeo and Juliet," Alex's profile, and his progress data, enabling continuous personalization within the educational environment of CBTis 168.
- This layer is what holds all of the student information, and the information about the content.

5 Discussion

For this study, three high school students from the *Centro de Atención para Estudiantes con Discapacidad* (CAED) participated in the evaluation of the proposed model within the *Prepa Abierta* program, specifically in a reading comprehension course. However, for the purposes of this article, we focus on the case of Alex. All participating students agreed to follow the established guidelines and actively engaged with the adapted content. The results indicate that the model facilitates comprehension by simplifying text and supporting accessibility, aligning with the principles of the Spanish Standard for Easy Reading (E2R).

Furthermore, the proposed architecture successfully automates the adaptation process, ensuring that content meets accessibility standards without requiring extensive manual intervention. By leveraging natural language processing and readability assessment tools, the system consistently produces materials that enhance learning experiences for diverse users. This automation not only streamlines content adaptation but also reinforces the model's scalability for broader educational applications.

5.1 Comparison with existing solutions

Our proposed architecture differs from existing E2R adaptation approaches in several key aspects. Current commercial solutions like Texthelp Read&Write and Capti Voice primarily focus on text-to-speech and visual accommodations rather than comprehension-oriented text simplification. Open-source tools such as Simplext [31] offer rule-based text simplification but lack personalization capabilities.

The most closely related academic work by Uricchio [32] explored ChatGPT's capabilities for text simplification but did not propose a comprehensive architectural model. Meanwhile, [33] proposed an AI framework for adapting Spanish short stories but without the multimodal delivery mechanisms or personalization features of our model.

Our approach is fresh in combining automated E2R adaptation with personalized delivery based on individual user profiles, real-time glossary generation, and multimodal presentation options. However, in our preliminary testing, we observed that while our system produced more contextually appropriate simplifications than rule-based systems, it occasionally introduced errors that weren't present in carefully human-edited texts. This suggests that human oversight remains valuable, particularly for educational materials.

5.2 Ethical considerations and limitations

While LLMs offer powerful capabilities for content adaptation, their use in educational contexts raises important ethical considerations. LLMs may perpetuate biases present in their training data, potentially introducing inappropriate or culturally insensitive content [34]. Our architecture incorporates readability assessment tools as a validation mechanism, but this cannot fully eliminate the risk of bias or factual errors.

The reliance on LLMs also raises questions about transparency and explainability. Educators and students using the system may not understand how or why content has been adapted in specific ways, potentially limiting their agency in the learning process. Future iterations should consider including explanation components that clarify the reasoning behind adaptations.

Additionally, our preliminary evaluation with only three students represents a significant limitation. The positive results observed cannot be generalized to broader populations without more extensive testing across diverse user groups, content types, and educational contexts. Future work should include larger-scale studies with statistical validation and longitudinal assessment of learning outcomes.

6 Conclusions

This paper has introduced a architectural model for enhancing content accessibility in inclusive education settings. By integrating GenAI with adaptive multimodal content delivery, our preliminary exploration suggests that the model can potentially enhance readability and inclusivity in literature classes. The architecture addresses key challenges—technological, pedagogical, and accessibility-related—with promising initial results in supporting students with diverse needs.

Our exploratory case study with three students, focusing particularly on one student with visual impairment, provided encouraging initial feedback. Through personalized content adaptation, dynamic feedback mechanisms, and an intuitive interface, complex literary works were transformed into more accessible formats that appeared to foster better comprehension and engagement.

However, these findings should be considered preliminary due to the limited sample size and short evaluation period. Future work should focus on: (1) expanding the evaluation to more diverse student populations; (2) conducting longitudinal studies to assess long-term learning outcomes; (3) refining the AI components to address potential biases and improve adaptation accuracy; and (4) developing explainability features to make the adaptation process more transparent to educators and students.

While much work remains to be done, this architectural model represents a step toward more inclusive educational environments where technology can help bridge accessibility gaps and provide equitable learning opportunities for all students.

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Application and Validation of STEAM Tech +G: Methodological Guide for the Integration of the STEAM Approach from a Gender Perspective in Technical Education

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Abstract. Technical education and STEAM (science, technology, engineer, arts, mathematics) share principles that make them compatible: both emphasize practical and applied learning, the development of technical and professional skills, problem solving and critical thinking, collaboration, teamwork, innovation, creativity, the use of advanced technology, a focus on project-based learning, and continuous assessment. Despite this, it is one of the least studied educational modalities and with less evidence of work carried out for its integration, as well as the existing gender gap that is common to other educational levels. This article presents the application of the methodological guide proposed to integrate STEAM in technical education under a gender perspective, detailing the implementation stage and the validation process carried out with the aim of proposing tools and methods that promote enriched, dynamic and inclusive learning environments that prepare learners for current challenges. The focus is on these two moments, not to diminish the relevance of the previous or subsequent stages, but because they are considered the core of the training execution where the instructor encounters the trainees and executes the plans and strategies through concrete actions. Validation is the way to confirm whether the aspects evaluated, such as coverage, applicability, gender perspective, evaluation, structure and approach, are adequate and appropriate. The results indicate the feasibility of applying the guide according to the Kappa coefficient obtained, which provides a measure of the level of agreement among experts.

Keywords: Collaborative Engineering, Gender Gap, STEAM, Technical Education.

1 Introduction

To integrate STEAM in technical education considering gender aspects it is necessary to have a framework that facilitates the implementation of the approach through a structured process allowing managers, teachers and the family environment to encourage the interest and participation of students in STEAM areas, challenging gender stereotypes, promoting equal opportunities and responding to the current dynamics.

This guide is based on a comprehensive review of the literature on topics such as interdisciplinary educational approaches STEM - STEAM; technical education, its particularities and approach; gender gap in STEAM and collaborative engineering as a key element for the interdisciplinarity demanded by STEAM. Subsequently, it is structured, relating the references that provide strategies and methodologies tested in other international and national contexts, detailing the stages and dimensions identified for integration and the associated processes, the actors involved and their roles, and suggesting some tools for its application. Finally, it is validated through the expert judgment method, describing the evaluation process and the results obtained to ensure the rigor and relevance of the proposal. The article presents a synthesis of the stages, dimensions and actors of the process and in detail the relevant elements of the application and validation of the guide in a real context.

2 Stages of integration of the STEAM approach in technical education

The guide considers conventional stages of processes such as the initial diagnosis to identify needs, capabilities and potentials; detailed planning to develop strategies and allocate resources; implementation where the proposed plan is executed; and continuous evaluation that allows for ongoing monitoring, reviewing effectiveness and adjusting as appropriate. Figure 1 shows the stages described for the integration process, sequentially and the objective of each one, indicating that the last stage favors the feedback process, thus, from the results of the evaluation, inputs are obtained to establish improvement mechanisms in the STEAM - technical education - gender integration. The proposals are not defined as isolated processes, but as relational phases, which depend on each other and provide feedback to reach the final objective of effective integration.

Fig. 1. Stages in the process of integration of the STEAM approach in technical education.

2.1 Integration dimensions of the STEAM approach in technical education.

The integration of STEAM in technical education is a process that must be addressed from a multidimensional approach that encompasses various curricular, pedagogical, organizational and technological aspects as confirmed by the references on which the methodological guide is based [1] [2] [3] [4]. Three key dimensions have been identified, which are indicated in Figure 2, each containing a set of efforts that can promote the integration of the approach considering gender issues.

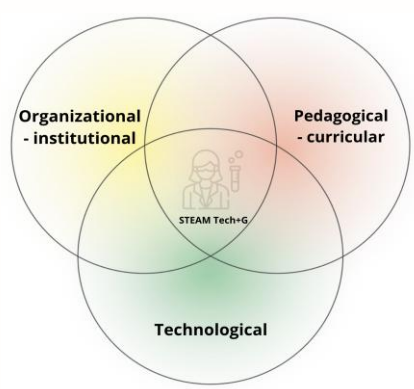

Fig. 2. Dimensions of STEAM integration in technical education with a gender perspective.

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Organizational - institutional dimension: corresponds to the definition and implementation of policies and programs for the integration of the STEAM approach in technical education. In this regard, the baseline is the different intentions, some of which have already materialized as initiatives and projects of varying scope, but which are applied to other levels of education. Defining new policies, regardless of their scope, is beyond the scope of this guide, as it is the responsibility of international, governmental or regional entities and organizations, therefore, what is proposed in this aspect is related to organizational and management issues that should be considered from the administrative area of the entity interested in integration.

Curricular - pedagogical dimension: It is directly associated to the execution of the training for which there are already institutional guidelines that define the instruments, tasks, responsible parties and clients, whose object and scope determine a roadmap for the teaching - learning - evaluation process. What is proposed is to integrate the approach in these elements in a more contextualized way, promoting practices that include the female example in STEAM and problems of the learners' own context together with the development of socio-emotional skills.

Technological dimension - This refers to the technological infrastructure available, which must be robust and updated to support STEAM teaching and learning needs, including access to devices, software, internet connectivity and digital platforms, simulation tools, augmented and virtual reality tools, all of which can be used to create immersive and engaging learning experiences that allow students to explore STEAM concepts in an interactive way.

2.2 Roles in the integration process

The guide considers the intervention of different agents, each with specific roles and responsibilities that complement each other to achieve institutional objectives.

- **Managers**: these are the actors who lead the entire process with a strategic vision, ensuring that institutional objectives and gender equity policies are aligned. They are in charge of coordinating, planning and monitoring the integration process, guaranteeing compliance with deadlines, the allocation and adequate use of resources and, in general, the fulfillment of objectives.
- **Teaching Staff**: intervenes mainly in the activities defined in the pedagogical-curricular dimension, since the teacher acts as a facilitator to guide learning through research and facilitates the identification of real problems by the students; in addition, he/she promotes critical thinking, creativity and collaborative work. The teacher participates in all the stages, in the training dynamics, in the selection and generation of STEAM content, and is responsible for the progress and success of the process, as he/she is the protagonist of all the actions that frame its development.
- **Learner**: is the main actor in the process as he/she is the one who actively participates in STEAM activities, applying the knowledge acquired in different disciplines in an integrated manner and developing different competencies that are crucial in the labor and academic world, including technical, collaborative and analytical skills, which are fundamental for innovation and development of the productive sector. It is mainly involved with the processes of the pedagogical-curricular dimension as it is the center of the teaching and learning process, however, it also intervenes in the other two dimensions.
- **Family environment**: it is an agent that is not taken into account in some processes of certain school levels; however, it has been established that they play an important role in providing support and motivation to learners, encouraging their interest and participation in STEAM activities as well as providing positive role models, demonstrating the value of education and contributing to gender equity dynamics, overcoming the biases that have traditionally been strengthened from the home.
- **Productive sector**: given the close relationship between technical education and the productive sector, the latter is a key actor in the process of integrating the approach, since it is considered fundamental to establish alliances and collaborations with companies and institutions in the environment to support the integration of STEAM and gender equity, for example, by offering practical learning opportunities, such as internships, visits to companies and collaborative projects that allow students to apply their STEAM knowledge in real contexts, and to manage resources and financing for the implementation of STEAM projects.

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2.3 Application of the methodological guide

To apply the guide, it is necessary to have completed the diagnostic and planning stages. The evaluation is the final stage of the cycle, which is carried out after the first implementation and which in turn provides guidelines for improvement for the continuity of the process. These stages are not detailed in this section due to the length of the document. The full contents of the guide can be consulted at https://goo.su/P3Y5SJ.

The implementation stage involves organizational, technological and curricular aspects and takes place during the teaching-learning process. It should be mentioned that technical education encompasses different dimensions and levels; institutional frameworks tend not to be unified, and its fields of action are broken down into different subsystems, most of which are associated with the countries' ministries of education. In the case of Colombia, technical education is defined as that which offers training programs in occupations of an operational and instrumental nature and specialization in their respective field of action, without prejudice to the humanistic aspects of this level [5]. The National Apprenticeship Service SENA is the national entity that, due to its public nature, represents one of the main training alternatives in this modality in the country and is linked to the Ministry of Labor; the other technical or technological institutes, which may be public or private, are linked to the Ministry of Education.

STEAM in project based learning: the National Learning Service SENA is the national entity in charge of providing technical level training in Colombia and has established as active didactic strategies framed in its pedagogical model the Training by Projects and Collaborative Learning, in both the trainee assumes an active role since he/she starts from the identification of a problematic situation in his/her environment and proposes possible viable, real, innovative solution alternatives that constitute the enabling path in the generation of knowledge and the development of competences in the trainee. [5] Learning projects are, therefore, an appropriate scenario to implement collaborative engineering under the STEAM approach: by encouraging interdisciplinarity and the resolution of real problems. Regarding the gender approach, collaborative projects allow working in diverse teams, assuming leadership roles and valuing gender diversity and perspectives, enriching the learning process and project outcomes.

Collaborative aspects in STEAMTech+G: The references of the guide indicate the collaborative aspect as inherent to the integration of the STEAM approach given the nature of the approach that unites different disciplines and perspectives and is oriented to obtain more innovative and complete solutions, where great relevance is given to soft skills such as communication and teamwork, problems of the real context are addressed, which are generally complex and require the intervention of multiple disciplines to find effective solutions; it is considered necessary to integrate into the guide principles of collaborative engineering, which arises from the "need to design, execute and structure collaborative processes within different groups, as a systematic approach to the design of repeatable collaborative processes, which can be used to increase efficiency and human effectiveness in organizations".[6] STEAMTech+G also considers it key to encourage the participation and leadership of girls in collaborative groups by assuming different roles, creating spaces for respect and collaboration. Another important aspect is the collaboration with other actors of the educational community such as families, institutions of other levels or the industry.

In the implementation stage and due to the interdisciplinary nature of the approach, it is proposed that each process is not carried out individually, but that groups of different areas are formed, resulting in several projects and activities for the variety of programs offered, that is, that there are instructors who can contribute from science, technology, engineering, arts and mathematics in the definition of training projects belonging to various training programs, generating a cooperation that would meet the objective of STEAM. This provides a favorable scenario to integrate collaborative engineering in order to optimize integration. The guide adopts the methodology for the development of collaborative processes proposed by Kolfschoten & de Vreede [1]. For this, the collaborative task is analyzed, decomposed into three activities (project planning, proposal verification and construction of the training project that integrates STEAM) that are subsequently "matched" with the 3 selected thinklets, an agenda is built using the results of the previous steps to finally validate and document the design.

STEAM dynamics to integrate into project and learning activities: The dynamics proposed in this section, like other elements of the guide are suggestions that can be applicable to one or more moments of project development and apprenticeship training. They are presented as a series of possibilities that can be reviewed and adjusted to each case, considering that the training is carried out through learning activities, which are the "smallest" units of project execution and that they are carried out on a day-to-day basis, and can be evaluated more directly than if the results of the entire project were verified.

It is necessary to refer that one or more of the dynamics presented here can be applied and that to integrate the STEAM approach, ideally it is expected to integrate the five areas that make it up, but there are cases in which it is not practical or feasible for the objective of the activity to include all of them simultaneously. Considering the interdisciplinary nature of the STEAM approach that lies in the integration of these areas, it is suggested that the activity should combine at least two or more of the STEAM areas so that learners can see how concepts from different disciplines are interrelated and applied in real-world contexts.

The aspects listed below should be considered for the proposed activities as they are inherent features of the STEAM approach:

1. Focus on problem solving: STEAM activities should foster critical thinking and complex problem solving, often through hands-on projects and real-world challenges.
2. Creativity and innovation: The Arts component in STEAM is not only re-focused on the visual arts, but also on creativity and innovation in the design and implementation of solutions.
3. Collaboration and teamwork: STEAM activities often require students to work in teams, which fosters collaborative and communication skills.
4. Practical Application: Activities should allow students to apply their theoretical knowledge in real-world situations.

***Phase 1: Analysis - Problem Definition - Science, Technology*:** Corresponds to the process of inquiry and exploration of the trainees, guided by the instructor to identify a real and relevant problem that requires an innovative solution. At this point the trainees must learn to question the environment, formulate clear and concise questions, gather relevant information and analyze it critically to understand in depth the nature of the problem.

The dynamics suggested for this phase, which are related to scientific thinking, are: observation of natural and social phenomena, objects, processes or interactions to raise questions, formulate hypotheses and seek answers; inquiry and exploration of the environment looking for information in order to expand their knowledge on the subject; formulation of clear, specific and relevant questions to guide the research; collection and synthesis of information defining the baseline of the problem from the information collected to arrive at a precise definition of the problem identifying its causes and consequences.

***Phase 2: Planning - Technology, Engineering, Mathematics, Arts*:** In this phase all disciplines can converge, engineering, technology and mathematics processes are very relevant; however, since this is the moment in which possible solution alternatives are structured, resources and time are allocated, among others, it is engineering that is the protagonist, without neglecting the interdisciplinary nature of the STEAM approach.

The processes that are articulated in this phase related to engineering are: design, since engineering provides the tools and systemic thinking to design innovative solutions; optimization, since as an engineering principle the best solution to a problem is always sought; and prototyping to test and refine the design.

In the area of mathematics, processes such as measurement, data collection, recording and analysis and calculations would be integrated to, for example, model relationships between variables, explain physical and chemical phenomena, predict results, contrast and compare results, requiring the application of calculations and mathematical functions with different levels of complexity depending on the case.

Phase 3: Execution - Science, Technology, Engineering, Mathematics, Arts: As in the previous phase, execution integrates all the disciplines of the STEAM approach and could be considered the center of the process since it is where the planning of the previous stages materialized.

The most common processes related to science in this phase are: experimentation to check whether the ideas and theories proposed during the initial phases are correct or require adjustments; observation as a process that is not as general and open as in the first phase, but more specific and structured, since the results of the actions

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must be not only observed but also recorded for later analysis; and research to argue the findings and support the decisions made.

The engineering area would integrate dynamics such as: construction to create prototypes and models; evaluation because tests and adjustments are made to improve the design and functionality of the project.

In the area of mathematics, processes such as measurement, data collection, recording and analysis and calculations would be integrated to, for example, model relationships between variables, explain physical and chemical phenomena, predict results, contrast and compare results, requiring the application of calculations and mathematical functions with different levels of complexity depending on the case.

***Phase 4 and 5: Follow-up and evaluation*:** In the final phases of the project the disciplines that could be integrated would be mainly science for hypothesis testing, mathematics for data analysis, assessing the accuracy and validity of the results, engineering for redesign processes and the arts for communicating results in a creative way.

Technology: Technology is a cross-cutting component in all phases of the project, from basic processes such as the documentation of each stage to the possibility of including artificial intelligence resources, simulators or augmented reality, technological tools are present in the integration of the STEAM approach in educational dynamics. Even in conventional educational dynamics, the introduction of digital media has led to significant changes in traditional classroom activities. Tasks such as taking notes, doing exercises with pencil and paper, writing on the blackboard with chalk and consulting textbooks and encyclopedias have been modified. These activities have been replaced or enhanced using office automation tools, digital information sources, video games, educational mobile applications and virtual learning environments. These new tools are supported by cloud technology and connected to an extensive information network. [7]

The technological tools available are so varied and diverse in the current offer that it would be impossible to make a "complete" list of all of them. In the development of a STEAM project, different technological tools can be used during all the phases that facilitate the research, design, implementation and evaluation of the activities. Some general categories of software and hardware resources are mentioned, assuming that the SENA learning environments already have a basic infrastructure made up of computer equipment and connectivity: Simulation and modeling software, application development tools, programming and robotics platforms, design and image editing software, video and animations, calculation and mathematical analysis tools, measuring instruments, signal capturing, sampling, robotics kits, augmented and virtual reality tools, prototyping tools, micro-controllers and development boards, communication devices.

Arts: By incorporating arts and design into the STEM areas, apprentices experience hands-on learning that fosters creativity and imagination. As with the technology component described in the previous section, artistic manifestations are present in all phases of the project and consequently in the learning activities that are executed in each. Art is linked as a key complement to scientific and technical disciplines and can be manifested in processes such as: presentation of ideas, advances or results using graphic design tools; interface design in the case of technological projects; production of multimedia content considering that current communication mechanisms are based on audiovisual content and modeling and prototyping due to the practical component associated with STEAM activities that require processes such as the creation of models and prototypes and other designs that generally incorporate technological elements.

2.4 Component "G"

For each of the stages defined in the guide and the dimensions that constitute them, actions are proposed to address the gender gap.

Diagnosis: Qualitative and quantitative indicators on gender issues are analyzed: enrollment, dropout, representation in leadership positions, career choice, school climate, roles in pedagogical practices, among others. In addition, existing gender biases in the curriculum and technological tools and resources that promote gender equity are identified.

In planning, the definition of a training plan on gender issues and inclusive methodologies is proposed, contents that promote gender equity should be designed and qualitative and quantitative metrics should be defined to monitor the process such as learner performance, perception data, attendance and demography; enrollment, participation, completion of studies, women's desertion in the training processes, among others.

In the implementation, key actions are proposed in the activities of the training process. These activities are aimed at forming mixed groups to foster collaboration and teamwork; assigning roles and responsibilities in an equitable manner, ensuring that all trainees have the opportunity to develop technical and leadership skills; and fostering an inclusive environment where all trainees feel valued and able to contribute. Actions are aimed at forming mixed groups in which women participate in different roles, integrating female role models in activities that make visible and highlight the performance of women in different areas of knowledge. It is also important to publicize the experiences in the labor environment and ensure that the leadership of the team is assumed by a female member.

Finally, in evaluation, tools and instruments are applied to obtain indicators, collect data, analyze results and establish a baseline for implementing continuous improvement processes in the three dimensions addressed by the guide, for example: in the area of institutional commitment, the percentage of female representation in management committees, school councils and decision-making groups; in teacher training, the availability of female teachers' programs, and the availability of female teachers in school management committees, school councils and decision-making groups: the availability of training and capacity building programs in gender perspective for teaching and administrative staff; in terms of STEAM integration and gender perspective: percentage of women enrolled in STEAM programs compared to men, participation of women in leadership positions within the institution and the perception of school climate favorable to women's participation in STEAM. It is also necessary to evaluate the internal and external articulation with other institutional policies (gender equity, educational innovation) and, in the technological aspect: records of use and access to technology, development of basic and specific digital competencies for STEAM and participation in training programs for apprentices and instructors.

3 Methodological guide validation

The validation of the guide is carried out in two stages: initially, it is socialized to the members of the Universidad Autónoma de Occidente who collaborate with this work from the Telematics and Applied Informatics Research Group, GITI. The organization and structure of the guide were presented in detail and adjustments were proposed to simplify the language used, to guarantee a better understanding of the proposal and a real applicability in the context of technical education, and to the modularity of the guide, using diagrams that illustrate in each phase the processes to follow, with the objective of contributing to the applicability of the methodological guide.

The second moment of validation is done by means of a known method such as expert judgment, since it was previously concluded that it should be carried out by instructors who have ample experience in this modality, due to the particularities of technical education, since they would be the ones who would apply the elements that constitute the methodological guide.

The second step of the validation process is described below, which follows a systematic process to compare the assessment made by people who are familiar with the topics addressed on different parameters of the proposed guide.

Validation by expert judgment: Validation by expert judgment is a method widely used in research that consists of asking a number of people to make a judgment about an object, an instrument, a teaching material, or their opinion about a specific aspect [8]. Following the guide proposed in [9] where the validation process is established in a systematic way, the steps are followed such as defining the objective, which is to validate the content and structure of the guide that has been designed and is assigned in this document; the judges are selected considering the criteria defined by [10], the collaboration of four instructors from different areas is requested and the trajectory, years of experience, academic training and their availability to participate in the process were taken into account. Subsequently, both the dimensions and the indicators that are measuring each of the elements of the guide are made explicit, considering that it is a guide that should be relevant, applicable, with a structure.

Subsequently, both the dimensions and the indicators that are measuring each of the elements of the guide are made explicit, considering that it is a guide that must be relevant, applicable, with an adequate structure, covering STEAM topics as its main objective and including a gender perspective. Likewise, it must have the possibility of evaluating the results of its application to ensure traceability of the results, feedback of the process and continuous improvement in its implementation. Table 1 details the items to be reviewed in this step:

Table 1. Dimensions and items to be evaluated by experts.

Dimension	Description	Item
Coverage	Reviews whether the guide addresses the topics and components necessary for effective implementation and their relevance to gender-sensitive technical education.	1.1 The guide is based on sound theoretical frameworks on STEAM, technical education and gender. 1.2 Includes processes that involve science, technology, engineering, arts and mathematics in technical education. 1.3 Adapts STEAM concepts to the specificities of technical education. Explicitly addresses gender inequalities in STEAM and proposes strategies to overcome them.
Structure	Verify the organization of the processes proposed for the implementation of the guide and their clarity in the application.	2.1 The language used is understandable for technical education instructors. 2.2 The phases follow each other in a coherent order. 2.3 The guide presents the information in a logical and sequential manner.
Applicability	This refers to the review of the feasibility of applying the guide in the context of technical education, if resources are available and if it is flexible to the particularities of each institution.	3.1 The guide's proposals are realistic and adaptable to the context of technical education. 3.2 The resources needed to implement the activities are within the reach of the educational institutions. 3.3 The guide allows for adaptations to the specific needs of each institution
Approach	Seeks to determine the aspects that are considered relevant at the time of implementing the guide.	4.1 Includes diverse educational strategies, such as project-based learning (PBL) and collaborative learning. 4.2 Promotes the development of key competencies such as critical thinking, creativity and problem solving. 4.3 Encourages students' active participation and teamwork. 4.4 Relates the contents and, in general, the whole learning process to real situations and problems.

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Gender Perspective	This dimension reviews the inclusion of the gender perspective in the elements of the guide.	5.1 It includes motivational strategies such as performance examples and success stories of women scientists, engineers and technologists. 5.2 Addresses the causes and consequences of the gender gap in STEAM. 5.3 Promotes the equal participation of men and women in all areas of STEAM.
Evaluation	Identifies mechanisms to measure the impact of the guide and the possibility of proposing improvements in its implementation.	6.1 Provides criteria for evaluating the effectiveness of integration. 6.2 Suggests appropriate evaluation instruments

For each dimension, numerical values are presented as indicators that each expert will apply in the scoring process. The objective of the test is then specified, for which virtual sessions were organized with the group of experts to clarify the instructions, discuss the relevance of the indicators and the feasibility of implementation in real contexts. The form was then designed in accordance with the objectives of the evaluation, consisting of an online form that was shared with each of the evaluators, in order to calculate the concordance between judges. For this, the Kappa coefficient (K) is used, which is applied to data on nominal scales, providing the degree of agreement between evaluators [9], which is the object of validation: to indicate the agreement between the experts who are reviewing and validating, in this case, the methodological guide.

Each expert independently evaluated the items of the guide grouped in dimensions and a rating scale from 1 to 4 that was included in the form. The data collected were analyzed using SPSS statistical software to calculate the Kappa coefficient as indicated in Figure 3. For this coefficient, the hypotheses used are:

H0: The degree of agreement is 0, i.e. there is no agreement.
H1: There is significant agreement between evaluators, i.e. K >0.

H0 is rejected when the observed value exceeds the critical value (with an α of 0.05). SPSS indicates the significance level, and when it is less than 0.05, H0 is rejected and it is concluded that there is agreement among the evaluators, the value of k gives the proportion of agreement by removing the agreement that may occur by chance. [9]

Fleiss Kappa

Overall Kappa

	Kappa	Asymptotic Standard Error	Z	P Value	Lower 95% Asymptotic CI Bound	Upper 95% Asymptotic CI Bound
Overall	.454	.088	5.159	.000	.281	.626

Kappas for Individual Categories

Rating Category	Conditional Probability	Kappa	Asymptotic Standard Error	Z	P Value	Lower 95% Asymptotic CI Bound	Upper 95% Asymptotic CI Bound
2	.000	-.013	.094	-.142	.887	-.197	.170
3	.513	.412	.094	4.402	.000	.229	.596
4	.914	.533	.094	5.691	.000	.349	.717

Fig. 3. Kappa Coefficient calculated in SPSS.

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For the interpretation of this coefficient, the scale established by Landis and Koch [11] was also taken into account, which qualitatively relates the level of agreement between evaluators with the value of the Kappa coefficient, as shown in Table 2.

Table 2. Level of concordance between evaluators - Kappa coefficient.

Description	Level of concordance
0	Poor
0,1 - 0,2	Slight
0,21 - 0,40	Acceptable
0,41 - 0,60	Moderate
0,61 - 0,80	Considerable
0,81 - 1,0	Near perfect

In conclusion, and by analyzing the results, it is found that the overall Kappa coefficient obtains a value greater than zero (K=0.454), therefore there is significant agreement between evaluators. If analyzed with the Landis and Koch scale [11] (Table 2), a Kappa value of 0.454 is considered moderate. This means that there is agreement beyond what is expected by chance, but it is not so high as to be considered substantial or near-perfect agreement.

Moderate agreement suggests that, although the experts have some consensus in their assessments, there are areas where opinions differ. This may indicate that some items in the methodological guide need to be revised or clarified to improve consistency in the assessments.

Consequently, the ratings assigned by the evaluators with the lowest scores, such as items 1.4 and 3.2 are reviewed in detail because they have the lowest scores: Item 1.4 has a consensus score, i.e., all evaluators assigned a value of 3 which corresponds to the fact that a particular adjustment was required to achieve the expected coverage. This aspect, which belongs to the coverage category, "Explicitly addresses gender inequalities in STEAM and proposes strategies to overcome them".

Among the observations generated by the evaluators, the need for examples, templates or models of activities that were designed from a gender perspective was mentioned; in response to this need, examples of classroom practices that could illustrate the application of the guide were designed.

Item 3.2 is related to resources, where the lowest score of the whole exercise was obtained. This aspect, which belongs to the category of applicability, evaluates whether the resources needed to implement the activities are within the reach of the educational institutions. Three of the evaluators determined that a specific adjustment is required for the guide to be applicable and one assigned a score of 2, which means that the item should be thoroughly reviewed and modified for the guide to be applicable; however, it is important to remember that in the description of the phases it was established that the infrastructure of the STEAM scenarios can be very broad and varied. From a room equipped with computer equipment and connectivity to an environment specifically equipped for training in these areas can be scenarios where these activities are carried out.

The acquisition of equipment, applications and tools, the availability of space and resources in general is a variable factor according to the availability of each institution. Like other elements of the guide, suggestions are presented that can be applied or adapted according to particular needs.

Items 1.1, 1.2, 2.2, 3.1, 3.3, 4.1, 4.3, 5.1, 5.2, 5.3, 6.1 and 6.2 have been assigned a score of 4, which corresponds to the highest value on the scale, considering that there is consensus according to the criteria of all the experts. In the other aspects, one of the evaluators assigned 3, which suggests minor adjustments to the item in question.

In category 4, which represents the highest value on the rating scale, a Kappa value of 0.914 was obtained. This value indicates an almost perfect agreement among the evaluators, which suggests that there is a greater consensus in the evaluation of the items that were rated with the highest value. This result translates into the viability of the methodological guide, as it indicates that the experts have a higher level of agreement in

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identifying the most relevant and well-defined items of the guide. This level of agreement is an indication that the methodological guide has a solid foundation and suggests high reliability and consistency in its evaluation. This result supports the validity and clarity of the guide by fulfilling the objective of the research work.

4 Conclusions

The guide has been designed to provide a structured and flexible framework that can be adapted to different educational contexts, according to the criteria of the team in charge of the process, available resources and other conditions of the particular environment. Its approach articulates the most representative dynamics of other experiences or references generated for other modalities that were considered of interest to be replicated but taking into account the particularities of technical education and that it should contribute to closing the gender gap. Stages and dimensions of the STEAM integration process have been defined, including organizational, pedagogical and technological aspects. This has made it possible to create a comprehensive approach ranging from the planning and design of activities to their evaluation and continuous improvement.

Technical education is one of the modalities with less evidence of interventions and initiatives related to STEAM; however, its characteristics, such as its focus on practical learning, its direct relationship with the productive sector, the methodological strategies it integrates of teamwork and project-based learning, constitute a favorable scenario for articulation with STEAM, since it shares several of these elements that make them highly compatible and complementary. It is useful to have a methodological guide such as the one proposed in this paper that specifies stages, processes, roles, tools and resources in a structured manner, providing the route and mechanisms to achieve the goal of a true integration that meets the objective.

The gender gap in STEAM is a general parameter present in all training modalities, even in the work context. Addressing the gap is a challenge for any implementation associated with STEAM, and, although there is governmental and organizational will, it is necessary to articulate concrete actions to overcome it. The guide proposes specific actions such as the promotion of women's participation in activities, motivation through successful female models in STEAM areas, linkage to academic networks, training in gender equity aspects, identification of biases, among others, to contribute to the issue. Indicators and metrics useful for measuring results and analyzing contributions, scope and associated opportunities for improvement are also related.

The incorporation of the arts into the generic STEM approach enriches the practices and their characteristic interdisciplinarity as it promotes creative thinking and the possibility of exploring new ideas and approaches to problem solving. Creativity is essential for the development of innovative solutions in science, technology, engineering and mathematics because art fosters the ability to think outside the box and generate original ideas. Together with technology, the dynamics suggested in the guide for integrating learning activities are considered transversal to all phases of training, since technological resources can be used in all phases, which are multiple and diverse, as well as artistic expressions, which provide tools and techniques for the communication and presentation of ideas, concepts and results.

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Bibliometric Analysis of Technologies Focused on Older Adults and Diabetes Management: A Human-Computer Interaction Approach

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Abstract. This article presents a bibliometric analysis of the scientific literature on technological solutions that employ human-computer interaction principles focused on older adults and diabetes management. Institutions, sources, countries, conceptual structure, and research trends were identified to determine the current state of development of the subject. The results revealed that 1% of the publications on technological solutions consider applying human-computer interaction concepts. In technological solutions for older adults using human-computer interaction concepts, 3620 publications were found between 2000 and 2025, with an annual growth rate of publications equal to 19%, being the United States and China the leaders of the research with 50.3% of the total number of publications, and the key topics are older adults, telemedicine, user experience, and Smart Homes. In technological solutions for diabetes management using human-computer interaction concepts, 390 publications were found between 2003 and 2025, with an annual growth rate of publications equal to 11%, being the United States and the United Kingdom the leaders of the research, and the key topics are self-management, telemedicine, older adults, and artificial intelligence. The main conclusion is that although there is research on technological solutions for older adults for diabetes management, those that employ human-computer interaction principles represent a low percentage of the total publications. Therefore, it is necessary to develop technological solutions from a human perspective, considering human-computer interaction guidelines to facilitate the appropriation of technological solutions to manage diabetes and other health conditions in older adults.

Keywords: Diabetes Management, Elderly, Patient Experience, Technology, Smart Home.

1 Introduction

According to the World Health Organization (WHO), the number of older adults has increased globally, corresponding to people over 60 years of age [1]. This is due to health, social, economic, and cultural advances, which have increased life expectancy and reduced birth and mortality rates worldwide [2]. The aging population will demand changes to provide solutions to the needs and challenges in all sectors of society that serve an increasingly older population. The International Telecommunication Union (ITU) supports the integration of digital health technologies. It makes recommendations at the international level as a key component in the interoperability of technologies associated with the Internet of Things (IoT) [3]. The Fourth Industrial Revolution (4IR) has considered the Smart Home scenario, which is based on new-generation Information and Communication Technologies (ICT), as a safe space for older adults capable of providing greater independence, autonomy, and improvement of their quality of life [4, 5].

The initial studies on Smart Homes analyzed aspects of home automation and network technologies that could support different functionalities. They sought to build user-friendly interfaces, but their designs were not focused on truly understanding the user's needs, which caused little use of such technological solutions [6]. Subsequently, different researches were carried out, considering the factors that affect the technological acceptance of older adults concerning the technological solutions proposed for monitoring their health status. These studies concluded that the previous solutions did not consider the user's needs, the high costs of technological deployment, and some aspects that generate concern among older adults, such as energy consumption, privacy, ease of use, and the number of additional devices at home [7-9].

Rogers proposes a strategy to facilitate older adults' use of technology by establishing a comprehensive representation of the users' needs [10]. Therefore, the need arises to consider Human-Computer Interaction (HCI) in the process of building technological solutions since it allows having a user-centered design and optimizing the interaction between people and machines in the most intuitive way possible for the user [11- 13].

Different authors have conducted bibliometric analyses. Wonyoung analyzed the integration of Smart Home and IoT technologies, the possible application areas, and determined that other disciplines can benefit from these solutions. Therefore, he suggests conducting multidisciplinary research [14]. Yurui analyzed 262 articles during an active publication period between 1999 and 2023 and identified Ziefle and Pal as the principal authors; and Germany, the United States, and China as the pioneers of research in the area [15]. Yurui concludes that progress is being made towards the personalization of Smart Homes according to the users and highlights the importance of collaboration between working groups [15]. Similarly, Yuan conducted a bibliometric review on the acceptance of Smart Homes by older adults in the period between 2004 and 2023, finding Demiris and Ziefle as the main authors, and determining that more studies on the acceptance of Smart Homes by older adults are urgently needed [16]. Ohlan conducted a bibliometric review of Smart Home research during the period from 2001 to 2021, considering 5167 Web of Science publications, identifying China and the United States as the pioneer countries in Smart Home research [17], concluding that scientific interest in Ambient Assisted Living (AAL) is growing, and the need for further research in smart sensors, energy saving, and specific application areas.

Considering Smart Home technologies and the needs of the older adult population, diabetes is analyzed since it is a disease that presents a high burden for the health systems of different countries in the world [19]. The number of diagnosed patients worldwide continues, currently corresponding to 800 million adults [18-20], and has a more significant impact on areas with limited economic resources [21]. It is estimated that 3 out of 4 people with diabetes live in low- and middle-income countries [22]. In addition, the probability of being diagnosed with diabetes increases with age. On the one hand, there is a higher prevalence of diabetes in China, India, Pakistan, and the United States [23], mainly due to population size, sedentary lifestyles, eating habits based on high consumption of added sugars and ultra-processed foods, lower socioeconomic status, and aging. On the other hand, Europe and Russia are the regions where the lowest growth of diabetic patients is expected, corresponding to 13% for the year 2045, due to lifestyle and healthy eating habits, unlike Southeast Asia, where an increase of 68% is considered for the year 2045, followed by Latin America with a projected growth of 53% [22].

Diabetes self-management is essential to achieving and maintaining the patient's blood sugar goals and delaying disease complications [24]. In recent years, the capabilities of technologies for disease management in older adults have been investigated [25]. However, issues related to technological acceptance and usability of the proposed solutions require further research and development [26, 27].

This bibliometric review analyzes the existing research on technological solutions developed using HCI concepts focused on older adults and diabetes management. It considers the projected growth of the older adult population [2], the possibility of having a diagnosis of diabetes, and the opportunities offered by technologies for health care, guaranteeing the independence and autonomy of older adults.

2 Materials and methods

This research presents a bibliometric analysis of the domain of technological solutions designed to consider aspects of HCI, focused on older adults, and used for diabetes management through descriptive and inferential analysis. The guidelines proposed by Donthu [28] and the Science mapping workflow [29] were used for data analysis and visualization. The Web of Science, Scopus, Pubmed, and IEEE databases were used as a source of information, considering that they contain the most significant number of relevant articles in the area of interest.

2.1 Information gathering

General search areas related to the topics of interest were defined, and each one is identified with a specific word and contains a set of synonyms or terms alluding to the same subject, as shown in Table 1. Subsequently, combinations of the sets of words were made to analyze different research lines and their current development.

The search initially focused on terms associated with "Technology" to identify relevant publications in the area of interest. Those related to "HCI" were further examined in the results obtained. Finally, publications addressing "Elderly" and "Diabetes" were filtered.

Table 1. Search words.

Identifier	Search words
Technology	("Ambient Assisted Living" OR "Smart Home" OR "Smart Healthcare" OR "Home Based Healthcare" OR "Internet of Medical Things" OR "Smart home model" OR "Internet of Things" OR "Framework for smart home" OR "Customized smart home service" OR "Health monitoring" OR "Technology")
Diabetes	("Continuous Glucose Monitoring" OR "Diabetes" OR "Diabetes management" OR "Glucose Monitoring")
Elderly	("Aging" OR "Elderly" OR "Aged" OR "Older Adults")
HCI	("User centered design" OR "User centred design" OR "User centered scenario" OR "User centred scenario" OR "Technology acceptance" OR "Passive interaction" OR "User experience" OR "Patient experience")

Two search lines were determined: the first analyzes technologies focused on older adults that consider HCI aspects, and the second one considers technologies for diabetes management that consider HCI aspects. Table 2 presents the search lines.

Table 2. Search lines.

Line	Search line
Line 1	Technology AND HCI AND Elderly
Line 2	Technology AND HCI AND Diabetes

2.2 Execution of the search

The search was performed on the selected databases' titles, keywords, and abstracts. A temporal filter was not applied to determine the active period of research. Articles written in English and Spanish, corresponding to primary and secondary sources, with complete metadata, were considered, and duplicate studies in the different databases were eliminated. The final documents were analyzed using Bibliometrix [30].

3 Results

This section analyzes the main results obtained in the searches performed descriptively and inferentially. Fig. 1 presents the overall results of the searches, a total of 5 668 968 publications were identified for the terms "technology," "smart homes," and their synonyms. Of this amount, only 1% contemplate aspects defined by the "HCI" chain, corresponding to 54817 publications, which denotes those technological solutions have been developed without considering factors related to HCI, such as the needs of the users and the quality of the user or patient experience when interacting with such solutions. From the technologies that consider HCI, 6.6% of the publications focus on older adults and only 0.7% on diabetes. This shows that, despite being a growing disease in the older adult population, research on using technologies for its management is in a maturation process.

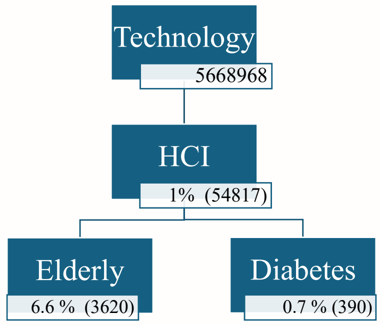

Fig. 1. Distribution of publications by search lines.

3.1 General information

The results of the search lines are presented in Table 3, which have an active publication period between 2000 and 2025. The annual growth rate of publications in line 1 is high and higher than 19%, which indicates the interest of the research community in technological solutions for older adults considering HCI aspects; in line 2, there is an 11% annual growth rate, which also denotes interest in technological solutions for diabetes management considering HCI aspects.

Table 3. General Information

	Line 1	**Line 2**
Period	2000:2025	2003:2025
Publications	3620	390
Annual growth rate (%)	19.16	11.03
The average age of documents	5.75	5.51
Average citations per	18.04	16.32
Average authors per document	5.1	5.7

The papers' average age is 5 years, which demonstrates recent work. The average number of citations per paper is higher in line 1; the average number of co-authors per paper is approximately equal. In line 2, there is a higher number of co-authors per paper, corresponding to 5.7, which can be attributed to the presence of researchers from the engineering and health areas in this line.

A comparative presentation of the types of publications found is provided in Fig. 2; journal papers predominate, corresponding to 63% in line 1 and 64.6% in line 2; as for books and book chapters, there is an initial production in line 1, while in line 2 there are no books, but four book chapters, which leads to the conclusion that there is little knowledge base on the topics.

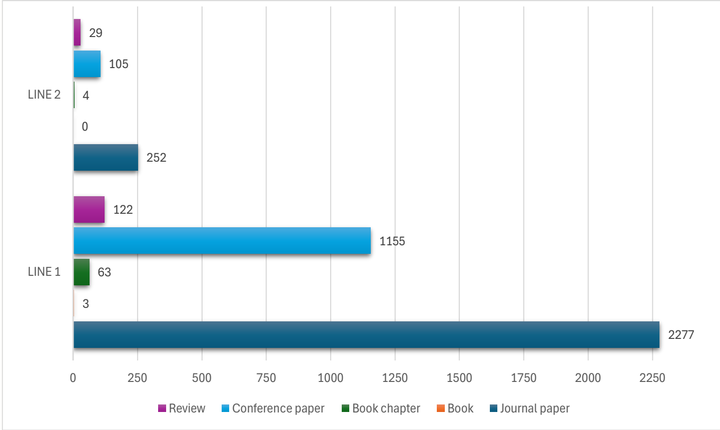

Fig. 2. Types of publications by search line.

There is a high percentage of works in conferences for both lines, which demonstrates active research, considering that conferences present partial results of research and disseminate knowledge before finishing research: 32% of the publications in line 1 are in conferences, and in line 2, these publications correspond to 27%. As for systematic reviews, there is a greater number of publications in line 2, which indicates that there is interest in determining the state of the art of this line, which allows for continuing its progress.

3.2 Annual scientific production

The growth of the scientific production in the defined search lines is shown in Fig. 3. Line 1, technological solutions for older adults considering HCI aspects, has a more significant number of publications, with a notable and continuous increase since 2011. The maximum value of growth in the year 2024 corresponds to 55.6%, with 616 publications. Regarding line 2, technological solutions for diabetes management considering HCI aspects, publications started in 2003; scientific production and its growth rate have been lower than line 1. The highest number of publications was presented in the year 2024, corresponding to 66, with a growth rate of scientific production higher than 50% in the years 2022 and 2024, which shows a high interest of the scientific community in this topic.

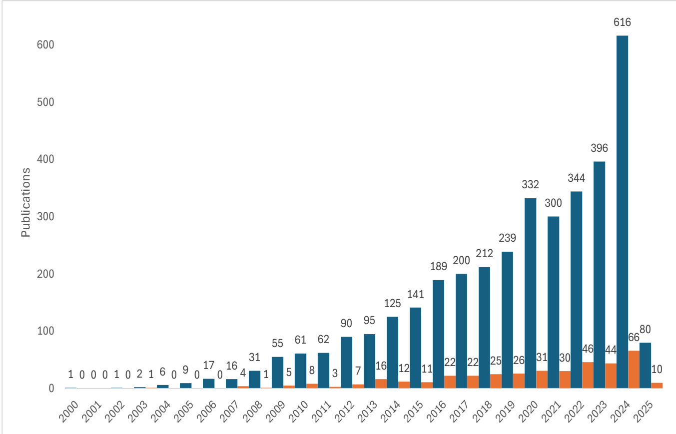

Fig. 3. Temporal evolution of the search lines.

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3.3 Most relevant sources in the domain

The most relevant sources in the defined search lines are presented in Fig. 4.

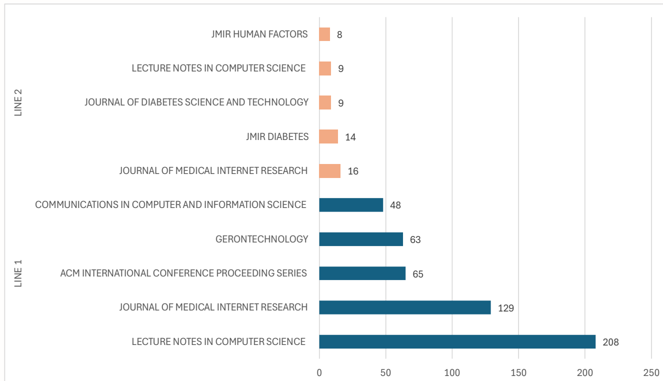

Fig. 4. Most relevant sources in the search lines.

Line 1, technological solutions for older adults considering HCI aspects, registers 1551 sources. The publication "Lecture Notes in Computer Science" has the highest number of papers, corresponding to 208, followed by the "Journal of Medical Internet Research" with 129 papers, and then the "ACM International Conference Proceedings Series" with 65 papers. Three of the five main sources correspond to book series that compile research results presented in conferences and monographs, and two publications correspond to high-impact journals.

In line 2, technological solutions for diabetes management considering HCI aspects, there are 253 sources, where "Journal of Medical Internet Research" is the journal with the highest production, corresponding to 16 publications, followed by the journal "JMIR diabetes" with 14 publications, "Lecture Notes in Computer Science" occupies fourth place with 9 publications, and the remaining publications correspond to journals. The "Journal of Medical Internet Research" and "Lecture Notes in Computer Science" have been found in both lines, highlighting their importance in developing the topics analyzed. Most of the publications come from Journal articles, which shows that there is an active research community working in the area.

3.4 Most relevant institutions in the domain

The top eight universities in terms of scientific production in the defined search lines are shown in Fig. 5.

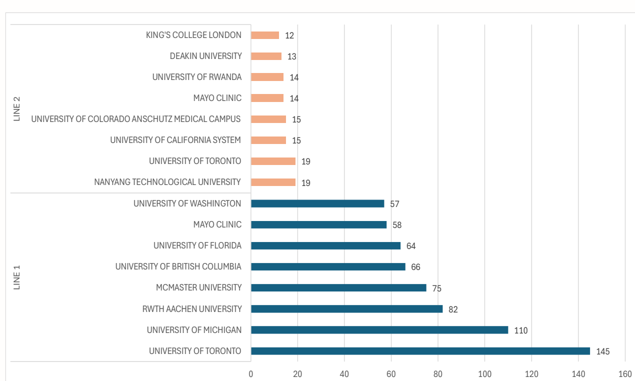

Fig. 5. Most relevant institutions in the search lines.

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In line 1, technological solutions for older adults considering HCI aspects, the University of Toronto has the first place with 145 publications, followed by the University of Michigan with 110. The following universities are from the United States, Canada and Germany.

Line 2, technological solutions for diabetes management considering HCI aspects, there is greater diversity, with Nanyang Technological University in Singapore and Toronto University in Canada being the leaders with 19 publications each, followed by three universities in the United States, the University of Rwanda, Deakin University in Australia and The King's College London in the United Kingdom which shows that the use of technology for diabetes considering HCI aspects is a topic of global interest, due to the impact it can have on people's quality of life.

3.5 Most productive countries in the domain

The countries with the highest scientific production in the defined search lines are shown in Fig. 6.

The United States has the highest productivity in the two lines, doubling the following country. China, Canada, the United Kingdom, Germany, Australia, and Italy are the pioneers in both lines of research. These countries are characterized by their high investment in research and development (over 3% of GDP).

In line 1, technological solutions for older adults considering HCI aspects, the countries with the highest scientific productivity are the United States, China, Canada, the United Kingdom, and Germany.

In line 2, technological solutions for diabetes management considering HCI aspects, the United States, United Kingdom, Australia, Canada, and Italy stand out, and it is essential to mention the appearance of India in 9th place with 22 publications. This country will be the most populated country on the planet in 2024, and its population over 65 years of age is growing annually at rates higher than 7%. Therefore, it is crucial to investigate the use of technologies to improve the care and health of this population.

Regarding Latin American production, in line 1, Brazil leads with 30 publications, followed by Chile with 24, Mexico with 15, Colombia with 11, Ecuador with 7, and Argentina, Uruguay, Peru, and Costa Rica with one publication. In line 2, Brazil has nine publications, followed by Colombia with four, Mexico with two, and Peru with one. This reflects the interest in developing solutions to the aging population phenomenon in Latin America.

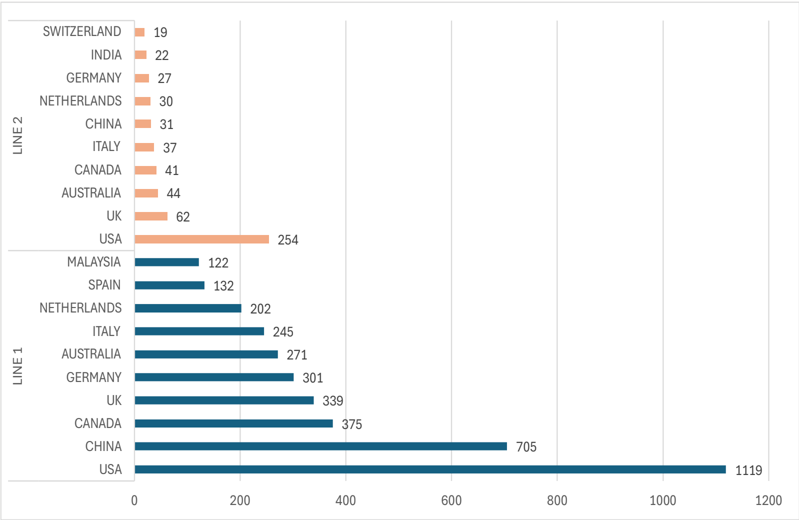

Fig. 6. Productivity by country in the search lines.

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3.6 Conceptual structure of the domain

The most frequent keywords authors are shown in Fig. 7.

The term technological acceptance has had significant relevance in line 1, technological solutions for older adults considering HCI aspects. The terms usability, user-centered design, and user experience also stand out, which denotes the importance of the user as an active actor in the design process of technological solutions so that they can be used effectively and impact the quality of life of older adults.

In line 2, technological solutions for diabetes management considering HCI aspects, the essential terms were self-management, smartphone, diabetes type 1 and 2, user experience, and telemedicine. These concepts show that the scientific community has begun to work on technological solutions that allow the diabetic patient to manage their disease using m-health and telemedicine, seeking alternatives to improve the user experience so that these solutions meet the expectations and needs of the users.

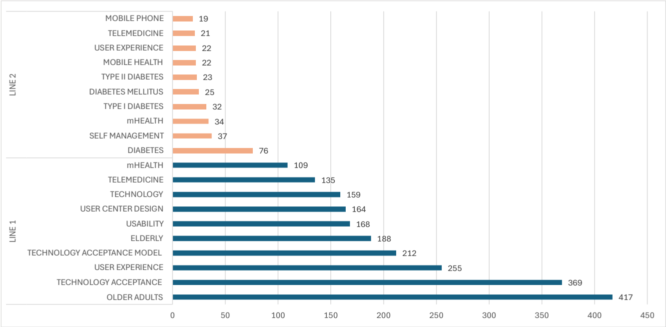

Fig. 7. Most frequent keywords authors in the search lines.

3.7 Thematic evolution of the domain

The thematic development of line 1, technological solutions for older adults considering HCI aspects is shown in Fig. 8.

In an initial stage, between 2000 and 2013, concepts related to technological acceptance, telemedicine, assisted living environments, and various technological solutions for health were worked on. Subsequently, between 2014 and 2017, the elderly population, smartphone-based solutions, and user requirements were considered to a greater degree. From 2018 to 2022, research focused on older adults and user experience. Finally, from 2023 to 2025, the focus remained on user experience, older adults, and the use of digital health tools.

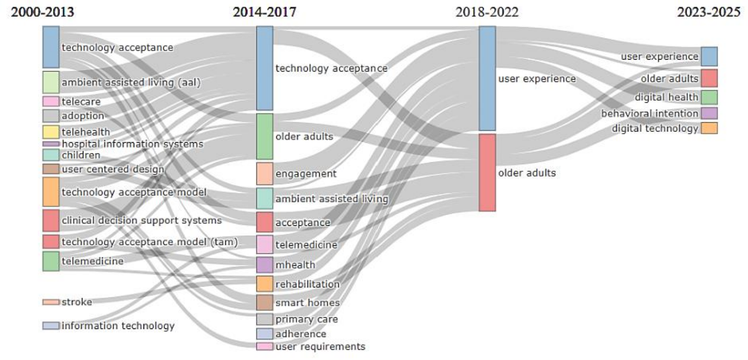

Fig. 8. Thematic evolution of the search line 1.

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The thematic evolution of line 2, technological solutions for diabetes management considering HCI aspects, shows that in the years 2003 to 2013, research was conducted around diabetes, user experience, and health care; subsequently, between the years 2014 and 2017, work was done on the use of information technologies for the area of health, and the concept of technological acceptance appeared, as shown in Fig. 9. From 2018 to 2022, the concept of patient experience, diabetes self-management, diabetes technology and usability, health informatics, and automatic insulin delivery systems appeared.

In the recent period from 2023 to 2025, research has focused on technology acceptance, continuous glucose monitoring, patient experience, and machine learning emerging as a disease management tool. Artificial intelligence offers excellent possibilities for prognosis in different areas of knowledge. In this specific case, it can be used to predict the behavior of glucose in a patient, considering data from continuous glucose monitoring and aspects related to food intake and physical activity, among others.

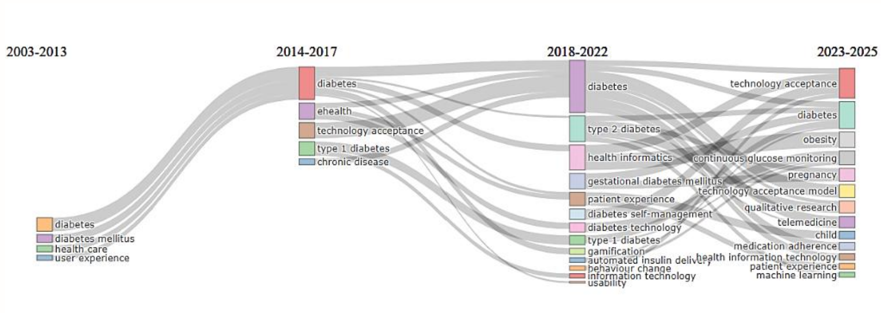

Fig. 9. Thematic evolution of the search line 2.

3.8 Network analysis

The co-occurrence network by author keywords for line 1, technological solutions for older adults considering HCI aspects, is shown in Fig. 10. Two clusters are identified, the central topics being "older adults" and "user experience,". The blue cluster is related to telemedicine and additional concepts such as "m-health," "digital health" and "patient experience". This cluster represents the use of mobile technologies for self-managed solutions, considering aspects of the quality of the patient experience. The red cluster focuses on the factors that affect the acceptance of technological solutions by older adults, where the model of technological acceptance, user experience, and usability is analyzed; towards the left side are associated with ambient assisted living, where IoT, augmented reality, and virtual reality are used for the creation of Smart Home and environments that allow and facilitate older adults their autonomy and independence.

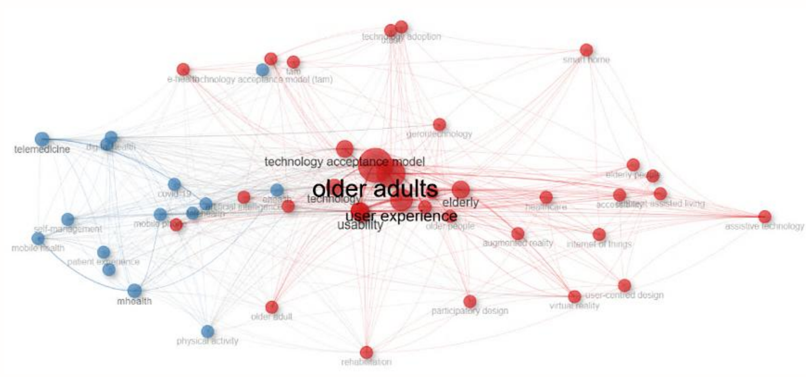

Fig. 10. Co-occurrence network by author keywords for search line 1.

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The co-occurrence network by author keywords for line 2, technological solutions for diabetes management considering HCI aspects, is shown in Fig. 11. The central topics being "diabetes", "self-management", "technology", and "health care". The cluster represented in red focused on diabetes and tools that enable self-management through the smartphone, considering various aspects of HCI, such as user-centered design, technological acceptance, and user experience. The purple cluster works on aspects of diabetes, hypertension, and telemedicine. The blue cluster focuses on type 1 diabetes. The green cluster studies specific aspects of diabetes, such as insulin management and continuous glucose monitoring. There is evidence of the emergence of artificial intelligence for diabetes management, and the focus on older adults is an isolated topic.

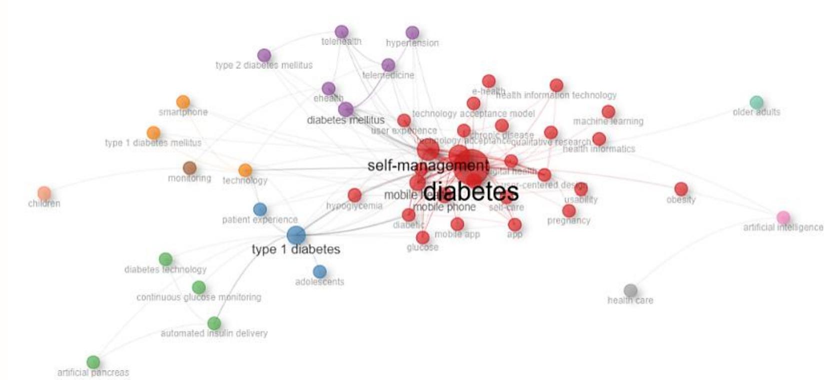

Fig. 11. Co-occurrence network by author keywords for search line 2.

4 Discussion

The results show that the research on technology for older adults is in an initial stage since only 1% of the publications related to technology consider HCI aspects, so most of the solutions developed for older adults have had little use and acceptance as they have been created from the perspective of the developer, without considering the needs, perceptions, expectations and specific characteristics of the users. From the point of view of the authors, HCI has not been widely developed because the solutions that have been created have not considered the elderly as the main user, which leads to low acceptance and low use of these solutions in the context for which they have been created

In Latin America, considering the growth of the elderly population, the outlook for the future is to provide usable technological solutions for diabetes management, especially for older adults. Advances have been made in developing technological solutions for diabetes management. However, they have not received the necessary acceptance to ensure a positive impact on disease monitoring.

Therefore, there are opportunities to generate research oriented to developing effective and minimally invasive technological solutions for diabetes management focused on older adults and developed by considering the principles of usability, accessibility, patient experience, and user-centered design. Based on the Smart Home and HCI guidelines, it is essential to start enabling technologies in older adults' homes. These guidelines make older adults' homes comfortable and safe places for managing diabetes and other health conditions without interfering with their daily routines, mobility, and privacy, guaranteeing their calm, independence, and autonomy.

There are challenges and opportunities related to interdisciplinary and interinstitutional work, such as scientific cooperation, which is necessary to support research, participative work with older adults, and generate solutions following their needs.

5 Conclusions

The bibliometric analysis provided an overview of the works developed around technological solutions that consider HCI principles for older adults and for diabetes management, allowing the identification of the leading researchers at the country and institutional levels, the most relevant sources, the key topics, and the gaps, and challenges and opportunities for research on the subject, from which it will be possible to study in greater depth possible areas of research through a systematic review of the literature.

The works focused on technological solutions that consider the principles of HCI correspond to only 1% of the publications related to the terms associated with Technology. Of these publications, 6.6% focus on older adults and 0.7% on diabetes management. Therefore, this area of research has not received the importance it deserves, and there is a need to develop works focused on technological solutions for older adults and diabetes developed from the HCI and Smart Homes perspective.

The line of technological solutions for older adults considering HCI aspects, has 3620 publications between 2000 and 2025, with a growth rate of more than 19% per year. The published works correspond to journals with 63% and conferences with 32%. Lecture Notes in Computer Science has the highest number of articles. The leading research countries are the United States, which has 1119 publications, and China, which has 705. The University of Toronto and the University of Michigan have the highest number of publications, with 145 and 110, respectively. Most of the published works are focused on older adults and telemedicine.

The line of technological solutions for diabetes management considering HCI aspects, has little development, according to the 390 publications found between 2003 and 2025. The increase in the production of scientific publications began in 2013, with the highest growth between 2023 and 2024 at 53%. Most publications are concentrated in journals with 64.6%, followed by conferences with 27%. The Journal of Medical Internet Research appears as the leading journal in which related results are published. The United States leads this line with 254 publications, followed by the United Kingdom with 62 publications. The pioneering research institutions are Nanyang Technological University in Singapore and the University of Toronto in Canada, each with 12 publications. The areas of work are concentrated on self-management of the disease and the use of telemedicine. The term older adults appears in isolation, and there is evidence of a trend towards solutions supported by artificial intelligence.

Future work is expected to initiate the development of technological solutions focused on a human-centered perspective using user-centered design and HCI techniques. This will allow the development of systems appropriate to the characteristics of older adults with diabetes problems that can be validated in Latin American contexts to determine the influence of cultural, social, and economic variables in processes of acceptance and usability.

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Characterizing Impact, Benefits and Challenges of AI in Relation to Computational Thinking for Software Engineering: A Systematic Mapping

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Abstract. Computational Thinking (CT) is defined as the process where individuals, using computing skills, help detect and solve errors through iteration. Artificial Intelligence (AI) refers to machines that replicate human intelligence functions such as perception, learning, and reasoning. Recently, Large Language Models (LLMs) have gained prominence for their capability to understand and generate text. These models assist programmers by saving time and simplifying tasks. However, LLMs may produce erroneous information, such as code with errors or outdated programming practices, leading to inefficient or unmaintainable solutions. This becomes particularly concerning for trainee programmers, who might fail to develop the critical thinking necessary to evaluate AI-generated results. This work proposes a systematic mapping of the state of the art to explore the impact, challenges, and benefits of using AI into CT, emphasizing the need to balance AI assistance with the cultivation of critical programming skills. Among the results, using AI in CT within software engineering has a predominantly positive impact (60%) and it also presents significant challenges in terms of negative impact (40%). As well, 55% of the articles addressed consider benefits of AI in CT and 82% highlight challenges, suggesting that the benefits exist, however, they are accompanied by significant obstacles. Also, HCI can help address abstract concepts related to CT, so it must prioritize not only operational efficiency but also feedback and educational transparency, balancing cognitive autonomy with automation.

Keywords: Artificial Intelligence, Impact, Benefits, Challenges, Computational Thinking, Systematic Mapping.

1 Introduction

Selby and Woollard [1] , defines Computational Thinking (CT) as "the process by which an individual, through computing skills, such as the design and representation of processes, helps through iteration to detect and solve errors. Computational thinking is vital in the design of efficient architectures, as well as in the structuring of code and the application of best practices to ensure it is extensible and maintainable. It also facilitates the identification and correction of errors in the code [2]. On a different scale, CT also helps in abstracting complex real-world problems and breaking them down into smaller, simpler problems and, ultimately, it helps in the creation of the algorithm that will solve the problem [3].

Artificial Intelligence (AI) is defined by UNESCO [4] as any machine capable of imitating the capabilities of human intelligence, such as perception, learning, or reasoning. Large Language Models (LLMs), a particular evolution of AI that is capable of understanding and generating texts, have been on the rise in recent years.

Among their many applications, LLMs in the form of chatbots are useful assistants in everyday tasks in the development of software. In Software Engineering, for example, these chatbots can be used as coding or design assistants [5].

On account of using AI, large language models are capable of performing some tasks that require CT. For example, when an LLM is presented with a computational problem, it can deliver an algorithm to solve it. Likewise, it can be asked to model a database. This can save time and make some tasks easier on the programmer. However, these models are not free from mistakes. There is a possibility that a model delivers code or a design with errors, that the code is inefficient, unmaintainable, or outdated, or that it falls short of good programming practices [6]. Any deficiency in the code produced by the LLM will require that the programmer make more effort to understand and fix it, therefore wasting time [7].

Another, more concerning problem, is the possibility that the programmer becomes too dependent on LLMs, to the extent that their CT capabilities weaken. Similarly, if it is a trainee programmer who uses these tools, they might fail to develop a satisfactory level of CT, which is essential to find errors and criticize the results of AI-generated code [6]. In the long term, serious consequences may ensue, especially if the programmer wishes to follow good programming and clean code practices.

In view of the current scenario, it is important to gauge the impact of AI on the development of CT, as well as the benefits or challenges of integrating AI to CT in the domain of software engineering. This work presents a systematic mapping on the state of the art made in order to analyze the impact, challenges, and benefits of AI on the development of CT. A systematic mapping allows for the consolidation of evidence on how AI transforms CT in software engineering, highlighting its advantages such as efficiency, design innovation, and code optimization, as well as its ethical challenges, skill adaptation, and algorithmic biases, in order to guide informed educational and technical decisions that balance its potential with a critical and sustainable approach.

The article is organized as follows: Section 2 presents related works; Section 3 presents the methodology adopted to carry out the systematic mapping and poses the research questions. Section 4 presents the state of the art relating to two domains of interest: the impact of using AI on the development of CT, and the benefits and challenges of integrating AI to CT for software engineering. Section 5 presents our findings and a possible answer to the research questions. This is followed by a discussion on our findings in Section 6, and conclusions in Section 7.

2 Related works

Few works have been found that relate the use of AI impacted the development of CT and the benefits and challenges of integrating AI into the CT in software engineering which enhances the importance of our work, these studies are listed below. Ndudi et al [8], perform a systematic review of 81 empirical studies on the operationalization of CT , highlighting its definition, components and relationship with programming under the PRISMA Methodology to analyze explicit/implicit definitions, key components (abstraction, algorithms, sequences) and its application in educational interventions. It is mentioned that as a gap there is a scarce exploration of CT outside of programming and STEM contexts. Hazrina et al [9], perform a systematic mapping on artificial intelligence (AI) techniques applied in software engineering, analyzing trends, contributions and gaps between 2015-2021. In the mapping, 60 studies could be found through academic bases (IEEE, Springer, etc.), classifying AI techniques (ML, data mining, heuristic algorithms) into 8 phases of the SE life cycle (planning, requirements, development, testing, etc.). As a gap, the lack of programs that teach the comprehensive application of AI in all phases of the software life cycle (requirements, design, testing, etc.) is mentioned. Lyon et al.[10], conduct a Systematic Review on the integration of CT in higher education, analyzing definitions, pedagogical methods and evaluation. The analysis was carried out with 13 empirical studies (2013-2018) from foundations such as ERIC and Engineering Village, applying inclusion/exclusion criteria. It was found that there is little exploration of synergies between AI (adaptive learning) and CT to personalize teaching, in addition to the fact that CT improves logical skills and problem solving, but clear pedagogical models, standardized metrics and ethical/inclusive approaches are required to scale its impact. Zawacki et al. [11], provide a systematic review describing AI applications in higher education through a synthesis of 2656 publications initially identified for the period between 2007 and 2018, 146 articles were included for the final synthesis, according to explicit inclusion and exclusion criteria. The results show that a large part of the disciplines involved in the AI in Education articles come from Computer Science and STEM. The article concludes, the lack of critical reflection on the challenges and risks of AI in education, in addition to the weak connection with theoretical pedagogical perspectives and the need for further exploration of educational and ethical approaches. Weng et al. [12], conducted a systematic review of 18 empirical studies analyzing the integration of Artificial Intelligence (AI) and CT in education, identifying two approaches: combining disciplinary knowledge and using AI tools to teach CT. They reviewed studies from databases (Web of Science, Scopus, IEEE, ACM) using mixed methodologies, highlighting educational contexts, tools (e.g. Scratch, MIT App Inventor), student-centered designs (project-based learning), and learning outcomes.

As a challenge, they mention the need to expand educational contexts, diversify pedagogical approaches, incorporate ethics, and develop theoretical frameworks that balance technical skills with critical and creative thinking. Agbo et al. [13], conduct a Systematic Review on the use of CT in teaching programming in higher education institutions (HEIs), analyzing approaches, tools and impact on students. They review 33 studies (out of 161 initial ones) between 2010-2018, extracted from databases such as ACM, IEEE Xplore and ScienceDirect, applying inclusion/exclusion criteria. They find that there is a predominant focus on developed countries and little research in low-resource contexts, where AI could democratize access to CT. A gap was identified in the state of the art: a lack of synthesis that assesses how AI impacts the development of CT in software engineering, integrating both its benefits and challenges in order to support practices that balance innovation with responsibility and to support educational strategies.

3 Methodology

A systematic mapping was carried out following two approaches: the guide for systematic reviews in software engineering proposed by Kitchenham [14] and the guide for conducting systematic mapping studies in software engineering proposed by Petersen et al. [15].

Research questions. This paper explores two specific aspects of the relationship between AI and CT: (i) the impact of using AI on the development of CT, and (ii) the benefits and challenges of integrating AI to CT for software engineering. Correspondingly, two research questions are posed:

- **RQ1**: What is the impact of using AI on the development of CT for software engineering?
- **RQ2**: What are the benefits and challenges of integrating AI to CT for software engineering?

Search string. In creating the search string (Table 1), main terms and possible synonyms were identified in order to obtain as many relevant primary studies as possible. The following main search strings were identified: "Artificial Intelligence", "CT", "Impact", "Benefits", "Challenges", "Software Engineering", and "Education". The alternative term "AI" was also identified.

Search strategy. Table 2 summarizes the search strategy. We retrieved documents from four digital repositories (ACM, Science Direct, IEEE Xplore, and Springer), applying the search strings to the fields Title, Abstract, and Keywords. We only included research papers, conference proceedings, books, technical reports, and dissertations published in the period 2019-2025 and written in English or Spanish.

Table 1. Search string.

Main Terms	Alternatives Terms
Artificial Intelligence CT Benefits Challenges Software Engineering Education	(AI OR Artificial Intelligence) AND (Computational Thinking) AND (Impact) AND (Benefits) AND (Challenges) AND (Software Engineering) AND (Education)

Table 2. Search strategy.

Item	Description
Repositories:	ACM, Science Direct, IEEE Xplore y Springer
Publication type:	Research papers, Conference papers, Books, Technical reports, Technical reports and Degree works
Search fields:	Title, Abstract y Keywords
Language:	Studies written in English or Spanish
Publication period:	2019 - 2025

Inclusion and Exclusion Criteria. Only academic and professional studies presented as part of conferences, journals, technical reports, or dissertations have been included. Personal blogs, web pages, and works written in Spanish were excluded unless their contribution to the research was significant. Workshop abstracts, works that do not refer directly to the research questions were also excluded. Duplicate works found across different repositories are counted once. Table 3 summarizes the inclusion and exclusion criteria.

According to Petersen et al. [15], quality assessment is most essential in systematic reviews to determine the rigor and relevance of primary studies. Performing a quality assessment in systematic mappings is not necessary but still recommendable. Classifying research types according to the categorization proposed by Wieringa et al. [16] would admit studies without empirical or scientific evidence.

Although the latter are not usually included in systematic reviews, they are important in systematic mappings, as they help to detect trends in the topics of interest. For this reason, this study includes findings with and without empirical evidence. To further refine the selection of studies, we used a checklist as proposed by Zarour et al. [17] (Table 4). Each item is given one of three possible answers and is assigned a score as follows: YES = 1 point, NO = 0 points, and PARTIALLY = 0.5 points. Using the first quartile (6/3 = 2) as the cut-off point, publications with a score < 2 are excluded from the final list of studies in order to avoid low-quality papers.

Table 3. Inclusion and exclusion criteria summary.

Criteria	Rules
Inclusion Criteria	Terms included in the search string. Studies reported in articles, conferences, books, technical reports or degree works. Studies written in English and Spanish. Publications from 2019 to 2025. Studies that establish impact, benefits, challenges of CT in software engineering using Artificial Intelligence.
Title and abstract Inclusion and exclusion criteria	Studies that do not address impact, benefits and challenges of CT in software engineering using Artificial Intelligence. Studies that only present abstracts or slide content. Content from web pages, personal blogs or brochures.
Exclusion criterion for full text	Studies presenting workshop abstracts

Table 4. Quality criteria checklist.

#	Question
QA1	Is the objective of the study sufficiently well explained?
QA2	Is the idea, approach and limitations presented clearly explained?
QA3	Are threats to validity taken into account?
QA4	Is there an adequate description of the context in which the study was conducted?
QA5	Are the results of the research clearly established?
QA6	The study was designed to achieve these objectives?

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4 Results

Application of the search string to the selected repositories yielded a total of 1487 results. These were filtered by title, abstract, and conclusion using search strategy shown in Table 2, and 100 works were selected. The inclusion and exclusion criteria shown in Table 3 were applied in order to exclude some works. Also, quality criteria shown in Table 4 were subsequently applied, reducing the selection to 20 works. The following sub-sections present in brief the contribution of the selected works in relation to the two research questions. Table 5 summarizes the results of the search and selection process.

Table 5. Summary of results after applying the search strategy.

Search String	Repositories	Results	Title, abstract and conclusions	Selected with quality criteria
1	ACM	479		
	Science Direct	354		
	Ieee Xplore	342		
	Springer	312		
	Total	1487	100	20

4.1 Impact of AI on the development of CT for software engineering

Rodriguez et al. [18], argue that introducing AI content in schools through practical projects is the way forward to educate conscious and critical citizens, to awaken vocations among young people, and to foster students' CT skills. LearningML is an educational tool aimed at teaching and learning the fundamentals of ML in school.

Teaching ML in school would be very suitable to foster critical thinking and prepare future generations for a highly technological world. Practical ML projects can be a very suitable instrument to foster the development of CT skills. Liao et al. [19], propose an intelligent programming scaffolding system using ChatGPT following the theoretical framework of CT and scaffolding. Two general design principles were proposed to apply scaffolding in programming courses to improve students' CT with the support of ChatGPT: 1) integrate ChatGPT with the key factors of scaffolding and 2) design interactive modules with ChatGPT following the development process of the PC. The findings show that most students had positive attitudes about the proposed system and it was effective in improving their overall CT but not their problem-solving skills. Therefore, further scaffolding strategies are discussed with the aim of improving students' CT, especially with respect to problem-solving skills.

Yilmaz et al. [20], investigate the effect of teaching programming using ChatGPT on students' CT skills, programming self-efficacy, and lesson motivation.

The research was conducted according to the experimental design with a pretest-posttest control group, while the experimental group benefited from ChatGPT in the programming learning process, students in the control group did not use this tool. It is noted that several studies have been conducted recently on its use for general educational purposes and that most of these studies are reviewed articles that include evaluations on how ChatGPT can be used for educational purposes. However, the effects of ChatGPT-supported education on students' learning processes and outcomes seem to be a gap in the literature that needs to be examined. Martinez et al. [21], analyzes the impact of artificial intelligence (AI) and computer science on the academic performance of students, evaluating how these technologies influence their learning, motivation, and attitudes, especially in STEM areas (Science, Technology, Engineering, and Mathematics). analyzes the impact of artificial intelligence (AI) and computer science on the academic performance of students, evaluating how these technologies influence their learning, motivation, and attitudes, especially in STEM areas (Science, Technology, Engineering, and Mathematics). Ethical and pedagogical challenges remain, such as teacher preparation to design inclusive AI environments and the need to address biases in algorithms. Bae et al. [22], address the need to integrate ethics into AI training by investigating the connection between CT and the ability to consider the ethical implications of AI solutions. Therefore, an educational program was designed that combined AI teaching with ethics, assessing students through self-assessments and analysis of practical projects. The research reveals that traditional AI ethics education lacks practical application, which prevents students from applying ethical principles in real-world contexts. As a solution, the development of educational programs that include systematic assessments to strengthen the relationship between CT and applied ethics is proposed. Current AI ethics education is limited to transmitting theoretical knowledge, without integrating it into practical problem-solving processes. This makes it difficult for students to apply ethical principles in real-world contexts. Philip et al. [23], this study examines how the use of ChatGPT influences students' programming self-efficacy and CT. The experimental group used ChatGPT for 5 weeks to solve practical tasks, while the control group followed traditional methods. The results were measured with validated questionnaires and it was found that the ChatGPT group achieved significant gains in self-efficacy and CT. The positive impact highlights the potential of tools such as ChatGPT to strengthen technical and cognitive skills. The research identifies a lack of empirical studies on the impact of generative AI tools such as ChatGPT in programming education. Furthermore, it is unknown how these tools affect self-efficacy and CT in practical settings. Zhai et al. [6], The study analyzes that relying too much on AI tools affects students' mental abilities, such as questioning ideas or making decisions. Although these tools help in academic tasks, they have quite a few risks since sometimes they give wrong information, which can make students accept everything without thinking twice. The research reviewed that the ethical problems of AI impact the way of reasoning in the long term and it is important to know how to teach how to use it without replacing personal analysis.

There is a lack of studies that directly link the ethical problems of AI with student overconfidence and its long-term impact on cognitive abilities. Aldoseri et al. [24], highlight all the problems that artificial intelligence has with the quality of the information it uses, taking into account that if the data is not accurate or not well organized, AI systems do not work as they should. Although there is a lot of information available today, it is still difficult to obtain data that truly reflects reality and is trustworthy. This is a major obstacle, because if they use incomplete information, AI tools can give incorrect results. As a solution, the text suggests methods to better organize and cleanse the information, something key to making these systems more reliable. Although there is a lot of data on the web today, much of it is incomplete or not very objective, which means that these tools do not give the expected results. Sarkar et al. [25], talk about how advanced language models (such as OpenAI Codex or GitHub Copilot) are used to help programming. These tools allow you to write code faster and learn while you work, since you can ask them things with normal words, as if you were talking to a person. But there is a problem: many programmers, especially those who are just starting out, do not know how to explain what they need properly, and this causes the system to sometimes generate code with errors. Therefore, it is important to study how to make this communication work better and how to check if the code that comes out of these models is really useful. Abdulrahman et al. [26], focus on important perspectives of AI in various fields such as higher education, how it interferes in the educational environment at an ethical and social level in addition to its implications in the future, for this purpose, a statistical study is used through an online survey, which reflects a favorable influence in several aspects. However, the evolution of these perceptions in the future is raised, which does not make this research so reliable, it will improve the vision of how environmental variables influence, the social impact and, above all, in pedagogical scenarios of higher education. Future research can address the limitations of the study by conducting intercultural and comparative studies, conducting interdisciplinary research on AI in education, and conducting comparative analysis with other educational contexts.

4.2 Benefits and challenges of integrating AI to CT for software engineering

Romero [27], offers a review of the challenges of lifelong learning in the AI era, from a CT, critical thinking and creative skills perspective, highlighting the implications for management and leadership in organizations. We must continue to sharpen our critical, creative and collaborative problem-solving skills, while adding a new string to our bow: the development of CT. Chen et al. [28], aim to assess the impact of Artificial Intelligence (AI) on education. used a qualitative research approach, leveraging the use of literature review as a research design and approach, which effectively facilitated the realization of the purpose of the study. Studies have highlighted the potential detrimental or adverse effects of AI on learning. Crowe et al. In their study, they observed that AI can encourage dishonesty and jeopardize academic integrity because it can facilitate or enable

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students to use paper mills and paper production sites or platforms. Huang and Qiao [29], integrate AI education with the STEAM model to improve students' CT skills. They propose AI curricula with STEAM models to carry out interdisciplinary AI knowledge acquisition. Future research can include primary and secondary school students in the research scope and focus on AI education combined with STEAM teaching mode for primary, secondary and high school students. Bae et al. [22], aim to analyze the relationship between CT and AI ethical competence through problem solving using AI. aims to analyze the relationship between CT and AI ethical competence through problem solving using AI. aims to analyze the relationship between CT and AI ethical competence through problem solving using AI. Asunda et al. [30], contribute to ongoing discussions among educators, employers, parents, and all those concerned with how best to prepare a digitally revolutionized citizenry. This article discusses the integration of CT practices of decomposition, pattern recognition, algorithmic thinking, and abstraction as key to problem-solving practices that can enhance the development of AI and ML capabilities in high school students. Alqahtani et al. [31], aim to contribute to the ongoing debate on the role of AI in education and research and highlight its potential to generate better outcomes for students, educators and researchers. This paper provides an in-depth introduction to AI, NLP and LLMs, analysing their potential impact on education and research. By exploring the advantages, challenges and innovative applications of these technologies, this review provides educators, researchers, students and readers with a comprehensive view of how AI could shape educational and research practices in the future, ultimately leading to better outcomes. The integration of AI and NLP in education and research presents both opportunities and challenges that need to be carefully managed. As the education and research landscape evolves, the adoption of AI tools and innovative learning approaches is vital to cultivating a flexible and adaptable environment.

Ghnemat et al. [32], present a revolutionary educational process called AI-based learning, which involves technologies within universities, cultures, practices, goals, and communities. The use of AI competency-based learning will enable students to achieve course outcomes more easily and quickly and will increase student engagement in solving real-life industrial problems in different application domains.

The paper also presents the implementation phases, benefits, and provides a comparison after applying the framework. This transformation reduces the gap between higher education outcomes and industry needs, by producing lifelong learners. Walter [33], examines the transformative impact of Artificial Intelligence (AI) in educational settings, focusing on the need for AI literacy, rapid engineering proficiency, and enhanced critical thinking skills. AI literacy is seen as crucial as it encompasses understanding of AI technologies and their broader societal impacts.

Direction engineering is highlighted as a key skill to elicit specific responses from AI systems, thereby enriching educational experiences and promoting critical thinking.

One of the most significant issues is the fact that its effectiveness depends on student compliance, which is not guaranteed. Many students may not thoroughly read these documents, leading to a gap in understanding and adherence. Benvenuti et al. [34], point out new reflections and research perspectives that could help researchers, teachers, educators (and consequently students) to reflect on the introduction of new technologies (e.g. artificial intelligence, robot tutors) and how these can affect the development of human behavior and the acquisition of new skills and competences (specifically: Creativity, Critical Thinking, Problem Solving and CT) for the educational context. The analysis carried out suggests a perspective on how creativity, critical thinking and problem solving can be effective in promoting CT, and how Artificial Intelligence (AI) could be a tool to help teachers in fostering creativity, critical thinking and problem solving in schools and educational contexts. Bahroun et al. [35], Guided by the PRISMA framework, this paper presents a comprehensive analysis of GAI in education, synthesizing key insights from a selection of 207 research papers to identify research gaps and future directions in the field. This study begins with a content analysis exploring the transformative impact of GAI in specific educational domains, including medical education and engineering education. The integration of GAI in education has sparked debates about ethics, academic integrity, and its potential to reshape teaching and learning methods.

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5 Findings

5.1 RQ1: What is the impact of using AI on the development of CT for software engineering?

Table 6. Findings of impact using AI on the development of CT.

#	Impact
1	A possibility is raised for classrooms to use technological tools to awaken students' computational thinking. The use of tools such as LearningML, which is focused on teaching Machine Learning, could help students to easily acquire computational thinking, as it provides them with a series of problems that they must solve efficiently and creatively [18].
2	The integration of tools such as ChatGPT into educational practices does not guarantee a positive effect on all aspects of learning. Some skills, such as problem solving on PCs, can be negatively affected without additional design [19] .
3	It was determined that the use of ChatGPT created significant differences compared to students who did not use this tool. It was observed that this process improves students' computational thinking skills, since instead of spending time writing code, students dedicate their time to creative thinking by formulating original questions. This is because the student can reach the answer on the code fragments they want by asking the most appropriate questions to ChatGPT [20].
4	The results support the positive impact that AI and computer science have on student performance, finding an increase in their attitude towards learning and their motivation, especially in STEM areas [21].
5	According to the study, it is established that people with advanced computational thinking skills also demonstrate a greater sense of ethics. Therefore, the inclusion of ethics in training using AI tools is crucial for the development of technological solutions that prioritize social well-being [22].
6	Students' computational thinking skills and programming self-efficacy improved significantly when ChatGPT was used in the classroom. The learning process and student outcomes improved when ChatGPT was included in programming instruction. This suggests that AI can enhance technical and cognitive skills in STEM education [23].
7	AI is of great help in streamlining research processes and improving academic efficiency, but a huge decline in critical cognitive skills has been evidenced due to ethical challenges such as misinformation, algorithmic biases, plagiarism, privacy violations, and transparency issues. This dependency occurs when users accept AI-generated recommendations without questioning them, leading to errors in task performance in the context of decision-making [6].
8	If the data used to train an AI model is inaccurate, it can cause quite a few complications with the results generated. When data is of poor quality, there is a risk of incorrect decisions being made based on the model's predictions, compromising the reliability of AI systems [24].
9	Many people who are just starting out with programming are delighted to see how accessible these tools are. This leads to a big problem, as they do not know how to describe what they really want to design, so these tools create programs that seem to work, but in reality, have hidden flaws, such as poorly executed operations or solutions that are not the best. In addition, programmers may trust these tools so much that they do not verify whether the results are correct [25].
10	AI has not yet made an advanced evolution, this means that it does not promise efficient or reliable responses, since it is subject to limitations attributed to it by biases within its results, which subjects its responses to possible failures, in addition, the research done so far cannot show a completely real positive impact, since there is no certainty

	about the real perception of AI by people both in its applications or reliability regarding its use within higher education, as well as at a social or work level [26].

The results presented in Table 6 indicate that using AI in computational thinking within software engineering has a predominantly positive impact (60%) in terms of benefits such as process acceleration, enhanced innovation, and improved decision-making. However, it also presents significant challenges in terms of negative impact (40%) such as over-dependence, bias, ethics, complexity, and transparency that must be addressed in order for its potential to be maximized. Therefore, it is necessary to delve deeper into these benefits and challenges that can be seen in the following research question.

5.2 RQ2: What are the benefits and challenges of integrating AI to CT for software engineering?

Table 7. Benefits identified.

#	Benefits
1	Computational thinking provides humans with the ability to analyze and solve problems, trains critical thinking and facilitates decision-making. These skills allow them to adapt to the digital age of AI [27].
2	Developing computational thinking skills also ensures the ability to understand AI, thus achieving human-AI collaboration both in education and in any context [27].
3	The implementation of AI as a work and development tool in the field of education promises to improve learning conditions for each student, since it will allow teaching methods to be adapted for each one, based on an analysis of their strengths and weaknesses so that everyone can enjoy a good learning pace [27].
4	By implementing AI education through STEAM education, computational thinking is greatly facilitated and engineering thinking, mathematical thinking as well as AI thinking are also activated, and together, transversal learning opportunities are increased through STEAM education [29].
5	AI education can be established as the promoter of computational thinking, which shares objectives with current computer science education, which allow the development of skills for solving problems in real life [22].
6	The objective of AI education is to promote the development of computational thinking skills, which allow humans to find solutions to problems through heuristic reasoning, which gives them the ability to identify and take into consideration errors or biases under defined real-life contexts.
7	AI can become a support system for educators with the aim of promoting computational thinking by stimulating critical thinking, creativity and therefore problem solving within educational contexts [22].
8	Despite the constant biases that the implementation of AI in an educational environment presents, strategies also emerge that largely resolve the uncertainty caused by adapting an AI culture, which can be an effective solution for the easy adaptation and responsible management of these technological tools [33].
9	Through a study, it is sought to confirm that people with computational thinking skills are clear about the social and ethical impact of AI, and this result is obtained through an analysis of the relationship between these two skills that the people to be analyzed have [22].
10	The purpose of STEM education is the integration of various disciplines, such as technology, mathematics and engineering, and in a certain way students can see how the integration of these can help them solve significant problems [30].
11	The use and implementation of AI in the educational field is becoming a tool that improves the performance and quality of life of educators every day, as it promotes the development of adaptive learning models, where teachers have enough information to provide personalized learning experiences that improve the quality of learning of students according to their needs [31].

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Table 8. Challenges identified.

#	Challenges
1	Tools Critical thinking as well as creativity are essential for the constant learning of people to provide them with knowledge and skills in order to be able to face the challenge of the constant evolution of AI over time [27].
2	The results that AI produces so far are not linked to critical thinking or moral assessment, and this constitutes an emerging challenge for AI implemented in education, which is why it faces an analysis and development of patterns that allow it to break with these human biases, in order to improve its performance in a personalized way for each student [28].
3	Fully define the potential of AI education with STEAM, in order to be implemented as pedagogical material in primary education, integrating interdisciplinary knowledge [29].
4	One of the main risks of using AI converges in that it represents a lack of confidence in its results, since these tools are not yet fully improved, which means that their risk, although not very high in certain areas of knowledge, does not show completely accurate results in its entirety [34].
5	To obtain more precise results on computational thinking and AI competence, it is mandatory to encourage research on them in order to carry out comparative analysis [22].
6	There are significant differences between computational thinking skills and ethics competence based on learning styles. Since AI must allow the creation and implementation of problem solving through strategies or models taking into account the social and ethical impact of AI under real contexts [22].
7	A great challenge is presented when promoting courses related to computational thinking at the basic levels of primary and secondary education in rural areas of any country, where the leaders of these communities do not see imparting this type of knowledge to their students as a priority and resources are also limited [30].
8	The adaptation of technologies such as AI represents the search for a balance within learning, both with human participation and with the use of AI, since AI is a great support tool, the connection and participation with what makes us human should not be left aside, nor should its excessive use be avoided. [31].
9	The recent implementation of AI and its premature use by students creates an important challenge within the educational field, since educators are forced to face the challenge of checking whether students actually carry out their learning process appropriately with the use of AI or do not even take the time to read what AI throws, which triggers ethical problems on the part of students [33].
10	The priority challenges that arise after studies on the responsible use of AI largely involve ethical implications, data security, biases that their responses entail, and, above all, the comprehensive educational quality based on the assimilation of GAI in educational environments [35].
11	Future research on the implications of using GAI should focus on improving the transparency of the models implemented in GAI, where the origin of the AI responses are clear to users, which would considerably increase the trust and acceptance of these tools, especially in educational environments [35].

The above in Table 7 and Table 8 show that, although 55% of the articles addressed consider benefits of AI in computational thinking in software engineering such as (i) analysis and problem solving, (ii) activating critical reasoning and (iii) understanding the social and ethical impact encouraging its responsible use. While a higher percentage 82% highlight challenges, suggesting that the benefits exist, however, they are accompanied by significant obstacles. This interesting contrast reflects that, in AI, although it is quite promising, it faces challenges such as: (i) Technical barriers (Implementation complexity), (ii) Ethical (algorithmic biases) and (iii) Pedagogical (over-dependence) that require greater attention in order to ensure a responsible and effective

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adoption. In other words, the predominance of challenges does not negate the effective potential of AI but highlights the need to balance innovation with practical and critical solutions.

6 Discussion

The advantages of using an AI are obvious, like optimizing coding time, second hand in code reviewing, a designer assistant, etc. But in its current state, where it can retrieve erroneous results, the context window is reduced; it cannot have enough context to be worth solving more complex problems. The programmer may experience problems with AI code generated, like logical errors, that can make it more difficult and a waste of time fixing it. If the programmer in formation uses LLM, it can be counterproductive, because it lacks CT and it cannot detect correctly if the AI made an error. Also, it makes the individual more dependent on the LLM affecting and degrading its CT. It is clear that in the current state, the impact of using AI in CT and learning can be significantly negative and harmful. Nowadays, this AI powered technology also affects the learning of everyone.

Educational AI content generated is found easily and sometimes this cannot be identified as it. This is dangerous because AI can bring erroneous results and if it is not correctly identified as AI generated content it can harm the general knowledge.

The impact of AI on the formation and development of CT poses a very important educational dilemma. Tools such as code assistants, generative models or debuggers streamline the creation and design tasks in systems, so this could encourage excessive dependence that limits the ability to break down problems, identify patterns or find errors autonomously. Delegating the resolution of complex problems to AI without questioning its results risks triggering a superficial understanding of the logical and algorithmic foundations. Human-computer interaction plays a fundamental role because when it is addressed it becomes a kind of pedagogical bridge since it facilitates operational efficiency and also cultivates cognitive autonomy. HCI can help address abstract concepts related to CT, so it must prioritize not only operational efficiency but also feedback and educational transparency, balancing cognitive autonomy with automation.

7 Conclusions

Artificial intelligence offers advantages such as efficiency in technical tasks, review and system design, however, excessive dependence can impair CT especially in beginners in software engineering. The presence of limited contexts and logical errors demands critical supervision, transforming the usefulness of AI if it is not balanced with reflective and autonomous learning. The generation and proliferation of educational material by AI, without clear identification, can threaten to spread misinformation affecting the construction of knowledge. The above situation demands strategies that prioritize verification, critical thinking and the ability to discern between human analysis and automated solutions. HCI can function as a pedagogical bridge, integrating operational efficiency without sacrificing the understanding of the logical foundations that are a key characteristic of CT. Therefore, it is key to prioritize transparency in the use of this type of tools, approaches that encourage autonomous problem solving, and educational feedback mitigating the high dependence on AI.

Future work includes integrating critical feedback mechanisms that expose AI biases and errors, as well as adapting educational curricula that prioritize CT in AI-assisted environments. We also plan to study the long-term impact of these technologies on the intellectual autonomy and technical skills of training professionals. Regarding HCI, we plan to explore models that balance cognitive automation, critical feedback, and algorithmic transparency without fostering excessive dependency.

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Comparison Among Novice Evaluators: Using the Granollers Method and DUXAIT-NG in Remote Heuristic Evaluation

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Abstract. This paper presents a case study using the Granollers method and the digital platform DUXAIT-NG by novice evaluators in remote heuristic evaluations. This study aims to share the results and findings obtained from the evaluators' experience. This case study describes the Remote Usability Evaluation carried out on the redesigned Figma prototype of the website of a public hospital in Peru as part of a redesign project and within the context of a university project to bring students closer to the university's research groups. In this sense, an evaluation team was formed, led by a researcher who acted as a guide, trainer, and facilitator of the whole experience. As part of the case planning, it was decided to perform a Remote Usability Evaluation, use the Granollers method to conduct heuristic evaluations, and perform the whole experience with the DUXAIT-NG platform as a support tool. The novice evaluators used the Granollers heuristic set for the first time, which stands out for its clear structure and practical approach. They also used the DUXAIT-NG platform to record all evaluation stages and visualize the results in a centralized platform. Integrating the method into DUXAIT-NG allowed evaluators to systematically track identified issues, improving organization and reducing common errors associated with traditional tools. The study included three novice evaluators and one evaluator with intermediate experience. The average SUS score for the platform was 81.88, indicating good usability for the platform utilized. Evaluators highlighted that the platform significantly facilitated the evaluation process, as evidenced by the SUS and TAM questionnaires. This study underscores the advantages of using the Granollers method with a digital platform such as DUXAIT-NG for Remote Usability Evaluations, where efficiency and organization are key.

Keywords: Human-Computer Interaction, Heuristic Evaluation, User Experience, Usability, Case Study, Healthcare, Remote Usability Evaluation.

1 Introduction

Heuristic evaluation **[1]** is one of the most widely used techniques in usability analysis and evaluation **[2][3]**. It allows for the structured and efficient identification of user interface issues. In this context, the Granollers method emerges as a detailed, structured alternative that expands on traditional heuristic principles **[4]**. Furthermore, digital tools, such as DUXAIT-NG, have transformed how these evaluations are conducted, optimizing the recording, analysis, and presentation of results, especially in remote settings.

In the field of heuristic evaluation, having well-trained evaluators is essential for effectively identifying usability issues **[5]**. However, novice evaluators often face challenges in their early experiences, such as interpreting heuristics, identifying and classifying problems, and documenting findings in a structured manner **[3]**. For this reason, a key aspect of this study is to analyze how evaluators with no prior experience can develop competencies in applying the Granollers method for Heuristic Evaluations and using digital support platforms such as DUXAIT-NG.

In this sense, this case study is proposed from two contexts. In the first context, a thesis project was underway to redesign the web portal of a public hospital in Peru using a user-centered approach, and the project leader required feedback on her proposal. Therefore, she asked the research group to conduct a usability evaluation of her prototype designed in Figma during the evaluation phase of her project.

In the second context, an internal university project called Re-inventa2 **[6]**, which seeks to bring students of the first semesters closer to the research groups, was underway. In that sense, a group of students without experience in Human-Computer Interaction (HCI) and User Experience (UX) evaluation was supported. Therefore, they entered a training and formation process to perform different usability evaluation techniques.

In these two contexts, it was proposed to constitute an evaluation team led by a researcher who would act as a guide, trainer, and facilitator of the whole experience. As part of the case planning, it was decided to perform a Remote Usability Evaluation, use the Granollers method to conduct heuristic evaluations and carry out the whole experience with the DUXAIT-NG platform as a support platform.

This study also aims to compare the performance of novice evaluators with an evaluator who had previously conducted an evaluation using the same method and platform. The objective is to analyze differences in aspects such as the number and type of problems identified, the time spent on the evaluation, and the perceived ease of use of the digital tool. This comparison not only helps measure the impact of prior experience on the effectiveness of Heuristic Evaluation but also identifies which aspects of the process can be optimized to improve the training of new evaluators. By centralizing the process in a structured platform, the study seeks to lower entry barriers for novice evaluators and enhance the quality of their analysis.

The paper is organized as follows: Sections 1 and 2 explain the evaluation method and the platform in detail. Section 3 describes the methods used to conduct the Heuristic Evaluation process and the selection of participants, including the addition of a fourth evaluator with prior experience using the tool and technique to compare performance. Section 4 presents the results, demonstrating how all evaluators completed the task and visualized the outcomes. In the final sections, participants highlighted how the platform significantly facilitated the process, evidenced by tools like the SUS and TAM questionnaires.

2 Background

This section defines the main concepts used in this research.

2.1 Heuristic evaluation

Heuristic evaluation is a widely used usability inspection method for identifying design problems in user interfaces **[1]**. It consists of evaluating an interface against a set of recognized design principles, known as heuristics. The most influential heuristics were developed by Nielsen and Molich **[7]** and provide a basis for evaluating the usability of a system. Heuristic evaluation is valued for its efficiency and ability to identify usability problems early in design development, and it applies to every stage in the design and redesign processes. However, the effectiveness of heuristic evaluation is highly dependent on the experience and knowledge of the evaluators **[5]**. Novice evaluators often face challenges interpreting heuristics, identifying relevant issues, and systematically documenting their findings **[5]**.

2.2 Granollers method for heuristic evaluations

The Granollers method **[4]** enhances and specifies traditional heuristic principles. It offers a more detailed and organized set of heuristics, making it easier for less experienced evaluators to apply them effectively. Notable for its practical approach, the method systematically guides evaluators throughout the evaluation process. It comprises 15 categories for a thorough and precise user experience analysis. Additionally, the Granollers method facilitates the calculation of a numerical value known as Usability Percentage, which can be utilized for comparisons and various quantitative analyses.

2.3 Digital tools for heuristic evaluations

Digital tools have transformed how usability evaluations are conducted. These tools facilitate the planning, execution, analysis, and presentation of evaluation results. In the context of heuristic evaluation, digital tools provide direct access to heuristics, enable systematic recording of identified issues, foster collaboration between evaluators, and generate automated reports. The DUXAIT-NG platform **[8]** exemplifies a digital tool designed to support the heuristic evaluation process, particularly in remote settings.

2.4 Usability in the healthcare domain

Applying usability principles in the healthcare domain presents many advantages **[9]**. However, prior usability evaluations of software products in this domain have uncovered significant issues that adversely affect the user experience, including content quality, information organization and retrieval, visual design, and navigability, among others **[10]**. Another study similarly emphasized that websites created without a user-centered approach tend to have low usage rates and often lead to user abandonment **[11]**.

In the context of the redesign project that motivates the present heuristic evaluation, it was identified that the original design process lacked a user-centered approach. This deficiency resulted in an interface that, although compliant with legal requirements, did not meet the needs and expectations of the end users.

As indicated in the previous section, a usability evaluation was required to validate the results of a redesign process. Specifically, three aspects were to be covered:

- Identify usability problems
- Evaluate compliance with usability heuristics
- Provide recommendations for redesign

Therefore, the heuristic evaluation detailed in this study was an important step in the redesign process. The goal was to transform an interface focused on legal compliance into one that prioritizes usability and user experience in healthcare.

3 Methods

This section details the methodology followed for the case study.

In general terms, the process followed can be seen in Figure 1.

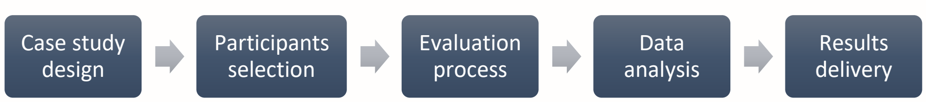

Fig. 1. Process followed.

3.1 Case study design

The page selected for analysis by the evaluators was the redesign proposal for the Hermilio Valdizán Hospital website [12]. As shown in Figure 2, this proposal is presented in the Figma tool and was designed to provide a more efficient and usable user experience, allowing patients to manage various medical services digitally. To achieve this goal, interviews were conducted with the patient's family members, who were the primary users of the hospital's website, to understand the main difficulties and expectations of the target audience.

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Based on the information collected, the designer created the prototype for Figma. Its interface enables navigation through different sections, such as information on medical specialties, doctors, consultation hours, and administrative processes. One of the key features is the appointment booking function, which is intended to allow users to select the type of consultation they need, their preferred specialist, and the most convenient available time slot through an interactive calendar option.

The lead of the evaluation team decided to evaluate the prototype using the Granollers heuristic set due to its clear structure and adaptability to different usability evaluation contexts. Unlike more general approaches, such as Nielsen's heuristics, the Granollers set expands and details heuristic principles, providing 15 categories for a more thorough and specific user experience analysis. Additionally, its formulation facilitates application by evaluators with different experience levels, making it an ideal choice for training novice evaluators.

Another key factor in this choice was integrating this set within the DUXAIT-NG platform, which enabled a more structured and efficient evaluation process, ensuring that evaluators had direct access to the heuristics within the platform without needing external references.

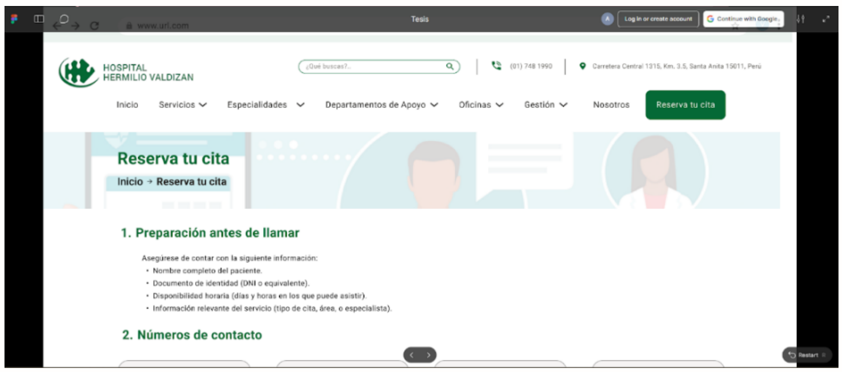

Fig. 2. Screenshot of Figma prototype " Hermilio Valdizan".

3.2 Participant selection

The evaluation of the Hospital Nacional "Hermilio Valdizán" prototype involved three novice evaluators (Evaluator 1, Evaluator 2, and Evaluator 3), one evaluator (Evaluator 4) with intermediate experience, and a moderator.

The novice evaluators had prior theoretical training in heuristic evaluations and had completed a case study following the formal process proposed by Freddy Paz (5) using Nielsen's heuristic set [1]. However, they had no previous experience conducting usability evaluations with the Granollers heuristics. Additionally, they had basic skills in using digital tools but had never interacted with the DUXAIT-NG platform for an evaluation before.

The evaluator with intermediate experience had previously participated in evaluations using the Granollers heuristics and had prior experience working with the DUXAIT-NG platform **[13]**.

The moderator had prior experience managing heuristic evaluations and using the DUXAIT-NG tool. In her role, she guided the Granollers heuristics, facilitated the evaluation process, monitored the evaluators' progress, and addressed their questions during the sessions.

3.3 Evaluation process

The evaluation process consisted of three synchronous sessions and one asynchronous session, in which both the three novice evaluators and the evaluator with intermediate experience participated. Figure 3 shows the scope of each of the four sessions.

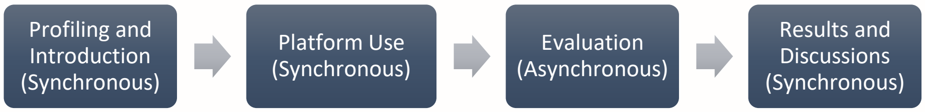

Fig. 3. Evaluation sessions.

Profiling and introduction. The first session was conducted to familiarize the new evaluators with applying the Granollers method using the DUXAIT-NG tool (8). Each new evaluator was profiled during this session, and the tool was briefly introduced. Additionally, all evaluators were assigned to the "Granollers Evaluation—Hermilio Valdizán Hospital Prototype" evaluation, as shown in Figure 4.

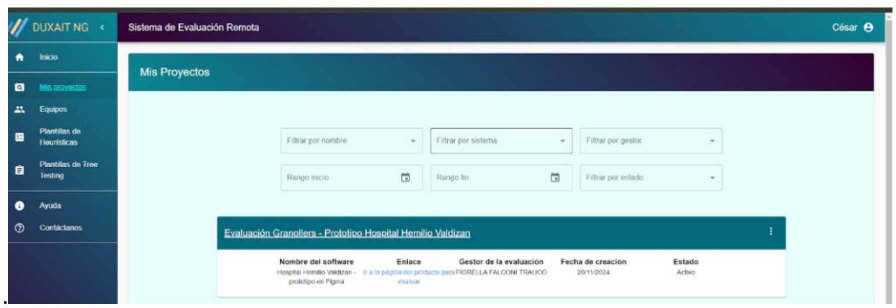

Fig. 4. Screenshot of the DUXAIT-NG platform of the evaluation.

Platform Use Induction. During the second session, an inspection of each heuristic used in the evaluation was conducted. The evaluation moderator led this inspection to identify any issues or questions regarding the 15 heuristics.

Evaluation. The evaluation process was asynchronous, where each evaluator took a different time on the test, as shown in Table 1.

Table 1. Evaluation time of each evaluator.

Evaluators	N° of sessions	Total time
Evaluator 1	1 session	2 hours
Evaluator 2	8 session	3 hours
Evaluator 3	1 session	1 hour
Evaluator 4	1 session	45 min

Results and discussion session. The fourth session was conducted with all evaluators and the moderator to align each evaluator's findings and identify common points.

Additionally, relevant comments were generated regarding the evaluation process, the time allocated for analysis, and the sessions conducted to complete the evaluation.

During the meeting, the following aspects were addressed:

– Experience with the platform: The effectiveness of DUXAIT-NG for the evaluation was discussed, focusing on navigation, accessibility, and understanding of the website prototype's design.
– Evaluation methodology: The evaluation criteria were assessed, considering whether the measurement variables were appropriate and whether DUXAIT-NG allowed for a fair and structured evaluation.
– Suggestions for improvement: To optimize future evaluations, recommendations were made, and improvements were proposed for the Hermilio Valdizán prototype.
– Perceived value: The usefulness and relevance of the process were highlighted, emphasizing the evaluation's impact and contribution to the continuous improvement of future systems to be analyzed.

3.4 Data analysis

Table 2 shows the usability rating assigned by each evaluator individually and asynchronously based on their responses to each heuristic.

Table 2. Results of evaluation 1.

#	Heuristics	Eval. 1	Eval. 2	Eval. 3	Eval. 4
1	Visibility and system state	4.75/5.00	2.50/3.00	4.50/5.00	5.00/5.00
2	Connection between the system and the real world, metaphor usage and human objects	2.75/4.00	3.50/4.00	3.75/4.00	4.00/4.00
3	User control and freedom	1.00/2.00	1.25/3.00	1.50/2.00	2.50/3.00
4	Consistency and standards	5.00/6.00	3.50/5.00	4.50/5.00	6.00/6.00
5	Recognition rather than memory, learning and anticipation	3.25/5.00	2.75/3.00	3.75/4.00	4.25/5.00
6	Flexibility and efficiency of use	0.75/1.00	0.00/0.00	1.25/2.00	2.00/2.00
7	Help users recognize, diagnose and recover from errors	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
8	Preventing errors	0.00/0.00	0.25/1.00	0.75/1.00	2.00/2.00
9	Aesthetic and minimalist design	2.00/4.00	2.50/4.00	3.50/4.00	4.00/4.00
10	Help and documentation	1.00/1.00	2.00/2.00	3.50/4.00	0.00/0.00
11	Save the state and protect the work	0.00/0.00	0.00/0.00	0.75/1.00	0.00/0.00
12	Color and readability	3.00/3.00	3.00/4.00	3.00/3.00	3.00/3.00
13	Autonomy	0.00/0.00	0.00/0.00	3.00/3.00	2.00/2.00
14	Defaults	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
15	Latency reduction	0.00/0.00	0.50/1.00	0.75/1.00	0.00/0.00

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Notable usability results were obtained in the website's evaluation using the Granollers method on the DUXAIT-NG platform. However, as Table 3 shows, there was some variability among the four evaluators.

Table 3. Comparison of usability scores among evaluators.

Evaluators	Total score	Answered questions that count (without not applicable)	Usability percentage
Evaluator 1	23.50	31	61.99%
Evaluator 2	21.75	30	57.24%
Evaluator 3	34.50	39	63.37%
Evaluator 4	32.75	34	71.66%

The data suggests a generally favorable perception of the website's usability, although slight differences between evaluators were identified. These variations may be attributed to personal criteria or specific interpretations of the heuristics.

The usability study conducted by the four evaluators reflects an overall percentage of 64.06%, indicating that the website meets usability principles at a moderate level. However, there are still areas for improvement. DUXAIT-NG generates a summary table with the data already averaged by each evaluator, as shown in Figure 5. The table in that figure presents the values obtained for the 15 evaluated heuristics. Some heuristics stand out due to their relatively high scores, such as HG04 (4.75/5.50) and HG01 (4.19/4.50). However, certain heuristics have considerably low values, such as HG07 (0.00/1.75), HG08 (0.25/1.00), and HG14 (0.00/0.25), highlighting critical areas that require improvement.

Some positive usability aspects observed in the prototype are as follows:

– The heuristics address essential aspects such as system status visibility, ensuring that users receive clear messages about their actions, such as scheduling an appointment or submitting a form.
– The system-world correspondence is maintained using clear and understandable language, avoiding unnecessary technical terms.
– The prototype ensures user control and freedom by providing options to cancel or undo actions.
– The interface adheres to standards using familiar icons and design patterns, facilitating comprehension.
– Cognitive load is reduced through dropdown menus and intuitive icons, promoting recognition over recall.
– The aesthetic and minimalist design highlights key information while avoiding unnecessary elements.
– Error tolerance allows users to edit data before submission.

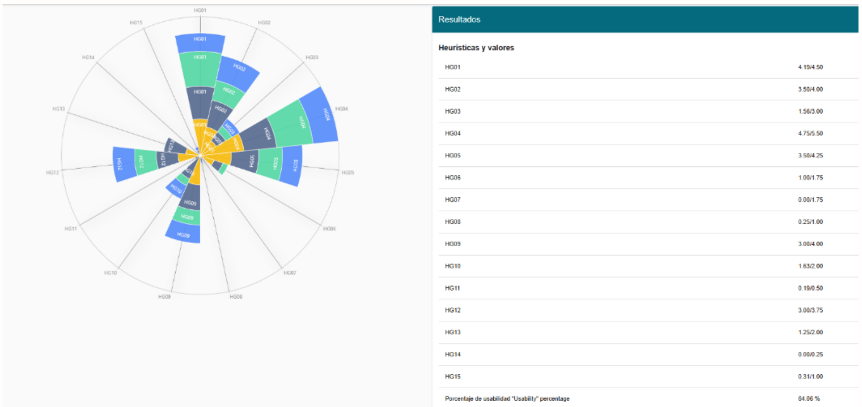

Fig. 5. Screenshot of the evaluation results in the platform.

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These results were returned to the redesign project leader, who had very positive feedback regarding the findings and executed a new iteration in the context of her project with the reported findings.

4 Results

This section details the main results and findings after the heuristic evaluation. Delivering these results is part of the methodological process indicated in the previous section.

4.1 Performance of novice evaluators

The novice evaluators learned how to use the DUXAIT-NG platform with their mentor before starting the evaluation in Session 1. They learned how to register, initiate an evaluation, and explore the platform's benefits, such as the ability to track each evaluator's progress online. Despite using this tool for the first time, the evaluators demonstrated a good understanding of how to interact with it. Thanks to the platform's features, the moderator could monitor the evaluators' progress, notify them of any incomplete steps, and check for potential difficulties.

During this evaluation, the heuristic related to latency reduction was excluded, as it could not be assessed within the prototype page.

On average, the evaluators used the platform for two hours, and no significant difficulties were reported in completing the evaluation, which the evaluators appreciated.

Upon completing the evaluation, each evaluator used the tool to visualize the results provided by the platform, which included detailed graphs and comments from all evaluators. These results allowed evaluators to generate a more straightforward and thorough report. They highlighted this functionality as highly useful for clients receiving the evaluation results and evaluators compiling their reports.

4.2 Comparison among evaluators

Table 4 shows differences in evaluator performance based on experience level, time spent, and the number of heuristics applied. These data help identify trends and patterns in how evaluators approached the analysis of the DUXAIT platform.

Table 4. Comparison among evaluators.

Evaluators	Level of Expertise	Usability percentage	Number of Applied Heuristics	Total time
Evaluator 1	Novice	61.99%	9	2 hours
Evaluator 2	Novice	57.24%	10	3 hours
Evaluator 3	Novice	63.37%	13	1 hour
Evaluator 4	Medium	71.66%	10	45 min

Evaluator 4, with medium expertise, completed the evaluation in 45 minutes, whereas the novice evaluators required between 1 and 3 hours for the same process. This difference suggests that experience plays a key role in evaluation efficiency, allowing for faster analysis without compromising the number of applied heuristics.

Among the novices, Evaluator 2 spent the most time (3 hours), which aligns with their strategy of dividing the evaluation into multiple sessions and conducting a prior inspection of the prototype. In contrast, Evaluator

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3 completed the evaluation in 1 hour, applying 13 heuristics, the highest among all evaluators. This indicates that some novice evaluators conducted a more extensive analysis in less time, possibly due to greater familiarity with the platform or a more agile evaluation approach.

The number of heuristics applied varied among evaluators, with Evaluator 3 identifying 13, while Evaluator 1 reported only 9. Despite using more heuristics, Evaluator 3 obtained a usability percentage of 63.37%, a figure close to Evaluator 1 (61.99%). This suggests that a higher number of applied heuristics does not necessarily translate into a higher usability percentage, as it depends on each evaluator's perception and interpretation of heuristics.

Evaluator 4, with medium expertise, achieved the highest usability percentage (71.66%). This indicates that their evaluation may have been more favorable toward the prototype than novice evaluators, who were more critical in their analysis.

4.3 Evaluation strategies and their impact on results

Evaluator 2 mentioned inspecting the prototype before starting the evaluation, which may have influenced their perception and the total time spent. However, their usability percentage was the lowest (57.24%), suggesting that their analysis was more critical than that of other evaluators.

On the other hand, Evaluator 3 used a faster evaluation strategy and applied more heuristics in less time, which could indicate a more efficient analysis. Nevertheless, their usability percentage was similar to that of Evaluator 1, implying that a quicker evaluation does not always result in significantly different outcomes.

Evaluator 4, with more experience, conducted the evaluation progressively and synchronously, allowing him to identify issues online and respond more directly. This efficient approach enabled him to complete the evaluation quickly while achieving the highest usability percentage.

4.4 Opinions and impact of the DUXAIT-NG tool

At the end of the evaluation process, the evaluators were asked to complete a SUS questionnaire **[14]**, a Total Average Mean questionnaire **[15]**, and their final comments on the DUXAIT-NG platform to provide a comprehensive understanding of the system's performance across different evaluators, shedding light on areas of strength as well as opportunities for improvement. Table 5 shows the results.

The System Usability Scale results showed an average score of 81.88, which indicates a generally good usability level for the system. A SUS score above 68 is typically considered above average, with higher scores reflecting better-perceived usability. Overall, the SUS results indicate that most evaluators deem the system highly usable, with a minor outlier (Evaluator 2) indicating room for improvement.

The TAM score, which provides insight into the overall user experience, yielded an average score of 5.51 out of 7. This suggests that, on average, the evaluators had a positive experience with the system, though there is still room for enhancement. The individual TAM results were as follows: While the TAM scores are generally favorable, the variation in individual results (particularly Evaluator 2) highlights potential issues or inconsistencies in the user experience that may require further investigation.

Table 5. TAM questionnaire results.

Evaluator	System Usability Scale (SUS) results	Total Average Mean (TAM) Results
Evaluator 1	87.5	138
Evaluator 2	67.5	108

Evaluator 3	80.0	143
Evaluator 4	92.5	136
Total Result	81.88	(529/96) = 5.51

While the system is generally well-received, the lower SUS score from Evaluator 2 suggests the presence of specific usability challenges. This may warrant further examination to identify potential pain points or usability issues, especially if similar feedback is found in a more extensive user sample.

In their final comments, the evaluators highlighted several benefits of the DUXAIT-NG platform. The platform was much easier to use due to the simplicity of completing the forms. These were well-organized by heuristics, and each question targeted a specific feature of the digital product's usability. This aspect was helpful since it was challenging during the first evaluation to formulate questions that would help identify usability issues in accordance with the heuristics.

On the platform, visual evidence in photos or screenshots was unnecessary, which some evaluators considered an advantage for streamlining the process. However, this also led to more detailed and complex descriptions that could still be understood without visual evidence.

5 Discussion

This study's findings highlight key aspects of the heuristic evaluation process using the Granollers method and the DUXAIT-NG platform. Several observations emerge from the results, particularly regarding evaluator performance, evaluation efficiency, and platform usability.

One of the main insights is the relationship between experience and evaluation efficiency. The more experienced evaluator completed the task significantly faster while still identifying comparable usability issues. This suggests that training and familiarity with heuristic evaluation methodologies can be crucial in optimizing the evaluation process.

Regarding the application of heuristics, the results indicate that a higher number of heuristics applied does not necessarily correlate with a higher usability percentage. This suggests that some evaluators may have been more critical in their assessments, leading to a more conservative usability rating. This raises an interesting question about how subjective factors influence heuristic evaluation outcomes.

Additionally, the TAM and SUS scores suggest that the DUXAIT-NG platform is generally well-received in terms of usability, but with some areas requiring improvement. The main usability issues were related to aspects such as error prevention and system feedback, which could be refined in future platform iterations.

Finally, while novice evaluators faced initial challenges, they completed the evaluation successfully, highlighting the potential of structured digital tools to facilitate the learning process. This aligns with the broader goal of improving UX evaluation methodologies by integrating digital support tools.

5.1 Limitations of the study

This study has some limitations that should be considered. The sample size was relatively small, which may limit the generalizability of the findings. In addition, the study focused on a specific context (the evaluation of a prototype hospital website), which may also limit the generalizability of the results to other types of systems or contexts.

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5.2 Implications for novice evaluator training

The findings of this study have several implications for the training of novice evaluators. First, the results suggest that using structured methods and digital tools can facilitate the learning process and improve the performance of novice evaluators. Second, the results highlight the importance of experience in evaluation efficiency, suggesting that training should focus on providing novice evaluators with opportunities to practice and develop their skills.

6 Conclusions and future works

The results of this study underscore the importance of relying on structured digital tools for heuristic evaluation processes, especially for novice evaluators. The novice evaluators' lack of experience was mitigated using the Granollers method with DUXAIT-NG. This integration effectively streamed the evaluation workflow and ensured a structured approach to usability evaluation.

Some additional findings that emerge from this study are as follows:

- Experience influences efficiency: More experienced evaluators completed the evaluation in less time and perceived usability more favorably.
- More applied heuristics do not always result in higher usability scores: Interpretation and judgment play a crucial role.
- Evaluation strategies vary: Some evaluators preferred a detailed initial analysis, while others conducted the evaluation progressively.
- Novice evaluators tend to be more critical: This could be due to stricter heuristic interpretation or a lack of familiarity with usability evaluation processes.

These findings provide valuable insights for enhancing future evaluations. Expanding the participant pool to include a more extensive and more diverse group of evaluators would help validate the results and identify broader usability patterns. Additionally, optimizing the training process for evaluators in heuristic inspections and developing more efficient strategies for utilizing the DUXAIT-NG platform could further improve the accuracy and effectiveness of usability assessments.

As for future work, there are two lines of work in the roadmap for the platform's evolution: the first is to continue carrying out new usability evaluations in other contexts, in other domains, and with other work teams with different profiles. The second line of work is the implementation of new modules that support other evaluation methods and techniques, as well as exploring AI techniques to further automate and digitize the user experience evaluation processes.

Finally, future research could address this study's limitations and expand its findings. For example, future studies could include larger sample sizes and examine the use of the Granollers method and the DUXAIT-NG platform in different contexts. In addition, future research could explore strategies to improve the training of novice raters and analyze the impact of different types of training on their performance.

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Conectando el Saber Ancestral y la Tecnología: Propuesta de una Herramienta Digital para la Preservación del Agua

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Resumen. La preservación de los saberes ancestrales en comunidades indígenas es fundamental ya que son el eje de la memoria colectiva, la pérdida de estos conocimientos y factores como el cambio climático y fenómenos como la sequía han afectado y han puesto en riesgo no solo el recurso hídrico, sino, también, la identidad cultural ligada a su gestión. La comunidad indígena Kisgo, ubicada en el municipio de Silvia (Cauca, Colombia), posee una relación ancestral directa con el agua, considerada esta como un elemento sagrado y un ordenador del territorio. Durante generaciones, la comunidad ha transmitido sus conocimientos oralmente, como la observación de ciclos naturales, rituales de siembra y cosecha alineados con fenómenos climáticos y técnicas de conservación como la "siembra de agua" para revitalizar las fuentes hídricas. Por lo tanto, en este artículo se muestra la fase inicial de una propuesta de desarrollo de una herramienta digital interactiva que facilite el aprendizaje y la aplicación de los conocimientos, integrando saberes ancestrales en la gestión del agua y tecnologías emergentes como el Internet de las cosas (IoT), Inteligencia Artificial (IA) y principios de Interacción Humano-Computador (IHC), elementos que buscan preservar y transmitir este conocimiento a los jóvenes de la comunidad de Kisgo, permitiendo la continuidad de los saberes ancestrales mientras se apoyan en nuevas tecnologías para fortalecer la gestión del agua y garantizar su preservación.

Palabras Clave: Preservación Cultural, Usabilidad Intercultural, Preservación del Agua, Conocimiento Ancestral, Tecnologías Emergentes.

1 Introducción

El acceso y la gestión sostenible del agua representan desafíos fundamentales para comunidades indígenas que dependen de este recurso para su supervivencia y continuidad cultural [1]. A lo largo de generaciones, los pueblos originarios han desarrollado prácticas avanzadas para conservar el agua, basadas en la observación de la naturaleza y la transmisión oral de conocimientos [2][3]. Sin embargo, la modernización, la expansión de infraestructuras urbanas y el impacto del cambio climático han puesto en riesgo estas prácticas, limitando su transmisión a nuevas generaciones y afectando la seguridad hídrica [4].

En la comunidad indígena de Kisgó, ubicada en el departamento del Cauca, se han identificado dificultades crecientes en la preservación del agua, en parte debido a la variabilidad climática y la reducción del acceso a fuentes tradicionales. Ante este panorama, surge la necesidad de desarrollar herramientas tecnológicas que permitan documentar, preservar y mejorar el uso del agua mediante el rescate del conocimiento ancestral [5].

Este artículo propone el desarrollo de una herramienta digital interactiva que integre Internet de las Cosas (IoT), principios de Interacción Humano-Computador (IHC) e Inteligencia Artificial (IA) para mejorar la gestión del agua en comunidades indígenas, articulando el conocimiento ancestral de la comunidad Kisgo con tecnologías emergentes [6]. El IoT permitirá la recolección y monitoreo en tiempo real de datos ambientales, como niveles de humedad del suelo, caudales de fuentes hídricas y patrones climáticos, mediante sensores distribuidos estratégicamente en el territorio. Estos datos se integrarán con el conocimiento tradicional de la comunidad sobre ciclos naturales, rituales de siembra y cosecha, y técnicas de conservación, como la "siembra de agua", para fortalecer la toma de decisiones en la gestión hídrica. La IA procesará esta información combinada para identificar patrones climáticos, predecir periodos de sequía y generar estrategias óptimas de

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conservación, respetando las prácticas indígenas y potenciando su aplicación con modelos de aprendizaje automático. Además, se generarán alertas tempranas y recomendaciones específicas basadas en la relación ancestral de la comunidad con el agua. Por otro lado, los principios de IHC garantizarán que la herramienta sea accesible y fácil de usar, diseñando interfaces intuitivas que reflejen la cosmovisión de la comunidad y faciliten la transmisión de los saberes ancestrales a nuevas generaciones. Se priorizarán representaciones visuales de los ciclos naturales y rituales indígenas, junto con modalidades de interacción basadas en voz para una mayor apropiación tecnológica. En conjunto, estas tecnologías permitirán documentar, preservar y aplicar el conocimiento ancestral en la gestión del agua, asegurando su continuidad y fortaleciendo la sostenibilidad del recurso en armonía con el entorno natural.

Con este enfoque, se busca empoderar a la comunidad Kisgo para que gestionen de manera autónoma sus recursos hídricos, fortaleciendo al mismo tiempo su identidad cultural y resiliencia frente al cambio climático.

2 Planteamiento del problema

El resguardo indígena de Kisgó, ubicado en el municipio de Silvia, Cauca, enfrenta una crisis creciente en la gestión sostenible del agua, un recurso esencial no solo para su supervivencia, sino también para la continuidad de su cosmovisión y prácticas culturales [6]. Durante varias generaciones, la comunidad ha desarrollado conocimientos ancestrales para la conservación del agua, basados en la observación del entorno y en la transmisión oral de prácticas ecológicas. Sin embargo, la combinación de factores como el cambio climático, la escasez hídrica y la presión externa sobre los recursos naturales ha provocado una transformación en los patrones de disponibilidad del agua, impactando negativamente la seguridad alimentaria y la vida comunitaria.

A pesar de que el pueblo Kisgo ha implementado estrategias tradicionales como la "siembra de agua" para la recuperación de lagunas, recientes sequías han afectado la estabilidad hídrica del resguardo, forzando modificaciones en las dinámicas agrícolas y en la distribución del recurso. A este panorama se suma la falta de herramientas tecnológicas que permitan a la comunidad monitorear y gestionar eficientemente sus fuentes hídricas, integrando su conocimiento ancestral con metodologías científicas y digitales [7].

En este sentido, uno de los mayores riesgos que enfrenta la comunidad de Kisgó es la pérdida de su conocimiento tradicional sobre la gestión del agua. La modernización y la falta de documentación sistemática han limitado la transmisión de estas prácticas a las nuevas generaciones [8]. El avance de tecnologías emergentes y la falta de un diálogo estructurado entre saberes ancestrales y ciencia moderna han generado una desconexión entre los métodos tradicionales y las soluciones actuales para la gestión hídrica.

Además, el acceso limitado a herramientas tecnológicas accesibles y adaptadas a la comunidad impide la apropiación de soluciones modernas que podrían mejorar la toma de decisiones en torno al uso del agua [9]. Aun cuando las tecnologías de Internet de las Cosas (IoT), sensores inteligentes e Inteligencia Artificial (IA) han demostrado ser efectivas en la gestión de recursos hídricos en otros contextos, su implementación en comunidades indígenas sigue siendo un reto debido a barreras culturales, económicas y de infraestructura [10], [11].

Por su parte, el uso de Interacción Humano-Computador (HCI) e Inteligencia Artificial (IA) representa una oportunidad para preservar y fortalecer los saberes ancestrales de Kisgó [12], [13], asegurando su transmisión y aplicación en la gestión sostenible del agua. Permitiendo diseñar interfaces accesibles que faciliten la comprensión y uso de tecnologías por parte de la comunidad, garantizando que la digitalización del conocimiento no sea una barrera, sino una herramienta de fortalecimiento cultural [14].

Integrar la tecnología con los saberes ancestrales permitiría fortalecer la gestión del agua al combinar el conocimiento empírico de la comunidad con herramientas innovadoras que optimicen su aplicación. La digitalización y el uso de sensores ambientales pueden mejorar la precisión en la recolección de datos sobre fuentes hídricas, facilitando la predicción de sequías y el monitoreo en tiempo real. Asimismo, la inteligencia artificial ayudaría a analizar patrones climáticos y recomendar estrategias basadas tanto en modelos científicos como en la observación tradicional. De esta manera, la tecnología no reemplaza el conocimiento ancestral, sino

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que lo amplifica y lo preserva, asegurando su continuidad y adaptación a los desafíos actuales sin perder su esencia cultural.

Para ello se debe tener en cuenta que el resguardo indígena de Kisgó se encuentra en la zona nororiental del departamento del Cauca, Colombia, específicamente en el municipio de Silvia. Está conformado por 13 veredas y abarca una extensión total de 75,46 km², equivalente aproximadamente a 7500 hectáreas. Su ubicación altitudinal varía entre 2400 y 3000 metros sobre el nivel del mar, lo que, de acuerdo con la clasificación de Caldas Holdridge, lo sitúa en una zona de clima frío, con temperaturas predominantes que oscilan entre 11 y 18 grados centígrados (IGAC, 2014) como se puede observar en la siguiente Fig. 1.

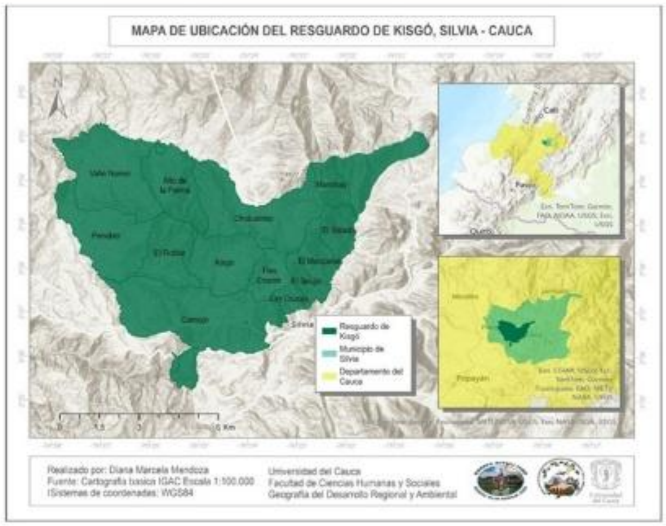

Fig. 1. Mapa de ubicación del resguardo indígena de Kisgó. Elaboración propia.

La investigación realizada en Kisgó ha evidenciado cómo el conocimiento ancestral sobre la gestión del agua se está perdiendo progresivamente, debido a múltiples factores que afectan la estabilidad del territorio y sus recursos naturales. Uno de los hallazgos clave del estudio "La casa del agua es mujer", llevado a cabo por la investigadora Diana Mendoza, es la creciente fragmentación en la gestión del agua, la cual ha generado conflictos internos en la comunidad. La implementación de soluciones modernas como los tanques de agua sin una adecuada integración con los conocimientos tradicionales ha provocado una disminución en la aplicación de prácticas ancestrales de conservación y uso del recurso hídrico.

Además, el cambio climático y el fenómeno del niño han alterado los ciclos naturales del agua, afectando los métodos tradicionales de captación, almacenamiento y distribución utilizados por la comunidad. Esta transformación no solo ha generado pérdidas en la seguridad hídrica y alimentaria, sino que también ha debilitado la transmisión de conocimientos intergeneracionales, ya que las nuevas generaciones enfrentan un contexto donde las prácticas ancestrales ya no resultan suficientes para responder a los desafíos ambientales actuales.

Si esta situación continúa, existe el riesgo de que los saberes tradicionales sobre la gestión del agua, la relación con los ciclos climáticos y la conservación de fuentes hídricas desaparezcan con el tiempo, reduciendo la capacidad de la comunidad para gestionar sus propios recursos de manera sostenible.

La Fig. 2. muestra un mapa de zonas de conflicto por recursos naturales en Kisgó, destacando áreas donde la competencia por el uso del agua ha generado tensiones. Se identifican elementos clave como tanques de agua, cultivos, ganadería, piscicultura y huertas comunitarias, los cuales influyen en la gestión del recurso hídrico. Las zonas sombreadas en púrpura representan áreas de mayor conflicto, evidenciando la necesidad de una gestión sostenible del agua para evitar disputas dentro de la comunidad.

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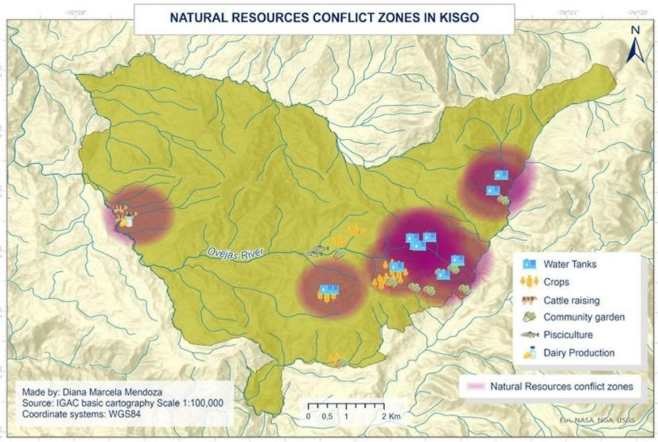

Fig. 2. Zonas de conflicto por recursos naturales en Kisgo. Elaboración propia.

Es por ello por lo que integrar los diferentes elementos tecnológicos y la IHC en una herramienta sería clave para preservar y fortalecer los conocimientos ancestrales sobre la gestión del agua en Kisgó. El diseño de una herramienta digital accesible facilitaría su apropiación sin afectar la cosmovisión indígena. A través de plataformas interactivas, la comunidad podría acceder a información hídrica, visualizar patrones climáticos y documentar saberes tradicionales. Aplicar principios de usabilidad y accesibilidad garantizaría que estas tecnologías complementen y potencien el conocimiento ancestral, asegurando su transmisión a futuras generaciones. Además, esta herramienta permitiría gestionar de manera más eficiente las zonas de conflicto identificadas, proporcionando información en tiempo real sobre el estado del recurso hídrico y facilitando la toma de decisiones comunitarias para su distribución equitativa, reduciendo así disputas y promoviendo una administración sostenible del agua.

3 Trabajos relacionados

La relación entre conocimientos indígenas y tecnologías digitales emergentes ha sido explorada desde diferentes enfoques y ha generado diversas iniciativas que son antecedentes relevantes para esta propuesta en el estudio del arte se presentan trabajos en las siguientes dos categorías consideradas como principales: preservación digital de conocimientos ancestrales y herramientas tecnológicas para la gestión del agua.

Preservación digital de conocimientos ancestrales.

Diversos estudios han abordado la documentación y preservación digital de saberes ancestrales, Díaz (2021) muestra cómo a estas alturas es necesario incluir Tecnologías de la Información y Comunicación (TIC) que permiten el desarrollo de las capacidades de los estudiantes, convirtiendo también en espacios de empoderamiento para los sectores rurales, ha demostrado que la incorporación de las tecnologías en contextos educativos rurales facilita la enseñanza de lenguas y prácticas ancestrales, reforzando la relación entre los estudiantes y sus raíces culturales[15]. Diversos estudios en diferentes países como México [16], Australia [17], Tailandia [18], India [19] y Colombia [20] demuestran que han digitalizado narraciones orales indígenas para preservar la cosmovisión de las comunidades permitiendo una transmisión de conocimientos de diferentes áreas. Permitiendo así la cultura, el dialecto y saberes ancestrales teniendo un alto impacto en las respectivas comunidades.

Herramientas tecnológicas para la gestión del agua.

Varios investigadores han implementado aplicación de tecnologías emergentes en la gestión del agua, demostrando ser efectiva en diversos entornos [7]. El agua es uno de los recursos más importantes, por eso, en los últimos años se han buscado herramientas tecnológicas [28] y tendencias tecnológicas que contribuyen a la gestión del agua [29]. Han desarrollado sistemas de monitoreo basado en sensores IoT que permiten un control

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preciso del recurso en comunidades con escasez hídrica, implementando también herramientas IA como forma revolucionaria de gestionar el agua [10], ya que según estudios la IA "ha demostrado ser una herramienta altamente efectiva en todas las etapas del ciclo del agua" [11]. La IHC ha sido utilizada para diseñar herramientas tecnológicas de forma que sea mucho más comprensible para aquellas personas que usan la tecnología y el mensaje llegue de forma eficaz a quien lee [21].

4 Objetivos y metodología

Para llevar a cabo el desarrollo de esta propuesta se pretende llevar a cabo los siguientes objetivos:

Objetivo General: Desarrollar una herramienta digital interactiva que facilite la documentación, transmisión y aplicación del conocimiento ancestral sobre la gestión del agua en la comunidad indígena de Kisgó, integrando sensores IoT para el monitoreo en tiempo real del recurso hídrico y modelos de Inteligencia Artificial para analizar patrones y predecir variaciones en su disponibilidad, enfocada en jóvenes entre 13 y 19 años que les permita aprender y aplicar estos saberes a través de tecnologías emergentes.

Objetivos Específicos

- Caracterizar las necesidades, habilidades tecnológicas y contexto cultural de los jóvenes de Kisgó, así como las prácticas ancestrales en la gestión del agua y los principales desafíos en su transmisión y aplicación, mediante entrevistas, talleres participativos y observación directa, asegurando un diseño centrado en el usuario que facilite la apropiación de la herramienta.
- Diseñar una herramienta digital interactiva, definiendo sus elementos de usabilidad y accesibilidad, integrando sensores IoT para la recopilación de datos en tiempo real sobre el recurso hídrico y modelos de Inteligencia Artificial para analizar patrones, predecir variaciones y fortalecer el aprendizaje de los jóvenes a través de información visual e interactiva.
- Evaluar la usabilidad y efectividad de la plataforma mediante pruebas con miembros de la comunidad, utilizando modelos de aceptación tecnológica para medir su impacto en el aprendizaje, la apropiación del conocimiento ancestral y la mejora en la gestión del agua.

Metodología

Para el desarrollo de esta investigación se seguirán tres fases basadas en el ciclo de investigación científica, aplicando metodologías de Interacción Humano-Computador (HCI), Diseño Centrado en el Usuario (UCD) y Co-Diseño. Estas metodologías han sido seleccionadas porque garantizan que la herramienta digital sea intuitiva, accesible y culturalmente pertinente, alineándose con las necesidades y conocimientos ancestrales de la comunidad de Kisgó.

- **El Diseño Centrado en el Usuario (UCD)** será un pilar metodológico clave en el desarrollo de la herramienta digital propuesta, debido a su enfoque en garantizar que las tecnologías no solo sean funcionales, sino también significativas, accesibles y apropiadas para sus usuarios finales [22]. En este caso, los principales beneficiarios son jóvenes indígenas de la comunidad de Kisgó, quienes tienen un contexto sociocultural y tecnológico específico que no puede ser ignorado en el diseño de interfaces.
- El UCD se implementará como un proceso iterativo y participativo que involucra activamente a los usuarios en todas las fases de diseño, desde la definición de requerimientos hasta la evaluación de prototipos. Esta metodología permite recoger información directamente de los jóvenes del resguardo, identificar sus **habilidades tecnológicas, preferencias cognitivas y formas de interacción**, y traducirlas en decisiones concretas de interfaz, navegación, contenidos y estilos visuales. Desde una perspectiva técnica, UCD también implica la aplicación de principios de usabilidad, como consistencia, visibilidad del estado del sistema, control por parte del usuario y diseño accesible para distintos niveles de alfabetización digital [26]. Esto es especialmente relevante en contextos rurales donde el acceso a internet es limitado o los dispositivos móviles son la principal vía de conectividad.
- **Co-Diseño y Diseño Participativo** se integrarán para involucrar a la comunidad en la creación de la herramienta digital [23], asegurando que refleje su cosmovisión y respete sus prácticas tradicionales

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en la gestión del agua. al involucrar a los jóvenes en la co-creación de prototipos, pruebas de navegación y validación funcional, se fortalece su sentido de pertenencia frente a la herramienta y se incrementa su disposición a utilizarla y compartirla.

1. Exploración

Entre los casos que servirán de referencia se encuentran:

- **Dayana Blanco (2023)**, desde Bolivia, lidera la restauración ecológica del lago Uru Uru usando saberes ancestrales y mapeo con herramientas digitales.
- **Participatory Mapping of Water Access Technologies in the Argentine Chaco (Lópes & Belmonte, 2024):** Este estudio documenta cómo comunidades indígenas y criollas del Chaco salteño utilizaron mapeo participativo y cartografía social para representar sus formas de acceso al agua (cisternas, pozos, lluvia, red), identificando conflictos, limitaciones y estrategias locales. El trabajo destaca cómo la apropiación tecnológica, combinada con metodologías participativas, permite empoderar a comunidades rurales en la gestión hídrica, y sirve como referente para el diseño de herramientas digitales en Kisgó que integren saberes ancestrales y tecnologías accesibles.

Además de estos ejemplos, se considerarán otras experiencias regionales e internacionales que aporten enfoques metodológicos o tecnológicos aplicables al contexto de Kisgó.

- **Trabajo de campo en la comunidad de Kisgó**: Se realizarán entrevistas semiestructuradas y talleres participativos con líderes y miembros de la comunidad para comprender sus prácticas tradicionales de gestión del agua, su transmisión generacional y los factores que han contribuido a su pérdida. Además, se evaluará el nivel de alfabetización digital, los hábitos de uso de la tecnología y las barreras tecnológicas y socioculturales, incluyendo limitaciones de conectividad e infraestructura, que podrían afectar la implementación de la herramienta digital.

- **Mapeo de requerimientos:** Se establecerán los requerimientos funcionales y no funcionales de la herramienta interactiva con base en la información recopilada durante la fase exploratoria, incluyendo entrevistas, observación participativa, talleres de co-diseño y diagnóstico tecnológico. Este proceso buscará traducir las necesidades, expectativas y limitaciones de los jóvenes del resguardo Kisgó en especificaciones claras para el desarrollo del sistema. Los requerimientos funcionales contemplarán las acciones que debe permitir la plataforma, como la navegación por mapas interactivos, reproducción de relatos orales, visualización de datos ambientales, acceso a multimedia cultural y personalización de contenidos. Los requerimientos no funcionales priorizarán la usabilidad (facilidad de aprendizaje, eficiencia, satisfacción), la accesibilidad (compatibilidad móvil, lectura clara, inclusión visual y auditiva) y la integración con la cosmovisión indígena, lo cual implica incorporar símbolos, narrativas y estructuras propias del pueblo Misak, como el territorio entendido como ser vivo o rutas circulares de navegación. Este mapeo será un proceso iterativo y participativo, que se ajustará durante el desarrollo de prototipos, garantizando así una solución tecnológicamente viable, culturalmente coherente y socialmente apropiada.

2. Formulación y desarrollo

Diseño de la herramienta gigital interactiva

- **Diseño Centrado en el Usuario (UCD) y Co-Diseño:** Desarrollo iterativo de prototipos en colaboración con la comunidad para garantizar una plataforma intuitiva, accesible y culturalmente pertinente.
- **Usabilidad y Accesibilidad**: Interfaz con navegación visual, textual e interactiva, adaptada a distintos niveles de alfabetización digital.
- **Integración de Sensores IoT:** Se propone el uso de sensores de bajo costo y bajo consumo energético para el monitoreo en tiempo real del recurso hídrico, cuya información será visualizada a través de la plataforma interactiva propuesta. Estos sensores permitirán registrar variables clave como nivel del agua, humedad del suelo, temperatura ambiental y calidad del agua, generando alertas y patrones útiles tanto para la comunidad como para los módulos de IA integrados.

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Entre los dispositivos recomendados se encuentran:

– Sensor ultrasónico HC-SR04 o JSN-SR04T: útil para medir el nivel de agua en tanques, pozos o quebradas, mediante detección por distancia. Es económico, resistente y compatible con plataformas como Arduino.
– Sensor de humedad del suelo YL-69 o capacitivo v2.0: permite identificar condiciones de humedad en cultivos y zonas de recarga hídrica, facilitando prácticas ancestrales como la siembra de agua.
– Sensor de temperatura y humedad DHT22 o BME280: mide variables climáticas que afectan la disponibilidad del agua, y puede ayudar a anticipar cambios asociados al fenómeno del Niño.
– Sensor de turbidez o calidad del agua (TSD-10 o SEN0189): útil para detectar contaminación en nacimientos, tanques o corrientes, ayudando a cuidar fuentes sensibles del resguardo.

Las principales ventajas de estos sensores radican en su bajo costo, facilidad de implementación con tecnologías abiertas (Arduino, ESP32), y su adaptabilidad a zonas rurales sin conexión constante a internet, ya que permiten almacenamiento local o transmisión por redes como LoRa o WiFi comunitaria. Además, al ser integrados en una interfaz visual y accesible, la comunidad podrá interpretar fácilmente los datos recolectados, reforzando la autonomía local en la gestión del agua y facilitando la combinación entre conocimiento ancestral y herramientas tecnológicas.

– **Módulo de Inteligencia Artificial (IA):** Se integrará un módulo de IA enfocado en el análisis de datos ambientales recolectados por sensores IoT, registros históricos del clima y patrones culturales tradicionales relacionados con el agua, con el fin de predecir variaciones en la disponibilidad hídrica, identificar posibles amenazas (sequías, contaminación) y generar recomendaciones adaptadas al contexto local. Además, este módulo permitirá alimentar contenidos educativos adaptativos dentro de la plataforma, fortaleciendo el aprendizaje de los jóvenes mediante visualizaciones interactivas y predicciones comprensibles.

Para este fin, se explorarán e implementarán modelos de IA que sean robustos, explicables y adecuados para contextos rurales con datos limitados. Entre los más relevantes para este tipo de sistema se encuentran:

– Random Forest: Modelo de aprendizaje supervisado ideal para manejar datos ambientales y multivariables. Es resistente al ruido, permite explicar qué variables influyen más en una predicción (por ejemplo, qué indicador predice sequía), y se puede entrenar fácilmente con datasets reducidos.
– XGBoost (Extreme Gradient Boosting): Potente modelo de clasificación y regresión que mejora el rendimiento sobre conjuntos de datos más estructurados (como series de humedad, temperatura, caudal). Es eficiente, rápido y adecuado para predicciones meteorológicas en tiempo real.
– Redes Neuronales LSTM (Long Short-Term Memory): Especializadas en análisis de series temporales, útiles para prever cambios en los niveles de agua con base en datos históricos. Estas redes permiten detectar patrones de sequía, cambios climáticos o comportamientos estacionales de fuentes de agua.
– AutoML (como Google AutoML o H2O.ai): Plataformas que automatizan elproceso de entrenamiento, selección y ajuste de modelos, facilitando su uso por técnicos o estudiantes sin conocimientos avanzados en IA. Son útiles en entornos colaborativos o con apoyo externo.

Estos modelos se integrarán con criterios de IA explicable (XAI) para que sus resultados puedan ser comprendidos por los usuarios de la comunidad, y permitirán ajustar alertas, contenidos educativos y decisiones de cuidado del agua de forma más precisa y culturalmente pertinente. La combinación de IA con datos del territorio fortalecerá tanto la autonomía técnica como el vínculo entre saberes ancestrales y nuevas tecnologías.**Documentación Interactiva:** Digitalización de saberes ancestrales en formatos audiovisuales, narraciones orales, mapas interactivos y guías prácticas.

3. Evaluación y validación

– **Aplicación del Modelo de Aceptación Tecnológica (TAM)**: Se evaluará la percepción de los usuarios sobre la facilidad de uso, utilidad y adaptabilidad de la herramienta digital.
– **Pruebas de usabilidad con la comunidad**: Se implementarán sesiones de prueba con jóvenes y adultos de Kisgó, midiendo la interacción con la plataforma y recopilando sugerencias para mejorar su diseño y funcionalidades.

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– **Medición del impacto en la transmisión del conocimiento ancestral**: Se analizará el grado en que la guía interactiva facilita la conservación y enseñanza del saber tradicional sobre la gestión del agua, comparando el nivel de apropiación antes y después de la implementación.
– **Iteración y ajustes finales**: Se realizarán modificaciones basadas en la retroalimentación obtenida durante la fase de evaluación, optimizando la plataforma antes de su implementación definitiva en la comunidad.

En la comunidad indígena de Kisgó, se han implementado iniciativas orientadas a la preservación de su cultura y conocimientos ancestrales. Un ejemplo destacado es la aprobación del Plan Integral de Reparación Colectiva (PIRC) en noviembre de 2023, que incluye acciones como la revitalización de prácticas culturales y la construcción de espacios para la transmisión de saberes tradicionales [24].

A nivel global, diversas comunidades indígenas han desarrollado proyectos que integran tecnología y conocimientos ancestrales para la gestión sostenible del agua. Por ejemplo:

Restauración del Lago Uru Uru en Bolivia: La comunidad aymara, liderada por jóvenes como Dayana Blanco, ha implementado técnicas tradicionales utilizando plantas nativas, como las totoras, para filtrar y mejorar la calidad del agua del lago, combinando saberes ancestrales con prácticas sostenibles [1].

Integración del conocimiento indígena en Guatemala: En el Altiplano Central y Occidental de Guatemala, se han fortalecido las prácticas tradicionales de gestión del agua mediante la participación activa de las comunidades indígenas en estrategias y políticas hídricas, promoviendo una gestión sostenible de los recursos naturales [25].

Estas experiencias resaltan la importancia de combinar el conocimiento ancestral con herramientas tecnológicas para abordar desafíos actuales en la gestión del agua y la preservación cultural. Aunque en Kisgó ya existen esfuerzos significativos en la revitalización cultural, la implementación de una herramienta digital interactiva podría potenciar la transmisión de conocimientos ancestrales sobre la preservación del agua, adaptándose a las necesidades y contextos específicos de los jóvenes de la comunidad.

5 Conclusiones y trabajo futuro

La preservación del conocimiento ancestral en comunidades indígenas es clave para su identidad y sostenibilidad. En Kisgó, la gestión del agua representa un desafío crítico que requiere la integración de saberes tradicionales con tecnologías emergentes. Este estudio ha propuesto una herramienta digital interactiva basada en principios de Interacción Humano-Computador (IHC), Inteligencia Artificial (IA) y sensores IoT, permitiendo documentar, visualizar y transmitir el conocimiento ancestral sobre el agua. La solución se espera que se diseñe para ser económica y de fácil implementación, asegurando que los sensores IoT puedan ser replicados con recursos accesibles dentro de la comunidad. Además, la información recolectada no solo permitirá el monitoreo en tiempo real del recurso hídrico, sino que también servirá como base para la toma de decisiones, combinando los conocimientos ancestrales con el análisis de datos proporcionado por la tecnología. De esta manera, se busca fortalecer la identidad cultural de Kisgó, empoderar a sus habitantes en la gestión sostenible del agua y facilitar el aprendizaje entre los jóvenes a través de experiencias interactivas.

Como trabajos futuros, se avanzará en la implementación y validación de la herramienta, asegurando su usabilidad y accesibilidad mediante la participación activa de la comunidad. Se priorizará la optimización de los sensores IoT para el monitoreo eficiente del agua y la mejora del módulo de IA para análisis predictivo. Además, se explorará la adaptación de esta iniciativa a otras comunidades con condiciones similares, ampliando su impacto en la preservación del conocimiento ancestral y la sostenibilidad del agua.

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Cybersecurity Strategies for the Digital Inclusion of Older Adults: A Systematic Literature Review

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Abstract. Digital inclusion for older adults is crucial for ensuring their secure engagement in the digital society. This study investigates the strategies and challenges associated with digital literacy and cybersecurity for this demographic through a Systematic Literature Review. To this end, we focus on five research areas: (1) cybersecurity strategies tailored for the inclusion of older adults, (2) essential digital competencies related to cybersecurity for older adults, (3) obstacles hindering the adoption of cybersecurity strategies in the context of older adults, (4) evaluation techniques for digital competencies among older adults, and (5) digital literacy approaches emphasizing digital competencies of older adults. Our research identified 57 primary studies presenting diverse findings. The findings emphasize strategies such as peer support, customized materials for specific sectors, and voluntary community networks. Key digital competencies identified include the ability to recognize safe websites, securely manage passwords, and safeguard online privacy. Some of the identified barriers include anxiety, social prejudice toward older adults, inadequate technical support, and the rapid digitization of services. Assessment methods like the Digital Competence Framework (DigComp) and workshop questionnaires are emphasized. Furthermore, digital platforms, educational games, family support, peer technical assistance, and in-person workshops are utilized as digital literacy approaches.

Keywords: Cybersecurity, Older adults, Inclusion. Digital literacy, Systematic Review.

1 Introduction

The rapid digital transformation has greatly changed the way people interact, communicate, and utilize services. Nonetheless, older adults encounter challenges in adapting to these new technologies, leading to an increased digital divide. This division extends into areas such as cybersecurity, where the limited digital literacy among older adults puts them at risk of cyber-threats, including fraud, identity theft, and extortion.

Despite numerous digital literacy initiatives, many fail to incorporate cybersecurity education. Furthermore, the available information on this topic primarily caters to younger demographics or individuals already well-versed in technology.

In response to this challenge, we conducted a Systematic Literature Review (SLR) following the guidelines from Kitchenham et al. [1]. Our primary objective is to uncover cybersecurity strategies that facilitate the integration of older adults into the digital landscape, covering the essential digital skills required from a cybersecurity standpoint, the obstacles impeding adoption for this demographic, the methodologies for assessing cybersecurity skills in older adults, and literacy approaches for older adults with a focus on digital skills. By synthesizing the collected data, this study aims to advance the development of inclusive cybersecurity education strategies tailored to the specific requirements of older adults.

This paper is organized as follows: Section 2 outlines the related work in the context of digital literacy for older adults, Section 3 delves into the research methodology employed, Section 4 discusses the study findings, Section 5 provides an analysis and discussion of the findings, Section 6 examines the potential threats to validity of this study, finally Section 7 offers the conclusions drawn from the study.

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2 Background and related work

After conducting a manual search for related literature, we identified a research gap in studies focused on cybersecurity issues for older adults, specifically exploring strategies to enhance their integration in this domain.

We encountered a scarcity of research dedicated to digital literacy for older adults, only finding studies primarily focused on TIC adoption [4][5]. In contrast, our study offers insights into identifying areas for enhancing digital literacy, delving into plans and methods that have exhibited good results in digital education within this domain.

The study presented in [4] reveals that limited access to TIC is often attributed to lower incomes and educational levels, further exacerbated by outdated device usage among older adults. It emphasizes the pressing need for increased attention and resources in advancing digital literacy among older populations. The study highlights findings that mastering tools like Zoom and WhatsApp can significantly boost digital literacy, mitigating isolation and enhancing overall well-being.

The research presented in [5] explores the evolution of the digital divide in older adults, its causative factors, and ongoing efforts by diverse organizations to address this issue proactively. Additionally, it assesses the efficacy of modern strategies for imparting digital education, be it through conventional face-to-face instruction or remote learning modalities. The research analyzes the influence of class frequency on educational outcomes and underscores the positive effects of intergenerational learning approaches on enhancing digital skills and reducing the digital divide.

3 Research method

This study follows the guidelines for conducting Systematic Literature Review (SLR) from [1], which comprises three primary phases: planning, execution, and reporting. The subsequent subsections present the planning and execution stages, with Section 4 detailing the reporting phase.

3.1 Planning

The planning phase involved activities to develop a review protocol, including: (1) formulating research questions, (2) outlining the search strategy, (3) identifying relevant studies, and (4) determining the synthesis method. From the research questions we defined keywords used for crafting the search string. Furthermore, in this phase we also completed tasks such as selecting databases, setting inclusion and exclusion criteria, outlining the primary study selection process, and creating a data extraction template. The research questions are presented in Table 1.

Research questions. The SLR aims to answer the research questions shown in Table 1.

Table 1. Research questions and motivation.

Questions	Motivation
RQ1. What are the cybersecurity strategies that promote the inclusion of older adults?	Identify and document cybersecurity strategies specifically designed for older adults.
RQ2. What digital competencies should older adults have from a cybersecurity perspective?	Discover the digital competencies necessary for older adults in terms of cybersecurity.
RQ3. What barriers are reported in the literature that hinder the	Analyze and understand the barriers that limit the adoption of cybersecurity strategies by older adults, providing insights to overcome them.

adoption of cybersecurity strategies by older adults?	
RQ4. What methods are employed to evaluate the digital competencies concerning cybersecurity among older adults?	Identify the methods used to assess digital competencies in cybersecurity among older adults.
RQ5. What literacy methods for older adults emphasize digital competencies?	Identify literacy methods reported in the literature for older adults to assess their potential adaptation to cybersecurity topics.

Search strategy. Our search strategy integrated manual, automated, and backward snowball [50] searches. This approach, guided by the quasi-gold method [2], commenced with a manual search of the ACM database, leading to the identification of 10 relevant studies. These studies formed the basis for evaluating search strings, in order to select a good search string to conduct the study.

Data Sources. We chose relevant databases in computer science as our primary data sources, including the ACM Digital Library, IEEE Xplore, Springer Link, and ScienceDirect. The selection of these search engines followed recommendations outlined by Zhang et al. [2].

Keywords. To construct an effective search string, we extracted keywords from the research questions and subsequently refined them based on the commonly used terms within the research topic as identified by the authors. Table 2 illustrates the keywords we have identified.

Table 2. Keywords to build the search string.

Concept	Related keywords
Cybersecurity	Online security, information security, digital protection, safety, online safety, cyber-safety.
Older adults	Senior, senior citizen, older person, elderly, older.
Digital skills	Digital literacy, digital proficiency, media literacy.
Inclusion	Inclusion
Literacy digital	Digital education, media literacy

Search string. The keywords facilitated the formulation of the search string used in this study. We evaluated nine distinct search string to identify the most effective variation based on Precision (1) and Recall (2) metrics. According to [2], a search string is considered good if it achieves a sensitivity equal to or exceeding 80%.

$$Precision = \frac{Rfound}{Ntotal} \tag{1}$$

$$Recall = \frac{Rfound}{R\ total} \tag{2}$$

(cybersecurity OR "online security" OR safety) AND (older OR elderly OR senior) AND ("digital literacy" OR "digital inclusion")

Selection criteria for primary studies. Table 3 and Table 4 show, respectively, the inclusion and exclusion criteria we used to select primary studies.

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Table 3. Inclusion criteria.

IC	Description
IC-1	The study was published between 2018 and 2024.
IC-2	The study is published in English.
IC-3	The title of the study relates to the topic of interest.
IC-4	The abstract of the study relates to the topic of interest.
IC-5	A full reading of the study confirms that the study answers at least one research question.

Table 4. Exclusion criteria.

EC	Description
EC-1	The study is a slideshow, workshop paper, or an incomplete document.
EC-2	Full access to the study is not available.
EC-3	The study is duplicated.

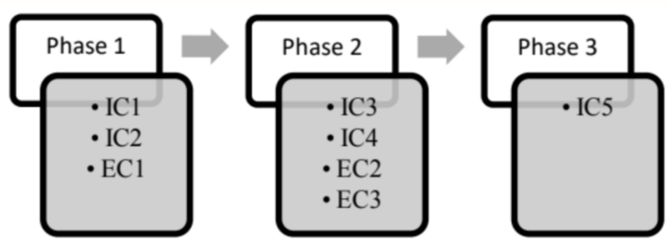

Fig. 1. Shows the order, divided in phases, in which we applied the selection criteria.

Data Extraction. Following the study selection process, we carried out data extraction for each primary study. To facilitate this, we designed a structured template containing key demographic details for each study, including title, authors, year, and DOI. The template also collects the answers found in each study for the research questions.

Synthesis. For synthesizing our results, we employed a narrative synthesis as described by Popay et al. [3]. This approach, viewed by the authors as a storytelling technique founded on research results, rests upon four elements: Developing a theory, creating a preliminary synthesis, exploring data relationships, and evaluating the synthesis's robustness.

Execution. The execution phase of the Systematic Literature Review started with the application of the chosen search string in the chosen databases to retrieve preliminary results. Subsequently, the selection process progressed in stages across the four databases, each phase resulting in specific numbers of articles chosen as detailed in Table 5.

Table 5. Primary studies selection phases.

Database	First Results	Phase 1	Phase 2	Phase 3
ACM Digital Library	907	773	23	23
IEEE Xplore	26	9	4	4
SpringerLink	2,675	799	7	7
ScienceDirect	2,475	782	9	5
Total	6,083	2,363	42	39

After the initial selection of primary studies, we employed backward snowballing, which involves the reviewing of references within the chosen primary studies to identify pertinent cited studies. Through this approach, we discovered 18 additional relevant studies not included in the initial search. To maintain consistency, we subjected these studies to the same inclusion and exclusion criteria. In this way, the total of studies we found is 57.

4 Results

In Figure 2, the distribution of selected studies per year is displayed. 2021 saw the highest number of studies published, with 17 in total. This count decreased to 7 in 2022, but rebounded to 14 in 2023, only to fall again to 5 studies by 2024.

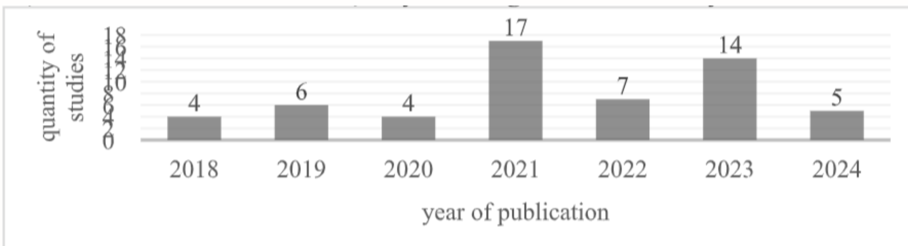

Fig. 2. Distribution of studies per year.

RQ1. What are the cybersecurity strategies that promote the inclusion of older adults?

Our study revealed that cybersecurity strategies promoting the inclusion of older adults differ based on factors such as population characteristics, culture, and country-specific contexts. However, all the strategies converge towards a common objective: ensuring secure digital inclusion for this demographic.

A notable strategy involves the identification of older adults with advanced technological knowledge in communities and providing them with training in privacy and digital security, this strategy is termed in the literature as 'CyberGuardians' [25,26]. This approach enables the indirect dissemination of knowledge, leveraging peer-to-peer communication [21]. The implementation of this knowledge-sharing strategy has proven effective in promoting cybersecurity awareness within the community. It underscores the significance of social support in enhancing the adoption of best practices, empowering older adults to become proactive promoters of knowledge [27].

Additional strategies include personalized education initiatives [32,38] and specialized models like "cyberwellness" [53] that prioritize cybersecurity. Conversely, proactive education endeavors to empower older adults by avoiding fear-based tactics [10]. Similarly, straightforward tactics such as sharing fundamental tips, verifying website security, and configuring privacy settings [19] have demonstrated effectiveness in bolstering cybersecurity awareness. An interesting strategy involves intergenerational learning programs [14], which leverage the assistance of younger family members to provide practical guidance [21,23,49], alongside networks of close friends.

Older adults tend to prefer in-person cybersecurity courses and the utilization of traditional mediums like radio for information dissemination [16]. Creating materials exclusively tailored for this demographic is crucial, necessitating features like appropriate font sizes, clear typography, detailed step-by-step guides, and printed resources for their convenience [53,60].

Moreover, game-based education has emerged as an effective approach in imparting cybersecurity concepts [30] and leveraging pre-existing skills, like grammar and writing, to discern fraudulent emails [29]. Online group activities and multimedia content also helped in sustaining engagement and facilitating learning during the pandemic [18].

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Overall, a combination of community social support, personalized education, and practical learning methods can significantly improve the digital inclusion of older adults.

Table 6 displays the most mentioned cybersecurity strategies, as presented in the literature, that promoted the inclusion of older adults.

Table 6. Cybersecurity strategies that promote the inclusion of older adults.

Strategy	Description
Identification and training of community leaders	Training older adults with higher digital literacy to educate their peers and promote cybersecurity awareness.
Close social support (friends and family)	Support from family members, especially children and young people, to receive guidance on privacy and mobile security issues.

RQ2. What digital competencies should older adults have from a cybersecurity perspective?

To ensure the safe participation of older adults in cyberspace, it is crucial to develop specific digital competencies, particularly from a cybersecurity standpoint. Unlike younger populations, older adults may encounter cognitive and social barriers that impact their ability to navigate the online world securely. Therefore, it is important to emphasize the following key competencies for older adults to enhance their online safety [16, 29]:

- Identifying safe websites
- Verifying reliable information
- Recognizing suspicious emails

The 'Cyber Wellbeing' model [28] underscores the importance of mastering password management, social media security, digital footprint management, and digital harassment management [63]. Additionally, [45,54] stress the significance of safeguarding privacy, preventing fraud, and critically evaluating online sources.

These finding highlight the necessity of educational initiatives that equip older adults with practical skills to facilitate secure and reliable digital inclusion. Table 7 outlines the cybersecurity skills for older adults identified in the literature.

Table 7. Cybersecurity digital skills that older adults should possess.

Competence	Description
Evaluation of reliable information	Ability to find and trust reliable sources and verify that information is accurate and from trustworthy places.
Identification of suspicious emails	Skill to recognize fraudulent emails by analyzing grammar and writing, regardless of whether it is a well-known brand.
Cyberbullying management	Ability to identify and appropriately handle online harassment.
Password management	Ability to create and protect passwords securely.
Digital footprint management	Skill to recognize what records and data are managed online.
Privacy protection	Strategies to limit personal information shared on social networks, use pseudonyms, and restrict access to personal data.

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RQ3. What barriers are reported in the literature that hinder the adoption of cybersecurity strategies by older adults?

Among the main barriers identified are stress and anxiety, as many older adults fear "doing something wrong" and prefer to avoid actions related to digital security [20, 35, 50, 56]. In addition, their limited digital social networks represent a challenge, as few older adults have technologically savvy contacts, which reduces opportunities to discuss security and privacy issues [16].

Another significant difficulty is the rapid transition of everyday services to digital platforms, such as online banking, where the lack of time to adapt generates mistrust and anxiety [15, 24,62]. This situation is aggravated by the negative social perception towards older adults, often considered "slow" or "uninterested" in learning new technologies, which limits their access to educational resources and digital opportunities [18,14,22].

Furthermore, the complexity of cybersecurity tasks [47,53], such as frequently changing passwords, and the lack of educational materials tailored to their needs, increase frustration and dependence on third parties to manage their digital security [7,17,19,31,46].

RQ4. How are digital competencies related to cybersecurity evaluated in older adults?

There is limited information in the literature on assessing digital cybersecurity competencies for older adults. Some studies introduce methodologies like the Digital Competence Framework (DigComp) [30], which evaluates skills across five crucial domains: security, communication, content creation, data literacy, and problem-solving. Alternative approaches involve post-workshop questionnaires to gauge knowledge and confidence [32], alongside tools such as the Senior Digital Literacy Evaluation (SDLE) [43], designed to assess computer, internet, and home device usage before and after each workshop.

RQ5. What literacy methods for older adults emphasize digital competencies?

Digital literacy initiatives for older adults should be customized to cater to their cognitive and social requirements. The studies suggest diverse approaches to foster the development of digital skills within this demographic. For instance, the study [6] introduces 'Elderlearn', a digital platform featuring a user-friendly interface and easily accessible content designed to enhance confidence and independence among older adults. Additionally, studies [14,36] propose a three-stage model that guides older adults through the process of technology adoption, introduction, and maintenance, enabling them to acclimate gradually and without pressure.

Other approaches include trial and error [12,57], which allow older adults to experiment on their own and learn from their mistakes. Another approach is the use of physical notes or physical materials they already know [44,48,55,59]. In addition, the use of mobile games [30] makes learning a more entertaining and engaging experience. Implementing educational chatbots such as 'Senior See Net' [34,35] also offers immediate answers to common questions.

Family support plays an important role in aiding older adults in comprehending and utilizing digital tools, considering the trust and reliance they place in family members [9, 13, 37, 39, 41, 51, 61]. Conversely, face-to-face and hybrid workshops [43, 60], along with peer tutoring [52], establish a secure and dependable learning atmosphere where older adults can actively engage, hone their skills, and seek solutions to any uncertainties they encounter.

5 Discussion

The findings show that there are different cybersecurity strategies for older adults, with social support and specialized educational resources being the most effective combination. Furthermore, training community leaders with greater digital knowledge [25] and peer learning [21] strengthen digital inclusion by creating support networks. However, identifying leaders can be a challenge in groups with homogeneous knowledge, where personalized education can be a solution, although it requires greater effort and investment. Although implementing this approach requires more significant effort in designing educational materials and an increase in financial investment, it can overcome initial barriers and offer better results.

A cybersecurity-focused literacy plan designed for older adults should be proactive and empowering [10], ensuring they make safe decisions in the digital environment without fear or feelings of vulnerability. The design of adapted educational materials is also key [53, 60], as general content often includes excessive technical jargon. Board games [30] and close social support from family and friends [21,23,49] are essential to reinforce acquired knowledge, although excessive dependence can limit autonomy and foster codependency, as they perceive that there will always be someone to solve their problems [14, 17].

Dissemination of security information through traditional media (radio, television, print media) [26], widely used in this sector, could be effective, depending on the efforts of institutions and the government. Face-to-face and blended workshops [43,60] that incorporate peer mentoring [44,48,55,59], traditional methods such as note-taking, step-by-step configurations, and trial-and-error strategies [12,57] can improve confidence and autonomy, promoting independence and safety in the use of TIC. In the case of blended workshops [6], digital platforms can include tools such as chatbots [34,35] that promote autonomous learning and digital games designed to reinforce skills. It is important to have methods for measuring cybersecurity skills to gauge the effectiveness of programs, regardless of the teaching method used. This helps to understand the effectiveness of the strategies.

The Senior Digital Literacy Assessment [43] is designed to assess the digital skills of older adults before and after participating in training courses. This instrument not only measures the initial level but also progress at the end of the sessions, which helps evaluate the program's impact. Although it is primarily used in face-to-face and blended workshops, its design could be adapted to include specific cybersecurity skills.

Furthermore, it is beneficial to administer questionnaires at the beginning and end of the programs [32]. These questionnaires clearly demonstrate the effectiveness of the program and allow for the identification of needs for improvement. If these questionnaires are designed with cybersecurity issues in mind, they could make educational strategies more beneficial for older adults.

Furthermore, it is essential to consider what prevents older adults from acquiring cybersecurity skills. Barriers such as stress, anxiety [20,35,50,56], negative social perceptions [18,14,22], and lack of adapted materials [7,17,19,31,46] highlight the need for more inclusive approaches. The findings emphasize that social support is a key factor in cybersecurity education for older adults.

6 Threats to validity

Reliability is a key aspect of any Systematic Literature Review, as highlighted in [1]. It must be maintained consistently throughout the research process, which we have diligently addressed.

To address the selection of relevant papers, we adopted a manual search methodology and set up inclusion and exclusion criteria according to the Quasi-Gold Standard [2]. This approach prevented us from relying solely on studies from a single search engine. Following the identification of primary studies, we expanded our research by including studies through a snowballing process. This method helps mitigate the risk of missing relevant studies and complements our search in instances where access to certain studies is limited. To minimize potential bias in data interpretation and analysis, the study results were reviewed by all authors, in case of dispute we applied a roundtable discussion. Furthermore, to further mitigate bias, we made efforts to align with the Digcom competency framework [30].

7 Conclusions

The aim of this SLR was to emphasize digital literacy strategies customized to address cybersecurity competences for older adults. Our analysis encompassed 57 studies from reputable sources, revealing effective strategies such as peer technical support, community leader training, and intergenerational learning.

A relevant challenge we found is the lack of adapted materials, which limits skill acquisition and tends to foster dependence on family members, rather than promoting digital autonomy. Likewise, we detected that more evaluation instruments need to be developed to measure cybersecurity competencies for older adults.

The analyzed studies predominantly focus on strategies that emphasize the social and community elements over individual instruction. This indicates a need for future research to investigate the enduring effects of these strategies, assessing the depth of knowledge acquisition and its practical application.

As part of our future work, we intend to conduct a field study targeting older adults within our community. Drawing on the insights gained from this study, our objective is to create a tailored digital literacy strategy that addresses cybersecurity competencies. This proposal will be based on the DigComp framework addressing the evaluation of reliable information, and password management.

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Data Analysis Using Artificial Intelligence Techniques: A Case Study in the STEM Methodology and its Impact on Decision Making

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Abstract. In recent years, the implementation of the STEM (Science, Technology, Engineering and Mathematics) methodology has gained significant relevance in global education due to its multidisciplinary approach, which aims to develop practical skills and critical thinking in students. However, although this approach has proven to be beneficial in many contexts, the efficiency of STEM still needs to be analyzed from different perspectives: its effectiveness at various educational levels, its ability to motivate students to learn, and its relationship with outcomes in technical skills and problem-solving abilities. This paper presents an analysis of data collected from an educational intervention where the STEM methodology was applied. Artificial Intelligence (AI) tools were used in the analysis, employing three techniques: simple linear regression, multiple linear regression, and logistic regression. The results showed that the aspects with the greatest impact on the development of meaningful learning when applying the STEM methodology are "course organization", "teaching resources", "suggested bibliography", "preparation time", and "theoretical-practical work". The multiple correlation analysis performed between the model, which includes these five aspects as independent variables and incorporates the level of concept comprehension as the dependent variable, revealed a Pearson correlation coefficient (ρ=0.85). This value indicates a strong positive correlation between the variables, suggesting that the aspects represented by the independent variables have a significant impact on the learning process, specifically on the students' ability to understand the concepts under study. In statistical terms, a correlation coefficient (ρ=0.85) is interpreted as a robust relationship that significantly influences the cognitive performance of the participants.

Keywords: STEM Methodology, Learning Outcomes, Educational Data Analysis, Learning Impact Assessment, AI Techniques, Predictive Analytics.

1 Introduction

In recent years, Artificial Intelligence (AI) has advanced significantly, driven by the development of algorithms and computational tools that facilitate the analysis of large volumes of data and the creation of predictive models. In this context, the Python ecosystem has established itself as one of the most widely used languages for AI research and development due to its simplicity, flexibility and the robustness of its libraries [1]. Among the most notable and widely used tools for the data analysis described in this work are Scikit-learn [2] and SciPy [3], which allow addressing a wide variety of machine learning, data processing and data analysis.

Another of the tools used for this data analysis was Numpy, which focuses on the efficient processing of large matrices and multidimensional arrays and is the cornerstone for high-performance numerical calculations. NumPy provides optimized data structures and advanced mathematical functions that allow working with data quickly and efficiently, which is essential in the implementation of machine learning models and other AI approaches [4]. Data analysis and results presented in this work were carried out from the data collected in an educational intervention where the STEM methodology was applied. The data collection instruments used in the educational intervention were interview formats that evaluated the direct contribution of various elements in the students' learning process, among which the following stand out: methodology, social interaction within the classroom, planning of practices, guidance or orientation in the development of practices, work combining theory and practice, preparation time for each session, resources used in the intervention, proposed bibliography, organization in the intervention, teacher performance and the level of understanding achieved by students on the topics taught in the educational intervention.

Based on the data obtained, the combined use of Scikit-learn and SciPy was implemented in the data analysis, which allowed us not only to build machine learning models [5], but also to address fundamental mathematical and statistical tasks that support these models. This article explores how these two libraries can be used together to solve real data analysis problems, from data cleaning and preprocessing to model interpretation and evaluation. This process is carried out with the purpose of providing accurate and efficient solutions [6].

Chapter 2 presents the state of the art on the approaches and techniques that have been used to analyze the STEM methodology. Chapter 3 describes the data analysis methodology used in this research work. Chapter 4 illustrates the results obtained from using the tools simple linear regression, multiple linear regression and logistic regression, finally Chapter 5 contains a discussion about the results obtained and the final conclusions.

2 State of the art of learning analysis techniques in STEM educational interventions

Over time, STEM methodology has gained increasing relevance in the educational field due to its comprehensive and multidisciplinary approach that fosters critical thinking, problem solving, and creativity among students. Its application in educational interventions seeks not only to improve the learning of technical concepts, but also to develop key skills for the 21st century, such as collaboration, innovation, and adaptability.

The success of applying STEM as a teaching methodology depends largely on an accurate and detailed evaluation of the results obtained, which has led to an increase in the use of data analysis strategies to measure the effectiveness of STEM pedagogical approaches. Through data analysis, educators can gain valuable insights into academic performance, student engagement, and the impact of the methodologies used in their learning process.

This article reviews the main analysis strategies and techniques used to evaluate the results of STEM educational interventions, exploring quantitative and qualitative approaches that allow for a deeper understanding of educational effects. This paper addresses methods such as statistical analysis, network analysis, machine learning, and data mining, which are essential for identifying patterns, predicting future performance, and improving teaching personalization. It also examines the challenges associated with implementing these techniques, including the data preprocessing stage, interpretation of results, and application of findings to adjust and improve pedagogical interventions. One of the most widely used techniques for the evaluation and analysis of results derived from the application of the STEM methodology are Machine learning algorithms, as described in the analysis presented in [7], this study aimed to evaluate and predict factors affecting STEM students' future intention to enroll in chemistry-related courses. Results showed that attitude toward chemistry and perceived behavioral control represent the most influential factors, followed by autonomy and affective behavior. Another case of analysis was applying the Multivariate analysis of variance (MANOVA) technique, this multivariate analysis was used to determine possible differences between male and female math anxiety and math self-efficacy levels. Male engineering students reported higher self-efficacy and lower math anxiety levels, and this difference was shown to be significant according to the MANOVA results [8]. In the research work presented in [9], the technique called Error Analysis (EA) was used in a wide corpus of exercises and essays written by third year students of mechanical engineering, with the main purpose of achieving a precise diagnosis of the students' strengths and weaknesses in writing skills. In the educational intervention described in [10], a Questionnaire developed from the TPB (Theory of Planned Behavior) model was applied, this study analyzed STEM education's effect on students' learning satisfaction. Extending the planned behavior theory, this study aimed to predict high school students' learning satisfaction with STEM education. Attitude is the most important factor influencing student satisfaction and acceptance toward STEM education. There are other works that focus on student satisfaction as described in [11], where it indicates that the National Student Survey (NSS) has become one of the most important metrics to assess student satisfaction that directly influences the university league tables and the Teaching Excellence Framework (TEF). The NSS results and it was concluded that there is strong evidence that "teaching" and "Organization and management" are the vital influential factors on the overall satisfaction of students.

Among the classification algorithms is the Classification algorithm CNN (Convolutional Neural Network). This technique was used in [12]. In this study, automatic assessment methods for piano performances were developed. The results show that the CNN (Convolutional Neural Network) approach is superior to the other approaches (Support Vector Machine (SVM), Naive Bayes (NB) and Long Short-Term Memory (LSTM), with a classification accuracy of more than eighty percent.

Analyses on STEM methodology have not only focused on students, but also on assessment processes as described in [13], where the Display and Evaluate (DE) technique was applied. This technique consists of self-evaluation, group evaluation, and teacher evaluation. Self-evaluation focuses on finding and filling new knowledge and skills in the learning process; group peer assessments can draw on peers' opinions and suggestions to provide a learning atmosphere for mutual learning and improvement; teacher evaluation focuses on process evaluation rather than just result.

Regarding correlation algorithms, the study presented in [14] describes the application of CT (Computational Thinking) assessment, this tool sheds light on the correlation between algorithmic thinking skills and age in early childhood, revealing that age is a predictor factor for algorithmic thinking and, therefore, for CT.

Another of the factors analyzed is the mood and mental health of the teachers. In the study presented in [15], a mixed-method approach (cross-sectional study and a bibliometric analysis) is described, this study analyzes the factors caused anxiety or depression in teachers during pandemic COVID-19 combining a cross-sectional study of university teachers from Ecuador and Spain with a medium of twenty years of working experience and a bibliometric analysis carried out in three databases. The combination of the results indicated that mental health in STEM teachers at universities is related to diverse factors, from training to the family and working balance.

In the review of the literature, various qualitative studies were also found, as illustrated in [16] where they carried out an analysis based on interests, prestige, and sex type, this study investigates career profiles of German university freshmen based on interests, prestige, and sex type. Of note, especially female students in STEM subjects with a low proportion of females distributed widely across the 11 profiles identified. Another qualitative investigation is presented in [17], where an analysis is carried out over the explanations and tasks set out in different science textbooks, findings showed inconsistencies detected in the distribution of volume measurement-related content, as well as in the strategies, units' tools used in the two areas.

Table 1 presents a summary of the studies that have been found in the state of the art on some Techniques for evaluating approaches to STEM methodology such as Machine learning algorithms, Multivariate analysis of variance, Classification algorithm CNN, Error Analysis, Computational Thinking, Mixed-method approach, Correlation analysis and others.

Table 1. Summary of studies.

Assessment	**Data Collection Instrument**	**Target Variable**	**Reference**
Machine learning algorithms	Multivariate analysis of variance (MANOVA)	Students' intention	[7]
AI	Quantitative	Anxiety	[8]
Error Analysis (EA)	Quantitative	Writing skills	[9]
TPB (Theory of Planned Behavior) model	Quantitative	Students' learning satisfaction	[10]
National Student Survey (NSS)	Quantitative	Satisfaction of students	[11]
Classification algorithm CNN (Convolutional Neural Network)	Quantitative	Performance of students	[12]

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Display and Evaluate (DE)	Quantitative (diversified)	Process evaluation	[13]
CT (Computational Thinking) assessment	Mixed-method approach (cross-sectional study and a bibliometric analysis)	Correlation between algorithmic thinking skills and age	[14]
Analysis based on interests, prestige, and sex type	Quantitative and Qualitative	Anxiety or depression in teachers; career profiles	[15]
Analysis over the explanations and tasks in science textbooks	Qualitative	University students	[16]
Analysis over the explanations and tasks in science textbooks	Qualitative	Inconsistencies in science textbooks	[17]

3 Methodology

The data analysis presented in this paper used the data collected from an educational intervention with high school students. The data collection instruments used were interviews and class diaries. The topics covered during this intervention were software development and hardware implementation. The STEM methodology was the teaching methodology applied during the educational intervention. In research papers [18] and [19] the experimental development of this teaching-learning experience is described. The data analysis was developed in three stages: Data preprocessing (stage 1), Linear correlation analysis (stage 2) and Dichotomic analysis (stage 3).

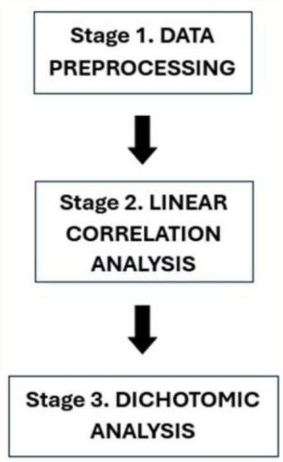

Fig. 1. Stages of data analysis performed.

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3.1 Data preprocessing

In the data preprocessing stage, the following actions were performed on the datasets collected from the educational intervention: Data extraction, imputation of null values, treatment of outliers, conversion of variables and ordinal coding of the independent variables and the dependent variable.

Data extraction. In this process, a database was created that included the column of the target variable (Level Comprehension) and the columns of the independent variables (Methodology, Social Interaction, Planning Practice, Practical Guidance, Theoretical-Practical Work, Preparation Time, Resources, Bibliography, Organization, Performance Teacher).

Imputation of Null Values. This action was performed using the "backward fill" technique.

Outliers Treatment. The variables were expressed in text categories, no outliers were found. Ordinal coding of variables. Coding was necessary to be able to process the numerical algorithms, this was because the data variables were originally of the "string" type. The diagram in Fig. 2 illustrates the actions performed in the data preprocessing stage.

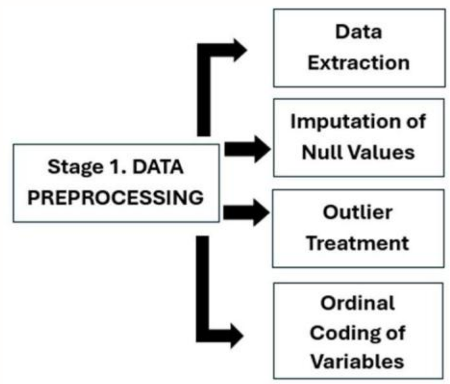

Fig. 2. Preprocessing stage actions.

3.2 Linear correlation analysis

In the linear correlation analysis stage, the following actions were performed on the dataset obtained from the previous stage (preprocessing): Definition of the dependent variable (target) and the independent variables, analysis of simple correlations and identification of the multiple linear regression model with the highest correlation with respect to the target variable.

Definition of variables. In this process, the dependent variable is assigned to a vector ("y") and the independent variables are assigned to a matrix array ("X").

Simple linear correlation analysis. In this action, the matrix of all correlations between the intersections of all numerical variables is obtained and the variables with the highest correlation with the target variable are identified using a heatmap.

Implementation of the multiple regression model. The variables identified in the previous step are used as inputs to the model to predict the target variable. Finally, the model is evaluated with the correlation (ρ) and determination (R2) coefficients obtained. The actions performed in the linear correlation analysis stage are described in Fig. 3.

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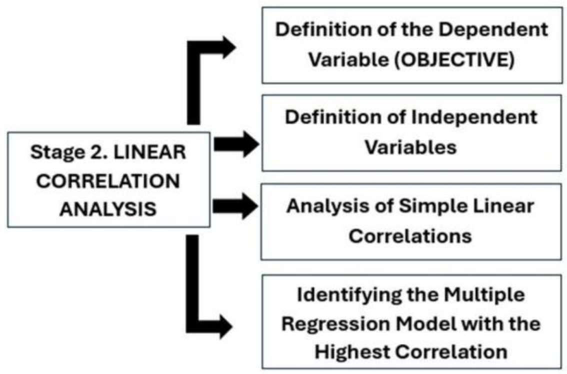

Fig. 3. Description of linear regression analysis.

3.3 Dichotomic analysis

In the dichotomic analysis stage, the following actions were performed with the preprocessed dataset: Adjustment of the test data corpus and the training data corpus, training the model, obtaining the confusion matrix and evaluating the model based on the precision, accuracy and sensitivity metrics.

Adjustment of the corpus. In this process, a percentage of the total data is assigned to the training set, and the remaining percentage of the data is assigned to the test set.

Training the model. In this action, a random state is established to be able to randomly assign the data to the training and test sets.

Obtaining Metrics. In this process, the performance of the model is analyzed based on the confusion matrix and the following metrics can be obtained: precision, accuracy and sensitivity. The actions performed in the dichotomic analysis stage are described in Fig. 4.

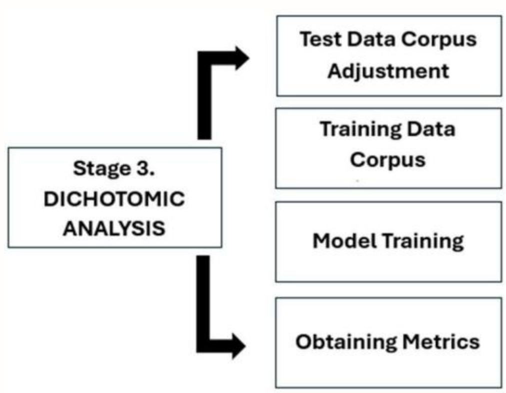

Fig. 4. Description of dichotomic analysis.

4 Results

Results derived from the data analysis are presented below in three sections: results of the simple linear regression analysis, results of the multiple linear regression analysis and results of the dichotomic analysis.

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4.1 Results of the data analysis with simple linear regression

The simple linear regression analysis fits the model with the dependent variable (Level Comprehension) and the independent variables (Methodology, Social Interaction, Planning Practice, Practical Guidance, Theoretical-Practical Work Preparation Time, Resources, Bibliography, Organization and Performance Teacher).

In the first step, Pearson correlation coefficients (ρ) were obtained for all combinations of variables, as illustrated in the heatmap in Fig. 5. In the second step, only the correlations related to the target variable were extracted and ordered from highest to lowest as shown in Table 2, where it can be observed that all independent variables have a correlation greater than ρ=0.67, which indicates that they are in a range of considerable correlation to strong correlation. In addition, the three variables that have the highest correlation with respect to the students' Level Comprehension are "Resources (ρ= 0.796273)", "Bibliography (ρ= 0.793834)" and "Preparation Time (ρ= 0.793679)".

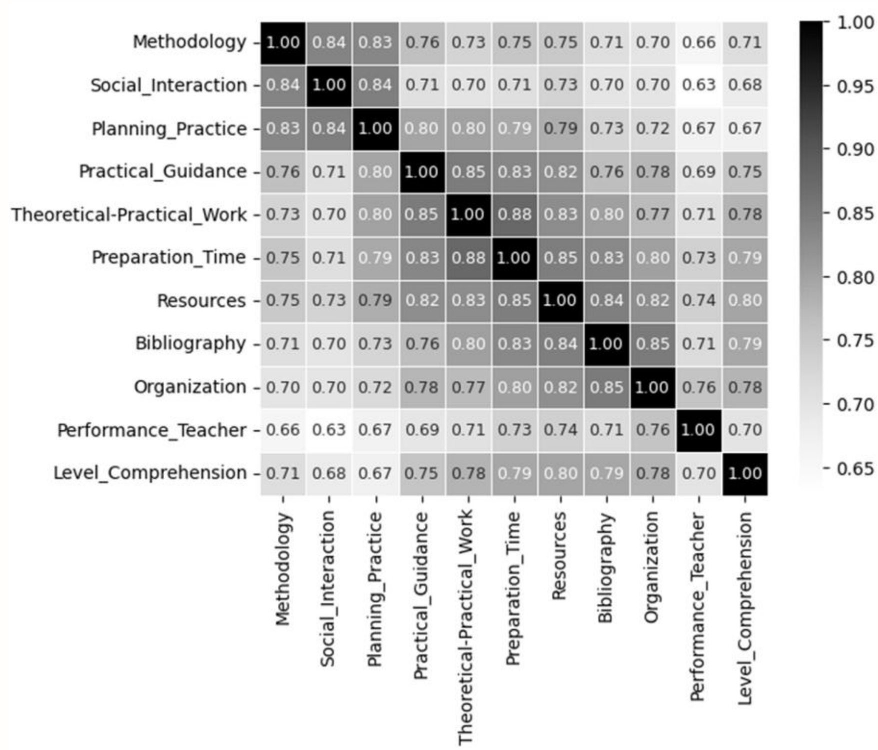

Fig. 5. Heatmap of simple linear correlations.

The graph in Fig. 6 illustrates the original values (blue dots) of the variable "Level Comprehension" compared to the predicted values (red dots) by the model with the highest correlation described in equation 1. The independent variable "Resources" represents the x-axis, while the dependent variable "Level Comprehension" represents the y-axis.

$$y = (0.798)x + 0.402 \quad \textbf{(1)}$$

Where:
y= Level Comprehension Predicted
x= Resources

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Table 2. Correlation table with respect to the target variable (Level Comprehension).

Independent variable	Correlation coefficient (ρ)	Coefficient of determination (R^2)
Resources	0.796273	0.63405
Bibliography	0.793834	0.63017
Preparation Time	0.793679	0.62992
Organization	0.778737	0.60643
Theoretical-Practical Work	0.778311	0.60576
Practical Guidance	0.753706	0.56807
Methodology	0.712076	0.50705
Performance Teacher	0.699197	0.48887
Social Interaction	0.682951	0.46642
Planning Practice	0.671273	0.45060

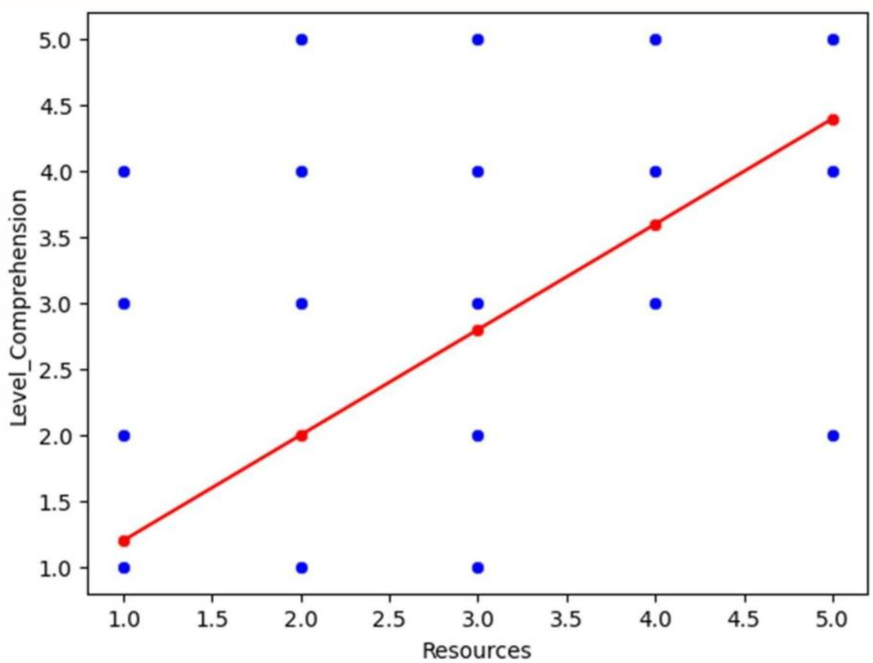

Fig. 6. Original values of level comprehension (blue dots) Predicted values with the simple linear regression model (red dots).

4.2 Results of the data analysis with multiple linear regression

In the multiple linear regression analysis, the 5 independent variables with the highest correlation (Resources, Bibliography, Preparation Time, Organization, TheoreticalPractical Work) with respect to the target variable (Level Comprehension) were chosen to adjust the prediction model.

The correlation obtained with the multiple linear regression model (described in equation 2), was (ρ = 0.8493) and a coefficient of determination of (R2 = 0.7213). The correlation achieved with the multiple regression model was greater than any correlation obtained with the simple linear regression models.

$$y= 0.169x1 + 0.171x2 + 0.193x3 + 0.196x4 + 0.197x5 + 0.158 \quad \textbf{(2)}$$

Where:
y= Level Comprehension Predicted
x_1= Theoretical-Practical Work
x_2= Preparation Time
x_3= Bibliography x_4= Resources x_5= Organization

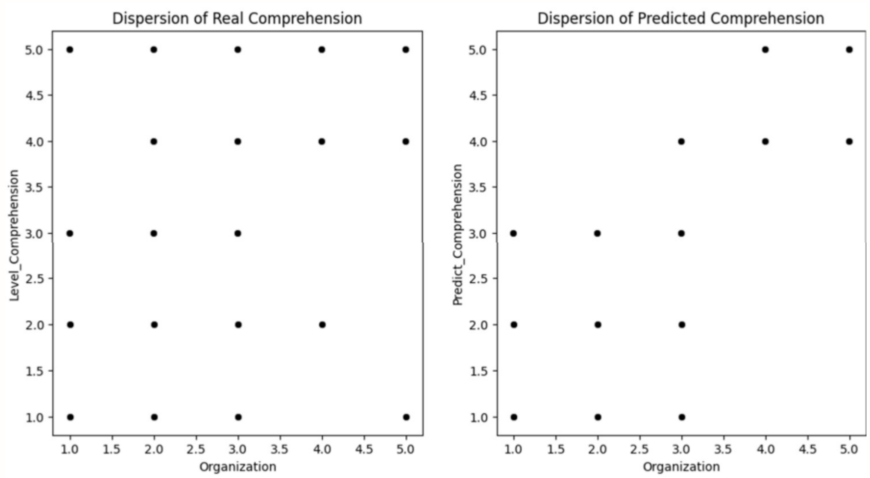

Fig. 7. Original values of level comprehension (left graph) vs Predicted values with the multiple linear regression model (right graph).

4.3 Results of the dichotomic analysis

In the dichotomous analysis, the first action performed was to convert the target variable ("Level of Comprehension") to a dichotomic variable. Before the conversion, the target variable consisted of 5 categories: "Totally agree", "Strongly agree", "Moderately agree", "neither agree nor disagree", and "Totally disagree". When converting the variable to dichotomic type, these 5 categories were grouped into two new categories as follows: 'High Level of Comprehension' ("Totally agree", "Strongly agree" and "Moderately agree") and 'Low Level of Comprehension' ("neither agree nor disagree", and "Totally disagree").

The second action in this analysis was to add the independent variables (Resources, Bibliography, Preparation Time, Organization, Theoretical-Practical Work) to the dichotomic regression model, the representation of these variables was of numerical type. The third action performed in this analysis was to adjust the size of the test corpus (30%) and the training corpus (70%) with respect to the total data. The independent variables were scaled so that their maximum and minimum values coincided.

The fourth action carried out was to train the model and calculate its performance metrics from the confusion matrix which is shown in Fig. 8.

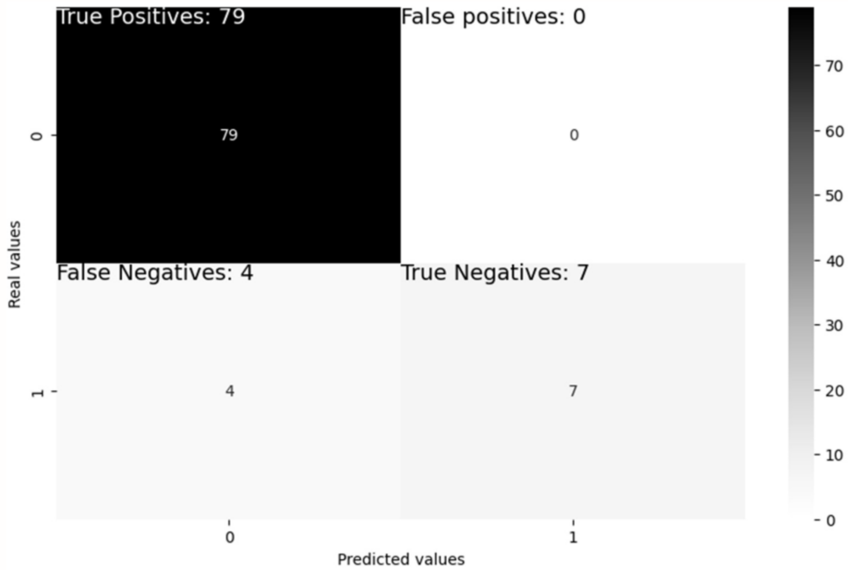

Fig. 8. Confusion matrix obtained from the dichotomic regression model.

In the confusion matrix description, true positives correspond to correct predictions made on the 'High Level of Comprehension' label, while true negatives correspond to correct predictions made on the 'Low Level of Comprehension' label.

Table 3 presents the performance metrics of the dichotomic regression model: precision, accuracy and sensitivity.

Table 3. Correlation table with respect to the target variable (Level Comprehension).

Metric	Label ("High Level of Comprehension")	Label ("Low Level of Comprehension")
Precision	0.97619	0.83333
Accuracy	0.96666	0.96666
Sensitivity	0.98795	0.71428

5 Conclusions

The development of this research showed various behaviors of the variables involved with the level of comprehension of the students. One of the findings showed that all the independent variables have a considerable or strong correlation with the dependent variable "Level Comprehension". This is reflected in the fact that all the correlations are greater than $\rho = 0.67$.

The three variables with the highest correlation with the level of comprehension of the students are Resources ($\rho = 0.796273$), Bibliography ($\rho = 0.793834$) and Preparation Time ($\rho = 0.793679$), which indicates that these are key factors to predict the level of comprehension.

When using the multiple linear regression with the five independent variables with the highest correlation (Resources, Bibliography, Preparation Time, Organization, Theoretical-Practical Work), the correlation obtained was $\rho = 0.8493$ and also a coefficient of determination $R^2 = 0.7213$.

This multiple model has a better predictive capacity than simple linear regression models, suggesting that these variables together provide a significant explanation for the variability in the level of comprehension.

In the dichotomic regression analysis, the confusion matrix showed that true positives (TP) correspond to correct predictions in the "High Level of Comprehension" category, while true negatives (TN) correspond to correct predictions in the "Low Level of Comprehension" category. This is crucial to assess the accuracy of the binary classification model.

The Resources, Bibliography, and Preparation Time variables are the ones that most influence the students' level of comprehension, which can guide future decisions on which aspects should be optimized to improve academic performance.

Also, the results indicate that the type of methodology (for this case study, the STEM methodology was applied) used in the educational intervention has a correlation of (ρ= 0.71) with respect to the target variable ("Level Comprehension"), which suggests that the two variables are strongly related. A correlation of (ρ= 0.71) indicates that there is a moderate to strong positive relationship between two variables. In addition, it can be deduced that all the variables selected as independent variables have a strong relationship with the level of comprehension of the students about the topics of STEM areas.

6 Future work

The work currently being carried out in the experimental area is based on an educational intervention applying the STEM methodology. The main topic is the development of IoT devices applying AI techniques to analyze and classify data obtained through commands. This information can be of great help in determining patterns of behavior regarding various physical and mental disorders. The results obtained from this work will be published as a continuation of the work presented in this paper.

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Design and Implementation of a Virtual Reality Videogame for Stress Regulation

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Abstract. Chronic stress represents a significant challenge to both mental and physical health, manifesting through physiological and psychological responses. The negative effects of prolonged stress require effective interventions. In this context, Virtual Reality (VR) video games emerge as a promising tool to mitigate these negative impacts. By utilizing immersive and controlled virtual environments, these video games not only provide entertainment but also offer stress management techniques. This research explores how virtual reality can provide a unique approach to stress relief through visually pleasant environments and specific game mechanics. This study proposes the design and development of a new virtual reality video game, using the Design and Creation methodology, which incorporates the "Preserve and Destroy" mechanic to encourage reflection and emotional management. This approach not only helps users handle negative thoughts but also promotes the retention of positive ones, thus contributing to improved emotional well-being. Previous studies suggest that this type of approach could have a significant impact on stress reduction, justifying further research in this field.

Keywords: Stress, Virtual Reality, Video Games, Immersive Experience, HCI.

1 Introduction

Stress is a natural physiological and psychological response of the body to situations perceived as threatening or challenging, releasing hormones such as cortisol and adrenaline. If stress becomes chronic, it can trigger negative effects on physical and mental health, including cardiovascular problems, exhaustion, and anxiety [1]. Anxiety, in turn, is the body's response to continuous stress, creating a cycle where stress fuels anxiety and vice versa, which can lead to more severe issues such as depression and other mental disorders [2].

While chronic stress can have significant detrimental effects on our health, technological innovations offer new solutions to mitigate these impacts. Among these solutions, virtual reality video games emerge as a promising option. By leveraging virtual reality's ability to create immersive and controlled environments, it is possible to design experiences or video games that not only entertain but also help users manage and reduce their stress levels [3]. This application of technology, initially developed in the 1960s and now finding applications across multiple fields, is positioning itself as a potential therapeutic tool to address the consequences of stress in modern life [4]. Virtual reality offers a range of interesting features, with immersion, presence, and interactivity standing out as key aspects that help users feel truly part of their surroundings. Some relevant works in the field present advancements in the application of this technology, for example:

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Fig. 1. Player's Field of View when entering thoughts and the same perspective in real life.

In 2016, the "Aerospace Medical Association" published a study that utilized virtual reality to train military personnel in stress management. For this, soldiers were exposed to high-stress situations to improve their response to such conditions. The results demonstrated that, thanks to VR experiences, soldiers learned coping techniques to manage stress in these situations [5].

In 2017, at a computing conference organized by the Institute of Electrical and Electronics Engineers (IEEE), a study was published that used virtual reality headsets, specifically the Oculus Rift, to manage stress in a workplace environment. The research involved immersing employees in two different modes: the first was designed purely for relaxation, placing them in calming and peaceful environments, while the second mode transferred part of their work to a more relaxing virtual space. The results were highly positive, as participants enjoyed the experience, felt more relaxed after using the application, and responded favorably to the idea of using virtual reality for workplace relaxation [6].

With these advancements, as can be seen, video games and virtual reality can be a great combination for mitigating stress. On the other hand, at the interactive industry level, there are some examples:

- "Alcove": This is a game available on the Oculus Store that allows players to explore different worlds, play casual games, and connect with friends through portals. This video game is described as a content platform with the mission of bringing families together and providing them with various experiences within the virtual reality ecosystem. This project aims to help people relax by allowing them to experience peaceful and enjoyable moments [7].
- "Fujii": This is a game on Steam that offers players a colorful and relaxing experience, where they explore a variety of beautiful landscapes while solving small puzzles. It is a very simple experience, featuring puzzles, relaxing music, and vibrant colors that create a sense of tranquility [8].
- "Beat Saber": This is a Steam game where players must slash cubes with lightsabers to the rhythm of the music. This game encourages people to exercise in a rhythmic and engaging way. This immersive experience requires users to focus on slicing the colored cubes with the corresponding lightsaber while considering the cube's orientation and avoiding obstacles that appear throughout the game [9].
- "Journey": This is an adventure and exploration video game in which players follow a nameless character on a journey through visually stunning and serene environments. It is an emotional experience designed to evoke various feelings in players through its landscapes, music, and gameplay. This game is available on the Steam platform [10].
- "Abzu": This is a game for the Nintendo Switch that provides players with a visually enriching experience. Thanks to its guided narrative, it offers a calm and satisfying gameplay experience [11].

A shared aspect of the aforementioned video games is the pursuit of providing relaxing and positive experiences through visually pleasing environments and gameplay mechanics aimed at reducing stress. However, they differ

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in their unique approaches, which may include exploration, puzzle-solving, musical rhythm, or storytelling. With this in mind, we can say that these games offer a way to relieve stress, but in diverse ways, making each one a unique experience.

Taking into consideration the aspects presented, in this exploratory study, we propose the design and development of a virtual reality video game specifically created to help users manage and reduce their stress levels. First, considering that the "Keep and Destroy" mechanic is based on the theory of cognitive restructuring [14], which suggests that modifying the way we interact with our thoughts can reduce their emotional impact; and second, the mechanics implemented by the popular virtual reality game "Beat Saber." In this game, players use two lightsabers to cut blocks to the rhythm of the music, combining elements of rhythm and action.

Applying these concepts in a virtual reality environment offers the possibility that, through this immersive medium, users may benefit, as these devices provide greater focus capacity and positive effects on the user, resulting from a positive experience.

The present work is structured as follows: in the Methodology section, the approach and methods used in this research will be described. Following this, the development process that led to the final product will be detailed. Finally, the study will conclude with a summary of the findings and a discussion on possible future work.

2 Methodology

The research and development methodology used in this work is Design and Creation [13] [17]. This methodology consists of five phases:

1. Awareness: This is the initial phase of the methodology, where the problem or need that this research aims to address is identified and understood.
2. Suggestion: Tentative ideas are generated to address the problem identified in the previous stage. Different solutions and approaches are proposed, such as creating an application that meets the identified need.
3. Development: This phase involves developing the previously mentioned idea. A proposal was designed based on the mechanics of the "Beat Saber"-style video game, aimed at relieving stress in young adults. Along with certain parameters, it seeks to measure stress levels before and after gameplay.
4. Evaluation: In this phase, the aforementioned parameters, along with surveys conducted by players, allow us to analyze and explain the obtained results.
5. Conclusion: This phase explains the overall outcome derived from all the evaluations conducted in the previous steps.

Steps 1, 2, and 3 are detailed in this section, while Steps 4 and 5 are addressed separately in their own sections.

2.1 Awareness

Positive and negative thoughts represent ideas, beliefs, or emotions that influence a person's emotional and mental state. Positive thoughts are usually associated with pleasant emotions, optimism, and well-being, while negative thoughts can generate anxiety, stress, or sadness. The Preserve and Break methodology proposes physical interaction with these thoughts, allowing individuals to symbolically preserve the positive ones and break the negative ones. This physical action toward thoughts aims to influence individuals positively, promoting reflection, emotional management, and stress reduction through a tangible and symbolic experience.

From a psychological perspective, the game's mechanics are aligned with techniques used in cognitive-behavioral therapy, where the externalization of negative thoughts helps reduce their emotional burden. Interaction in VR enables a tangible simulation of this process, which may enhance its effectiveness compared to traditional techniques.

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On the other hand, each game is a unique user experience, as players must input thoughts that are relevant exclusively to them. Therefore, the mechanics are inherently personal and unique for each user.

The "Preserve and Break" methodology not only facilitates tangible interaction with thoughts but also aligns with psychological theories that emphasize the importance of cognitive restructuring in therapy. Cognitive therapy posits that modifying dysfunctional thoughts can lead to changes in emotions and behaviors, resulting in an overall improvement in well-being [14]. By applying this technique, individuals may experience a process similar to that described in exposure therapy, where confronting and actively managing negative thoughts reduces their emotional impact [15].

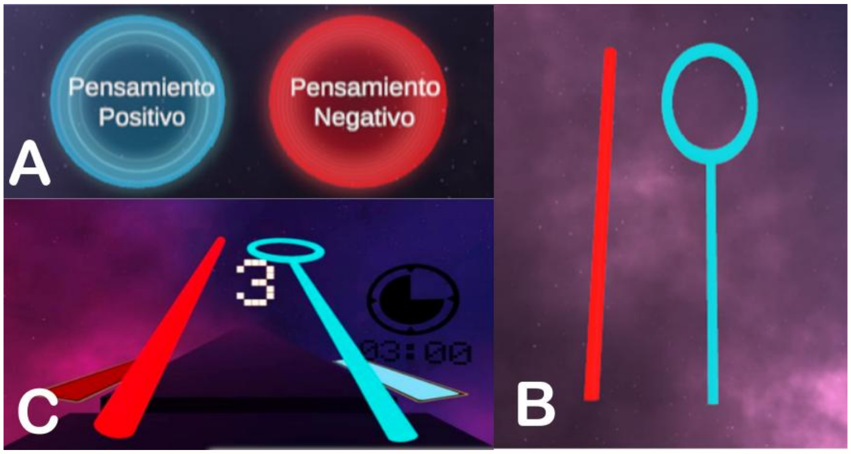

Fig. 2. 3D models for positive and negative thoughts. When interacting with the player's saber or net, they generate a particle system. Design of 3D models for the saber and net that the player will use to interact with thoughts. Player's point of view or Field of View (FOV) at the beginning of the game.

Moreover, recent studies have shown that physical interaction with objects representing negative or positive thoughts can enhance the effectiveness of cognitive restructuring, making the process more concrete and memorable for the individual [16]. Therefore, the "Preserve and Break" methodology not only provides an innovative approach to emotional management but is also grounded in established psychological principles that support its effectiveness in stress reduction and the promotion of a healthier mental state.

2.2 Suggestion

The most important factor to consider is the "Keep and Destroy" strategy, as it must be adapted to a virtual reality experience. The first step in this process was understanding how it functions, given that it involves working with people's thoughts. Therefore, a game similar to "Beat Saber" was proposed, where instead of destroying red and blue cubes, players would interact with their thoughts in a similar manner to the game.

Figure 2 shows a sketch of the initial idea for the video game, where positive and negative thoughts, represented by blue and red colors, move toward the player.

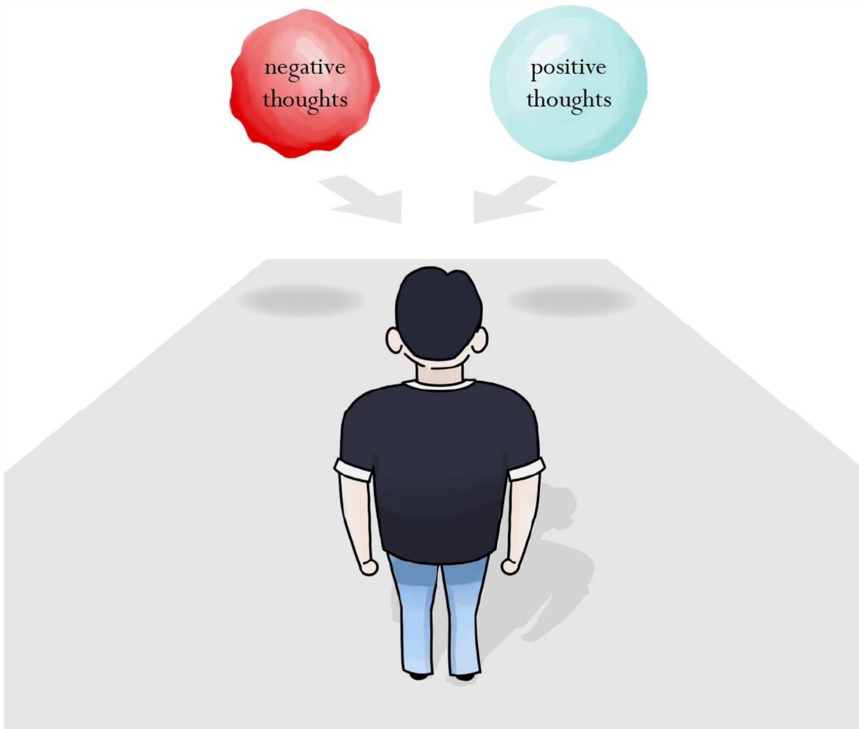

Fig. 3. Sketch of the initial idea of the video game.

Apart from considering the strategy, the initial analysis revealed other factors to take into account. Since the application is designed to mitigate stress, careful attention must be given to selecting colors, typography, degrees of freedom within the application, music, and game speed. Previously, stress-relief-oriented video games were detailed, and one common factor among them was their calm and peaceful environments. With this in mind, the idea of creating a setting that generates a sense of tranquility for the player was established.

With this objective and through expert judgment, key functionalities and design aspects were outlined to prioritize: 1) avoiding virtual reality sickness, and 2) a simple graphical user interface (GUI) to ensure a positive user experience. In this context, two relevant use cases are presented: the first describes the player's interaction with the graphical user interface, while the second addresses the general game mechanics and the user's full interaction with the system.

2.3 Development

In the development of the video game "Keep and Destroy," created in Unity 2021.3.40f1, game mechanics were designed based on the "Preserve and Break" methodology, where players interact with positive and negative thoughts using colored sabers to either preserve or destroy them. However, before entering this scene, players must input their thoughts. At the beginning of the experience, they are required to enter four positive and four negative thoughts through a simple interface. The interface features a text box where players input their thoughts using a virtual keyboard. Additionally, users specify the intensity of each thought by adjusting a slider, which evaluates its level of complexity or positivity (see Figure 3).

To differentiate the thoughts within the scene, two distinct 3D models were designed to represent them, distinguishing positive and negative thoughts through different colors and shapes (see Figure 3-A).

To provide a GUI consistent with the core mechanic, a saber and a net were created for players to interact with the thoughts. The saber is designed to destroy negative thoughts and is represented in red to indicate its

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function of interacting with the negative thoughts of the same color. On the other hand, the light blue net is intended to preserve positive thoughts. Its light blue tone is meant to suggest to the player that this object is associated with positive thoughts, encouraging interaction with them (see Figure 3-B).

Finally, the game environment was developed, consisting of a long, horizontal track where thoughts appear randomly, requiring the player to interact with them. Additionally, functionalities were implemented to store and organize the information generated during gameplay.

To enhance player feedback, timers were incorporated: one to count down to the start of the game and another to indicate the remaining time. Furthermore, on both sides of the player, two progress bars are displayed, which fill up as the player correctly interacts with the thoughts (see Figure 3-C, 4).

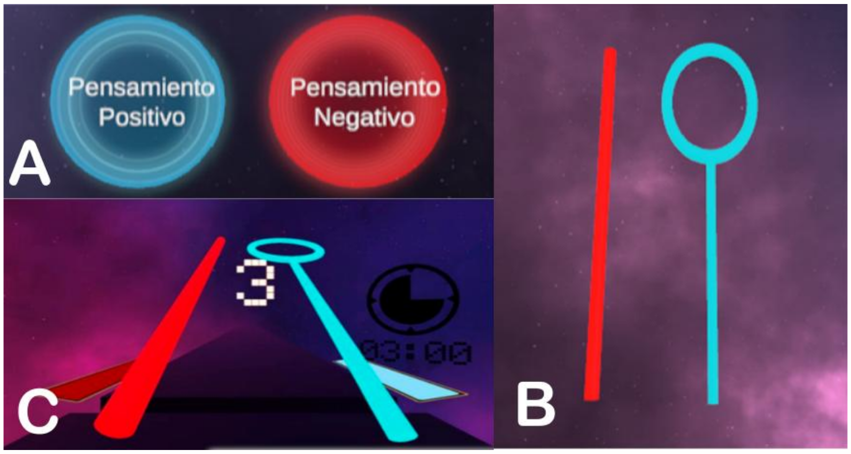

Fig. 4. 3D models for positive and negative thoughts. When interacting with the player's saber or net, they generate a particle system. Design of 3D models for the saber and net that the player will use to interact with thoughts. Player's point of view or Field of View (FOV) at the beginning of the game.

3 Results

This study presents two key results: 1) the development of a virtual reality software described in the previous subsections, and 2) an exploratory study with users.

In Figure 4, the final product representation is shown, along with a video detailing the gameplay functionalities.

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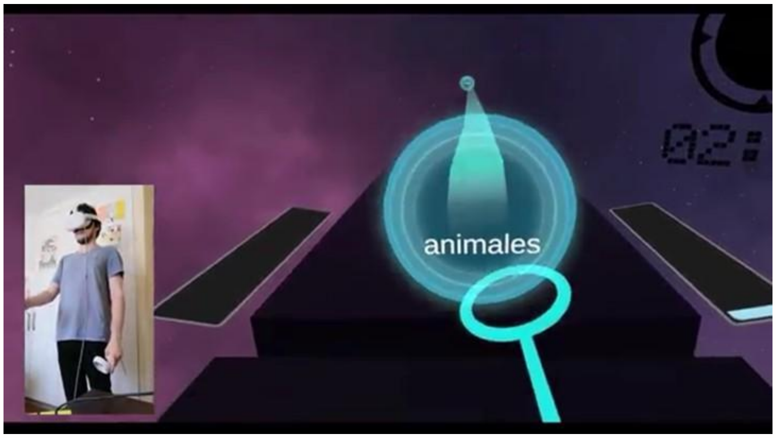

Fig. 5. Sample of the two perspectives: the player and the player testing the experience. To watch the full video: https://youtu.be/KTOjPNf 0so

3.1 Exploratory user study

To assess the impact of the video game on stress regulation, an exploratory study was conducted with 22 university students (16 men, 6 women, average age: 21.8 years).

- Measurement instrument: The State Anxiety Questionnaire (STAI) [18] was used. In this study, the "State Anxiety" subscale was employed, which measures anxiety as a transient state induced by specific situations. The scale consists of 20 items evaluated on a scale from 0 to 3, where higher scores indicate greater levels of anxiety. To obtain the total STAI score, the responses of the 20 items were summed, after reversing the scores of inversely formulated items. The total score ranges from 20 to 60, where higher values reflect greater levels of anxiety at the time of measurement. Participants completed the scale in digital format before and after the VR experience. The data were processed and analyzed using a paired-sample t-test to determine whether there was a significant reduction in anxiety levels after interacting with the video game.
- Procedure: The study was conducted in a controlled environment to avoid external factors that could influence participants' anxiety levels. Oculus Quest 2 virtual reality headsets were provided, and the purpose of the experiment as well as the video game mechanics were explained. First, participants completed an initial anxiety measurement using the STAI instrument. Then, they interacted with the video game for 3 minutes, experiencing the "Save and Break" mechanics in an immersive environment. Finally, they were asked to complete.

Table 1. Paired Sample Statistics Table.

Type	Mean	N	Std. Deviation	Std. Error Mean
Pre	30.18	22	4.043	.862
Pos	18.73	22	5.505	1.174

The results indicate a significant reduction in anxiety levels after the virtual reality experience. For the pre-game group, the STAI mean was 30.18 with a standard deviation of 4.043. Subsequently, after the virtual reality experience, the mean decreased to 18.73 with a standard deviation of 5.505. A paired-sample t-test was conducted, which showed a statistically significant difference, obtaining a p value $< .001$.

These findings suggest that the video game has potential as a tool for mitigating stress. However, further studies with a control group and a larger sample are recommended to confirm these effects.

4 Conclusions and future work

Following the Design and Creation methodology, a software for Oculus Quest 2 running at 60 fps was successfully developed, allowing users to effectively experience the Save and Break mechanic. This software provides users with the opportunity to interact with positive and negative thoughts, symbolically allowing them to save the positive ones and break the negative ones using the joysticks. The implementation of the mechanic was carried out successfully, enabling users to tangibly experience the proposed dynamics for emotional management and stress reduction.

In this regard, the function of the Save and Break methodology within the software worked correctly, allowing the collection of metrics both inside and outside the game. Initial exploratory results show that interaction with positive and negative thoughts was performed effectively, giving users the opportunity to reflect on their emotions and practice emotional management in a symbolic and immersive way. Through this dynamic, the aim is to provide users with a meaningful experience that allows them to explore and work with their thoughts in an interactive and stimulating manner.

While the initial results are promising, future work should include a larger sample and consider additional variables, such as external factors, long-term impact, and comparisons with other stress management methods.

As part of future work, the plan is to advance in the integration of more elaborate visual effects, additional 3D models, and the implementation of more refined interfaces in the program design to enhance the user experience. The goal is to measure presence, immersion, and engagement and analyze the relationship of these variables with the final results.

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Designing a Math App with UCD for Students with Down Syndrome

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Abstract. People with Down syndrome face difficulties in mathematical learning due to slower cognitive processing and problems in working memory. To address this problem, a mobile application based on Cuisenaire's power strips was designed, with counting, addition and subtraction exercises. Therefore, in order to generate an application that is appropriate to the context of a person with DS, we followed a user-centric approach, ensuring accessibility and intuitiveness. A group of students from a Down Institute in a city of Mexico participated providing feedback along the whole process of development. As a pedagogical guide, the institute's teachers were consulted to define the scope of the operations, which was determined as basic for adding, subtracting, and counting without reaching tens. Its effectiveness was evaluated by means of a pre and post-test. As a result, it was possible to verify that the institute's students could correctly manipulate the different sections of the application and in general they felt committed to use it. It is important to point out that the DS is very personal, therefore, in this research we do not pretend to analyze the learning as a personal objective in the students, but to make students feel comfortable and engaged with the app. However, the results let us know that the application presents great potential to work with this population since in some cases a significant improvement could be observed.

Keywords: Maths, Down Syndrome, Mobile application, User Centered Design, Cuisenaire rods.

1 Introduction

Mathematics is essential in society, as it is present in everyday activities such as counting money or calculating distances. According to [4], technological innovation depends on the support of mathematics and its methods, which positions it as a key discipline in curricular training. However, learning it represents a challenge for people with disabilities, such as Down Syndrome, due to different actors that make it difficult to acquire it [9].

Various studies highlight how technology can mitigate these barriers through innovative educational strategies. For example, the use of manipulative materials [3], and problems based on everyday situations [9] has been shown to be effective.

This work details the design and implementation of a mobile application whose objective is to help people with Down Syndrome to understand fundamental mathematical concepts, such as counting, addition and subtraction, promoting their inclusion and learning, but having as a primary goal to produce a usable application contextualized to their particular needs of them.

1.1 Background

The rapid adoption of information and communication technologies has placed accessibility at the center of the debate. According to the Web Accessibility Initiative (WAI), accessibility ensures that all people, including those with disabilities, can use digital technologies to perceive, understand, and interact on the web. This promotes digital inclusion and equal opportunities, making technology a key resource for social integration.

The Convention on the Rights of Persons with Disabilities highlights the importance of developing accessible technologies that enable all members of society to participate fully. Information and Communication Technology (ICT) designed with accessibility can remove barriers and create inclusive environments. From a technological perspective, accessibility not only improves interaction, but also optimizes communicability, a concept that [7], measures the quality of the message transmitted through the interface, guaranteeing clarity and functionality for all users.

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Intellectual disability, recognized in the International Classification of Functioning (ICF), represents one of the greatest challenges for inclusion among its main causes is Down Syndrome, a genetic condition caused by trisomy of chromosome 21, with an incidence of approximately 1 in 800,000 births [10]. People with this condition face specific challenges in areas such as attention and problem-solving, which affects their academic performance, especially in mathematics. These difficulties limit their independence in everyday activities such as handling money [9]. To address these challenges, it is recommended to introduce logical-mathematical concepts from an early age, linking them with everyday experiences that facilitate the transfer of knowledge to the real environment [9].

In this context, the Belgian teacher George Cuisenaire designed a series of strips which had different sizes and colors, and that each one was related to a number from 1 to 10, see **Fig. 1.** In that way the strips took their last name Cuisenaire's strips. Therefore, such strips have proven to be an effective pedagogical resource for teaching mathematics through the manipulation of tangible materials. These tools allow us to understand abstract concepts through constructivist exploration and learning, empowering students as the protagonists of their learning [3].

On the other hand, the use of ICT in education expands the possibilities of inclusion, allowing learning to be personalized. Research such as [6] and [13] highlights that mobile applications, interactive simulators and accessible platforms facilitate teaching to people with special educational needs. Some of the most relevant proposals are: SynMax[12], a computer app that teaches basic numerical skills like number identification, relationships between numbers and counting; MathDS [1], a mobile application for children with learning disabilities to learn the numbers from one to ten; CETA [8], augmented reality system that uses wooden blocks that represent the length of each number and with which operations can be performed in a workspace that is processed through computer vision techniques. These tools combine multimedia elements, interactivity and adaptability, promoting the understanding and learning of abstract concepts.

Therefore, accessible Information and Communication Technology (ICT) represent an opportunity to transform educational environments into more inclusive spaces, helping students to develop their full potential and overcome learning barriers. For this, the present research combines the use of tangible materials, brought to a non-tangible environment (mobile application), which is attractive and interactive for students with Down syndrome.

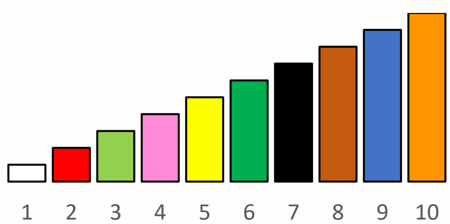

Fig. 1. Visually representation de numbers by color in Cuisenaire's strips.

1.2 Problem statement

People with Down Syndrome face significant challenges in learning mathematics due to deficits in memory, attention, and sensory processing [9]. These difficulties affect the acquisition of basic concepts such as counting and operations, which are essential for their social and personal integration [1]. In addition, they present problems in transferring knowledge to different contexts, which limits the effectiveness of traditional pedagogical strategies [9].

Technology offers opportunities to personalize learning, but faces barriers such as lack of accessibility and UCD [6]. Therefore, it is crucial to create accessible, interactive and adapted tools that promote knowledge transfer and respond to their specific needs. This requires an inclusive approach that combines technical and pedagogical accessibility to ensure its effectiveness and promote social inclusion [14].

2 Application Development and Deployment

Taking as motivation the problem raised in the previous section, the design and development of the application is proposed following a design philosophy called User-Centered Design (UCD) [15]. This methodology has four stages, briefly described below:

- **Understand the Context of Use**: Focusing on identifying the intended users, their goals, the tasks they need to perform, and the environment in which they will use the product or service. Usually, surveys and interviews are required.
- **Specify User Requirements:** Involves clearly defining the needs of the users. As artefacts, user stories or uses cases are generally used.
- **Design Solutions**: In this stage potential solutions are created based on requirements. As a result, prototypes (from low to high fidelity) allow explore alternatives.
- **Evaluate Designs**: Lastly, designs and prototypes are evaluated by representative users to gather feedback and identify usability issues.

In **Fig. 2.** a graphical representation of the relation between stage is shown.

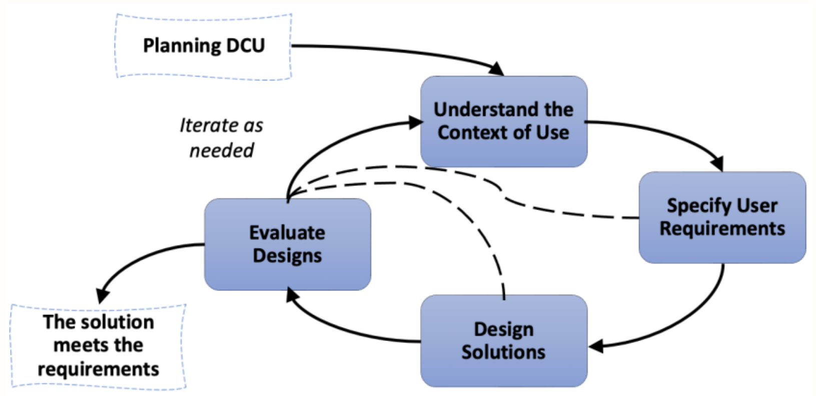

Fig. 2. Stages for the User-Centered Design.

2.1 Understand the Context of Use.

A first approach was made with a Down Institute in a city of Mexico in which the objectives to be carried out were presented. Later, a first activity was planned in which the students were asked to draw a picture about what they like to do most on their cell phone, see **Fig. 3.**

Fig. 3. A first approach with students from the Down Institute.

In order to demographically characterize the institute participants, a summary of them is presented in **Table 1**.

Table 1. General information about students.

Id	Gender	Age	Finish the testing phase
A01	M	33	Yes
A02	M	27	No
A03	M	41	No
A04	F	22	No
A05	M	37	Yes
A06	F	26	Yes
A07	F	19	Yes

As a result, it was possible to define as artifacts of the HCI, a UX Persona which is shown in **Fig. 4.**

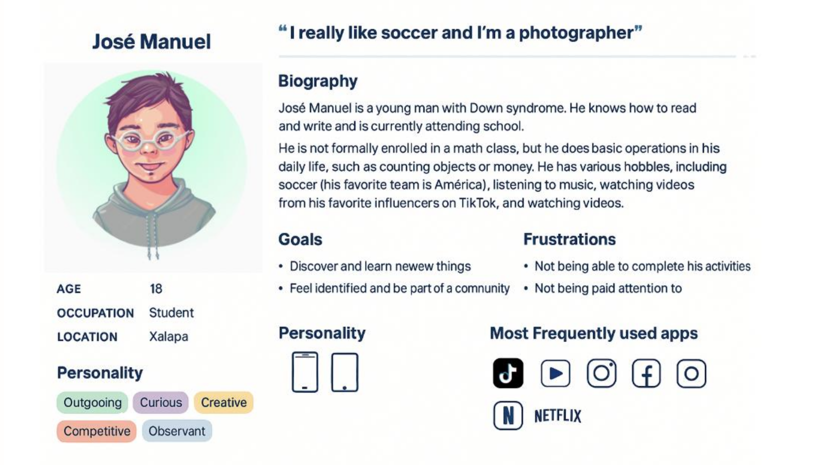

Fig. 4. UX persona considering the interviews con the users.

2.2 Specify User Requirements

In order to have more clarity regarding the needs of the students, a meeting was held with the teachers of the institute, who shared their experiences and pedagogical concerns, of which the following requirements were identified:

1. Use Cuisenaire's power strips as the main resource for teaching mathematical concepts.
2. Incorporate interactive lessons and activities.
3. Apply reinforcement exercises and group them by difficulty.
4. Start with the basic units and operations.
5. Include clues with which the student can be guided when consulting a lesson or exercise.
6. Add interaction to graphic elements such as images or instructions.
7. Avoid ambiguity in exercise instructions.
8. Highlight interactive elements in the interface.

This made possible to define the following functional and non-functional requirements:

Functional requirements.

- **RF001:** The application must incorporate a login and registration screen.
- **RF002:** include a welcome screen that includes an introductory video about the context of the application.

- **RF003:** Group learning units, lessons, and exercises by difficulty levels and make them unlockable as you progress through the application.
- **RF004:** the application must show the exercises on a screen, the content of which will be different, but the following sections will be highlighted:
    - Instruction.
    - Graphic element.
    - List of options available in response.
    - Clues to solve the exercise.
    - Navigation buttons.
- **RF005:** The application will provide feedback through a modal screen, which will be displayed when solving exercises and lessons.

Non-functional requirements

- **RNF001:** Have clear and concise instructions.
- **RNF002:** Graphics elements will be appropriately sized on screen.
- **RNF003:** Use of resources such as vibration or sounds to give feedback to the user in different actions such as solving exercises or consulting lessons.

2.3 Design solutions.

In this stage, the necessary requirements were already in place to start the development of the application, but first we decided to make a paper prototype and applied the Wizard of Oz technique in order to validate the ideas and concepts before to implement it. **Fig. 5.** shows the preliminary prototype in paper. Here, the contents were grouped by: 1) Modules ordered by difficulty, starting with the basic units. 2) Lessons and exercises. 3) Lesson details. 4) Detail of the exercise.

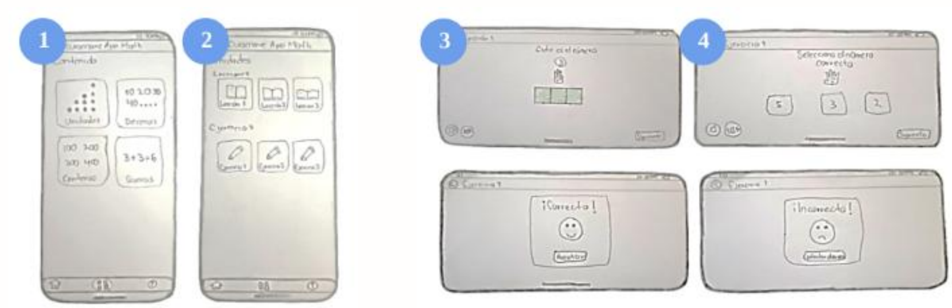

Fig. 5. Paper prototype.

Functional prototype.
Subsequently, the implementation of a first version of the prototype of the application began, for which the following technologies were used:

- *Ionic Framework:* for developing hybrid applications.
- *Angular:* to create web applications and define the structure of the project.
- *HTML, CSS, Typescript.*
- *Capacitor:* library for manipulating native elements on mobile devices.
- *Firebase:* Google*'s platform* for storing user information and multimedia content in the application.

The results of such implementation are shown in **Fig. 6.**

Fig. 6. Application deployment.

2.4 Evaluate designs

A set of tasks were defined, which were evaluated with students from a Down Institute, a total of six, of the seven initial students participated, where the tasks to be evaluated were three types: app installation, access (considering registration and authentication), general interaction. In **Table 2**, we presented the results of observing the execution of the tasks.

Table 2. Tasks definition and observation for evaluating designs solution.

Task	Observations
Installation of app	Most users carried out this process without problem, however, it was a bit tedious since at this time the application was not yet available on a platform such as *Google Playstore*
Registration and authentication	We identify that it was necessary to modify the form of access since most users had problems when they were asked for an email and password.
Interaction with graphic elements	Most of the following observations were focused here: Larger size in texts. Add interaction in images and graphic elements, since most users touched these elements with the intention that they would trigger an action. Include contrasting colors in button text. Add navigation buttons on the screens so that there is no problem returning to a previous section.

It is important to mention that these observations were detected during the first iteration of the DCU, in total three iterations were made and the observations that continued to be presented were those in the graphic elements: such as size of texts and images.

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For the last iteration these were resolved. Finally, we decide to test the skills of the students, for this purpose we defined a new evaluation methodology, which go beyond UCD because its purpose it to evaluate the effectiveness of the application to understanding mathematical concepts. The following section is dedicated to this purpose.

3 Evaluation methodology

To carry out an evaluation process corresponding comprehension of mathematical concepts with students with Down Syndrome, an experimental study was proposed. It was based on five stage methodology, where a set of activities were carried out, see as a reference the **Fig. 7.**, and in later sections each one is described.

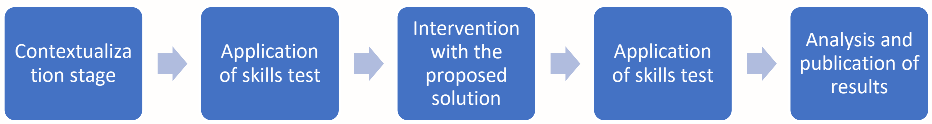

Fig. 7. Stages of the experimental evaluation.

3.1 Contextualization stage

First approach of the students with the Cuisenaire strips, four sessions were planned in which the students had the strips, identified them by color, added and subtracted. At this stage, the following observations were identified:

- Two students are able to count on their own, from 1 to 10, the rest do, but up to a certain number.
- The colors of each strip are identified, however, it was observed that sometimes it was necessary to pay close attention and look at it closely.
- Only two students were able to make the additions on their own, the rest needed a very detailed explanation for them to achieve it, but even so the difficulties prevailed.
- In terms of subtraction, all the students presented difficulties and did not carry out the activity as planned.

3.2 Skills test application

The "Basic Skills Test for Initiation to Calculus" [9] was taken as a basis, through which three areas were evaluated: counting, addition and subtraction. A total of 4 students participated, see **Fig. 8.** (a), and the results are shown in the section **Analysis of results**.

(a) ***(b)***

Fig. 8. (a) Student interacting with physical Cuisenaire strips, (b) Student interacting with digital Cuisenaire strips

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3.3 Intervention with the proposed solution

Five sessions were planned in which 4 users participated, in each session the concepts of counting, addition and subtraction were addressed but now reviewing the contents in the application. The sessions were held at the Down Institute, see **Fig.** (b).

Throughout the sessions, the following could be observed in terms of interaction with the interface and contents:

– The videos of addition and subtraction were of interest to users and it was commented that it would be good to include more.
– The audio and vibration tracks were helpful when the user was in a situation where they didn't know how to continue with the activity.
– In the particular case of a user who was distracted during the contextualization stage or uninterested, when using the application the opposite could be observed.
– The size of the elements was not a problem, since they managed to identify the contents such as instructions and images without any problem.
– They liked the feedback when answering exercises.
– Some students gave their opinion and consider that with more videos they would better understand some concepts such as addition and subtraction.

3.4 Skills test application

After finishing the sessions with the application, the test was applied again to the same students to determine the progress in the areas previously described, the results can be consulted in the next section.

4 Analysis of results

Once the tests were applied before and after using the application, the results obtained are discussed after carrying out a comparative analysis, which seeks to identify the advances and difficulties in each area, as well as to evaluate the impact of the technological tool on learning. To do this, the differences between the scores of both tests were calculated, obtaining the mean and standard deviation. Finally, the t-test was applied to determine if the observed differences are statistically significant, using a significance level of 0.05 to determine whether or not there is progress.

That is why, in the following sections, the results of both tests are shown for each area evaluated, the blue color represents the first test, while red, the second.

4.1 Counting

In the **Fig. 9.**, the results for the counting area are shown, after the statistical analysis a mean of 3.5 was obtained in the differences in scores between both tests, with a standard deviation of 3.87 and a T value of 1.181. Considering the degrees of freedom $(n - 1) = 3$, the critical value is 2.3534. Since $t = 1.181 < 2.3534$, a significant difference in student performance after using the mobile app cannot be confirmed.

4.2 Additions

In the **Fig. 10.**, the results for the addition are analyzed, from which a mean of 0.5 points is obtained in the scores of both tests, with a standard deviation of 0.57 and a T-value of 1.732. Considering the degrees of freedom $(n - 1) = 3$, the critical value is 2.3534. Since $t = 1.732 < 2.3534$, suggesting that, based on the results, a significant difference in student performance after using the mobile app cannot be confirmed.

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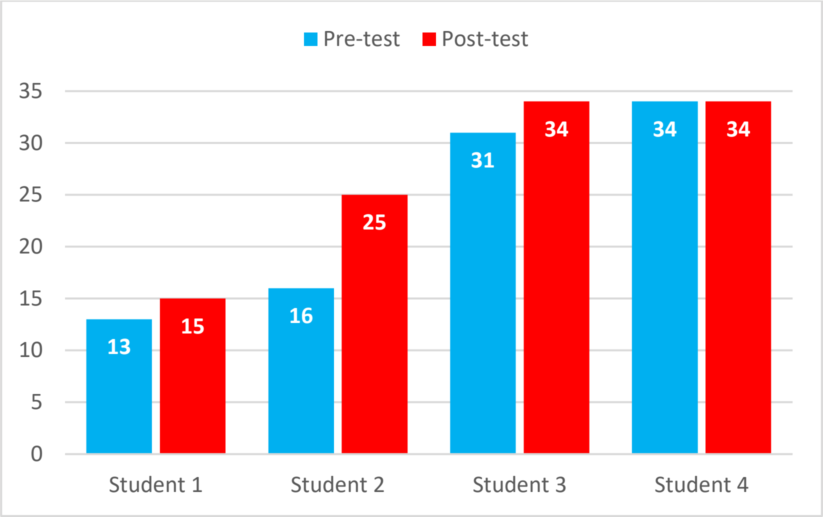

Fig. 9. Counting results.

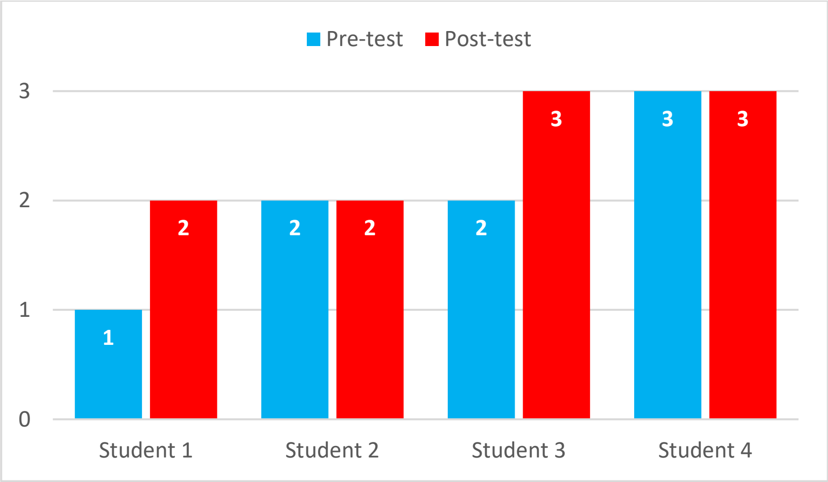

Fig. 10. Addition results.

4.3 Subtraction

The **Fig. 11.**, shows the analysis of subtraction scores for both tests, the mean score was 0.25, with a standard deviation of 0.5. Considering the degrees of freedom and the value of t obtained, $t = 1 < 2.3534$, the results indicate that there is no significant difference in performance when using the application.

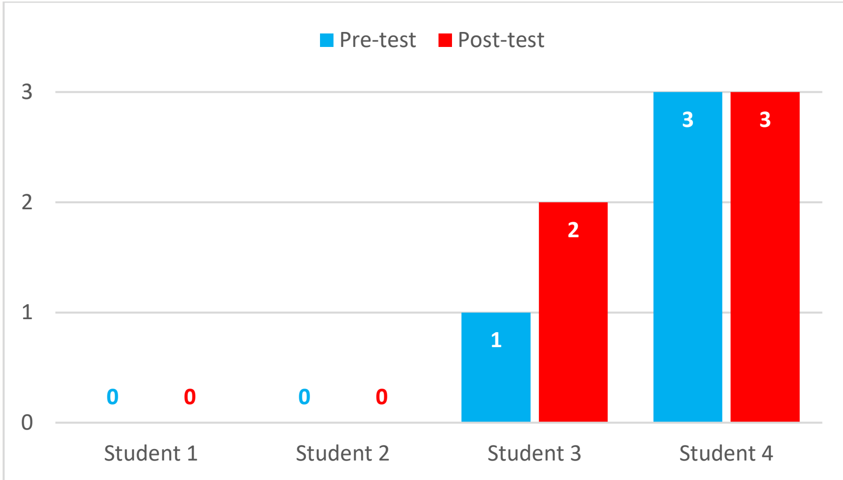

Fig. 11. Subtraction results.

5 Discussion

This study present some limitations. Firstly, the number of students; the Down Institute has a population of around 40 students, which are grouped by groups of age. For example, they have infants, adolescents and adults. In our case we were allowed to interact with seven adults considering they have skills such as use of oral language, besides they have basic knowledge in mathematics. The rest of the population doesn't have this conditions. Secondly, from the initial group of seven participants, some of them were removed from the results because they were not present in some of the contextualization sessions. For that reason our final group was only four people. Thirdly, we applied a solid methodological process for designing the mobile application, consequently the application took in consideration not only the needs of students, but also, we validate the contents and the use of the application with teachers from the institute. As a limitation, we need to apply heuristics evaluation in the future.

Despite these limitations, a slight improvement could be detected in students one and two, for example, student two during the contextualization sessions with the physical strips was distracted and not very participative, however, when using the application, he was more attentive, interacting with the multimedia elements and performing activities such as counting and addition. With student one it was similar, he had a hard time following the activity with the physical strips, but at the time of using the application he was able to maintain his attention and perform part of the activity.

6 Conclusions

The objective of this research was to develop a mobile application designed to help people with Down Syndrome to understand basic mathematical concepts, specifically counting, addition and subtraction, through digital representations of Cuisenaire strips. To achieve this purpose, a User-Centered Design (UCD) methodology was adopted, which prioritized the needs, abilities, and limitations of people with Down Syndrome at each stage of the development process.

The User-Centered Design (UCD) included an initial phase of analysis to under-stand the cognitive and motor characteristics of the end users, which made it possible to define specific requirements for the application, such as simple interfaces, contrasting colors, large buttons, and interactive activities that encouraged exploration and playful learning. Iterative testing was carried out with users, this helped to adjust design and functionality elements to improve accessibility, clarity of instructions, and effectiveness of proposed activities.

Although the t-test does not show a statistically significant difference, an average improvement trend (3.5 points) is observed. For people with Down syndrome, even small advances can be significant in educational or functional terms. The lack of statistical significance with n = 4 and high variability does not imply the absence of an effect; it simply indicates that, with this sample size and conditions, it has not been possible to confirm it conclusively. Therefore, this suggests that *CuisemathApp* could have a positive impact on some users, especially those whose features favor this type of learning.

These results highlight the need for continuous and personalized assessment, as some users may require adjustments to teaching activities or methods. Adopting this approach will improve the functionalities of the application and better adapt it to the needs and learning rhythms of students with Down Syndrome.

Finally, the creation of this application can be defined as a contribution to the de-sign of inclusive technologies, providing a solution for people with Down Syndrome, expanding the scope of mobile applications in contexts of functional diversity. Like-wise, the UCD allowed the needs, capacities and limitations of the population to be the central axis during each stage. However, it is important to emphasize that areas for improvement were identified, mainly in subtraction activities, so a clear direction is established for future design iterations.

6.1 Future work

As future work we propose that it would be valuable to take the evaluation process to a larger group for more statistically significant results. A more detailed feedback system could also be integrated so that educators/tutors can monitor each user's individual progress and how consistent they are using the app.

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Development of a Clinical Decision Support Tool for Diabetes Diagnosis Using Machine Learning

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Abstract. Type 2 diabetes is a highly prevalent chronic disease worldwide and a leading cause of cardiovascular, renal, and ocular complications. Early detection is essential to mitigate adverse effects, yet traditional diagnostic methods often remain inaccessible to certain populations. This study presents the development of a machine learning-based clinical decision support system designed to facilitate the pre-diagnosis of type 2 diabetes. A clinical dataset from the Instituto Mexicano del Seguro Social was used to train and evaluate multiple machine learning models, including logistic regression, naive bayes, decision trees, random forest, support vector machines, and k-nearest neighbors. A feature selection process was conducted using SHapley Additive exPlanations, identifying the most relevant predictive variables. The models were assessed based on the receiver operating characteristic curve, area under the curve, sensitivity, specificity, accuracy and F1-score. Results demonstrated that the random forest model achieved the highest performance, with an area under the curve of 0.969, indicating strong classification capabilities. This model was subsequently implemented in an interactive application developed in R using the Shiny framework, providing an intuitive interface for healthcare professionals. This application was developed following the User Centered Design approach described in the ISO 9241-210:2010 standard, ensuring a user-centered approach to usability. This system allows for clinical data entry and generates a visual pre-diagnosis, supporting medical decision-making. In conclusion, this study highlights the potential of machine learning to enhance early diabetes detection by offering a user-friendly, and clinical relevant diagnostic aid. While the system does not replace medical expertise, it serves as a valuable complement to optimize diagnostic times and improve patient care.

Keywords: Type 2 Diabetes, Machine Learning, Random Forest, SHAP, Diagnosis, UCD.

1 Introduction

Diabetes is a chronic degenerative disease that affects millions of people worldwide. It is characterized by the body's inability to produce or effectively utilize insulin, a hormone essential for regulating blood sugar levels. According to the International Diabetes Federation (IDF), an estimated 463 million people had diabetes in 2019, with projections indicating an increase to 578 million by 2030 and 700 million by 2045.

Approximately two-thirds of individuals with diabetes live in urban areas, and three out of four are working age [1]. In Mexico, diabetes is a major public health concern, ranking among the leading causes of heart attacks, vascular diseases, strokes, blindness, and non-traumatic amputations. Additionally, it poses a significant economic burden due to the high cost associated with treating complications [2]. Early diagnosis and effective disease management are crucial in preventing severe complications such as cardiovascular diseases, kidney failure, and ophthalmologic damage [3]. However, traditional diagnostic methods, typically based on laboratory tests, remain inaccessible to many patients, particularly in rural and low-resource regions. In this context advancements in digital health technology have emerged as a promising solution to enhance diagnostic accessibility and accuracy. Among these technologies, machine learning (ML) stands out as a powerful tool for developing innovative diagnostic solutions, optimizing clinical workflows, and reducing waiting times for medical results. This study presents the development and optimization of a ML model integrated into a clinical decision support system for assisting healthcare professionals in the pre-diagnosis of type 2 diabetes (T2D). The primary goal of this software is to facilitate early accurate diagnosis, providing a user-friendly and efficient interface tailored to the needs of medical practitioners. Unlike general-purpose digital health applications, this tool is exclusively designed for medical professionals. Its purpose is not to replace clinical expertise, but rather to improve diagnostic accuracy and efficiency. By leveraging ML algorithms, the software rapidly analyzes clinical data to generate a preliminary diagnosis based on objective information. However, it is essential to emphasize that the final diagnosis remains under physician's discretion, ensuring that clinical judgment prevails in each case.

2 Materials and methods

This section describes the techniques used in this study. As shown in **Fig. 1**, the process consists of four main steps. First, a dataset was collected and preprocessed to ensure data quality. Second, the most relevant features were selected using SHapley Additive exPlanations (SHAP) to improve model interpretability and performance. In the third step, several ML algorithms - including logistic regression (LR), naive bayes (NB), decision trees (DT), random forest (RF), support vector machines (SVM), and k-nearest neighbors (K-NN) - were applied to identify the best-performing model. Finally, the selected model was integrated into an interactive clinical decision support application, designed to perform classification tasks and provide real-time predictions, facilitating the pre-diagnosis of T2D.

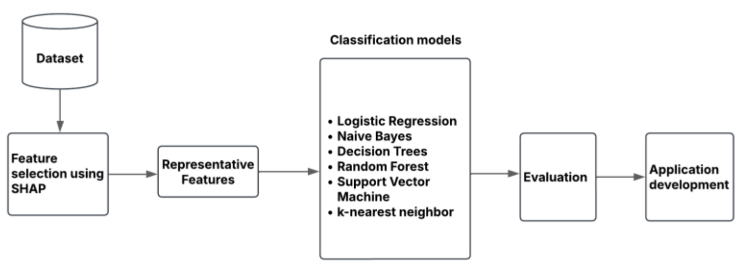

Fig. 1. Flow diagram of applied methodology.

2.1 Dataset

The dataset used in this study was provided by the Biomedical Research Unit of the Instituto Mexicano del Seguro Social (IMSS), located in Zacatecas, Mexico. All patients provided informed consent, and the dataset complies with the ethical approval of opinion R-2017-785-131, following the protocol "Differential Metabolomic and Transcriptomic Analysis in Urine and Serum of Pediatric, Diabetic, and Diabetic.

Nephropathy Patients to Identify Potential Prognostic Biomarkers of Renal DamagThe dataset included metabolomic, anthropometric, clinical, and laboratory data from 372 patients, covering 51 variables. To guarantee data integrity and reliability, a preprocessing phase was conducted, reducing the dataset to 50 features and 149 patients of which 75 suffered T2D and 74 were control patients. This process involved: (1) handling missing data through imputation techniques; (2) identifying and treating outliers to minimize their impact on the analysis, and (3) performing class balancing to mitigate potential biases in the classification tasks.

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2.2 Feature selection method using SHAP

SHAP has become a widely used method for interpreting the predictions of ML models. Based on game-theoretic principles [4], SHAP quantifies the contribution of each feature to a given prediction. It belongs to a family of model-agnostic additive feature attribution methods, making it applicable across various ML models. For feature selection, SHAP operates with a classification model, such as RF (used in this study), which is trained on the entire dataset. The SHAP values for each attribute are computed and aggregated across all instances to obtain the mean absolute value for each feature.

Two key SHAP values are calculated:

1. Mean SHAP value - Represents the average influence of a feature on model predictions across the dataset.
2. Absolute SHAP value - Measures the importance of a feature, regardless of whether its impact is positive or negative.

By ranking features in descending order bases in their mean absolute SHAP values, those with higher SHAP values are identified as the most influential in model predictions [5].

2.3 Machine learning

It is a subfield of Artificial Intelligence (AI) that enables systems to learn from data without being explicitly programmed. By processing large volumes of data, ML algorithms identify patterns and make predictions, allowing for continuous improvement in performance [6]. In this study, ML techniques were employed to recognize patterns among clinical variables and improve the predictive accuracy of T2D classification. The following ML algorithms were trained and evaluated:

LR: a supervised learning algorithm used for binary classification, LR models the relationship between independent variables and a categorical dependent variable through the logistic (sigmoid) function[7]. The model was configured with the binomial family to define it as a classifier.

NB: a probabilistic classifier based on Bayes' theorem, assuming independence among predictors. It estimates conditional probabilities using observed frequencies to classify new instances[8]. This study configured the model with Laplace smoothing (laplace = 2) and a kernel density estimation to accommodate non-Gaussian distributions.

DT: a rule-based hierarchical classifier that partitions the feature space through recursive binary splitting. Each internal node represents a feature, branches correspond to decision paths, and leaf nodes indicate class labels[9]. The model was initialized with a root node containing 150 features.

RF: an ensemble learning method that constructs multiple DTs and aggregates their outputs to improve classification performance while reducing overfitting [10]. Each tree is trained using random subsets of features, ensuring model robustness. The RF model was built with 500 DTs, selecting two random variables (mtry = 2) at each split.

SVM: a discriminative classifier that finds the optimal hyperplane to maximize the margin between classes in an N-dimensional feature space, where N is the number of independent variables[7]. This model was configured with the radial basis function (RBF) kernel, which improves decision boundaries for non-linearly separable data.

KNN: a non-parametric classification algorithm that assigns a class label based on the majority class among the KNN. The hyperparameter k determines the number of neighbors considered for classification [7]. In this study k = 11 was used, meaning predictions were based on the 11 closest neighbors.

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2.4 Evaluation metrics

To evaluate the performance of the ML models, several metrics were considered, including the receiver operating characteristic (ROC) curve, area under the curve (AUC), accuracy, recall, specificity, and F1-score.

These metrics offer a comprehensive assessment of the model's ability to differentiate between diabetic and non-diabetic cases.

ROC Curve: is a statistical tool used to evaluate the discriminative ability of a binary classifier. It plots recall (true positive rate) against 1-specificity (false positive rate) at various decision thresholds [11]. This curve helps to: select the optimal threshold for classification, assess the overall performance of the model, and compare different diagnostic models.

Area Under Curve (AUC): measures the overall performance of the ROC curve, representing the probability that the model correctly ranks randomly chosen positive instances higher than a randomly chosen negative one [12].

AUC = 0: the model performs worse than random classification;
AUC = 0.5: the model performs no better than random guessing;
AUC = 1: the model has excellent discriminatory ability.

Accuracy: measures the overall correctness of the model's predictions. It is defined as the ratio of correctly classified instances (true positives and true negatives) to the total number of cases:

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN} \tag{1}$$

where:
True positives (TP): correctly classified diabetic cases;
True negatives (TN): correctly classified non-diabetic cases;
False positives (FP): non-diabetic cases misclassified as diabetic;
False negatives (FN): diabetic cases misclassified as non-diabetic.

Recall: also known as sensitivity, measures the model's ability to correctly identify all positive cases. It is calculated as:

$$Recall = \frac{TP}{TP + FN} \tag{2}$$

A high recall indicates that the model correctly detects most diabetic patients, minimizing FNs [13]

Specificity: quantifies the model's ability to correctly classify negative cases, avoiding FPs. It is defined as:

$$Specificity = \frac{TN}{TN + FP} \tag{3}$$

A high specificity means the model is effective at reducing false alarms by correctly identifying non-diabetic cases [13]

F1-score: is the harmonic mean of precision and recall, providing a measure of their balance. It is calculated as:

$$F1 - score = 2 * \frac{Specificity * Recall}{Specificity + Recall} \tag{4}$$

This metric is particularly useful for evaluating classification models, especially when dealing with imbalanced datasets.

2.5 App design

As illustrated in **Fig. 2**. This process consists of four key stages: (1) specifying the context of use, (2) specifying user requirements, (3) producing design solutions, and (4) evaluating the design. If the evaluation confirms that user requirements have been met, the process concludes; otherwise, the cycle is repeated iteratively until the design fulfills all user needs.

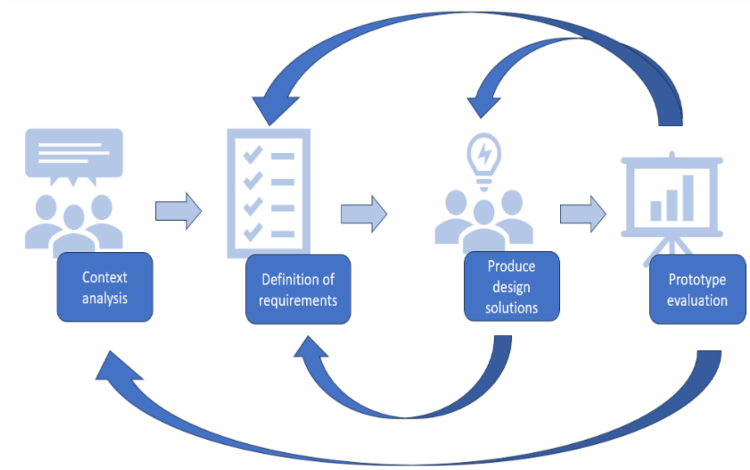

Fig. 2. User-Centered Design (UCD) process outlined in the ISO 9241-210:2019 standard.

The application was developed in R using the Shiny library[14, 15], which enables the efficient creation of interactive web applications. Shiny integrates both the user interface (UI) and the server within the same environment, allowing seamless interaction between components. The UI defines the application's structure and contains various visual elements, including input forms, interactive buttons, and graphical visualizations. This section allows users to enter patient data, while dedicated action buttons trigger specific server functions. On the server side, the application processes the input data and utilizes a ML model to compute the probabilities of each diagnosis. The results are displayed both in text format and visually represented in a pie chart for better interpretation. Additionally, the server performs data validation, ensuring that all required fields are correctly completed before generating a prediction. Shiny's reactive framework allows the application to dynamically update in real time, supporting immediate feedback for users.

Likert scale: The Likert scale was implemented for the evaluation of the App. These value and estimation scales are those that are used to determine the perception of some qualitative variable that by its nature denotes some order[16]. A set of specific questions was developed to evaluate key usability attributes such as learnability, usability, user satisfaction, error frequency, task performance time, efficiency, retention over time, and flexibility.

3 Results

In this study, SHAP was initially employed to identify the most relevant features influencing the likelihood of T2D. These selected variables were subsequently used for the training and evaluation of multiple ML models. All models were trained under standardized conditions, utilizing a 70-30% train-test split. To enhance model validation and mitigate overfitting, a 10-fold cross validation (CV) strategy was applied, ensuring that performance metrics remained reliable and unbiased. This section presents the outcomes of the SHAP analysis, the comparative evaluation of ML models, and the integration of the final model into a Shiny-based application for interactive clinical decision support.

3.1 SHAP analysis

Fig. 3 presents a SHAP value plot, which visualizes the contribution of each feature to the model's predictions. Each point represents an individual observation in the dataset, with colors indicating feature values (blue represents lower values and red represents higher values). The x-axis position reflects the impact of each variable on the model's output. A positive SHAP value suggests an increased likelihood of T2D, while a negative value indicates a reduced risk.

Several key patterns emerge from the SHAP analysis:

1. Age.
2. Systolic pressure.
3. Hypertension treatment.
4. Leukocytes.
5. Lymphocytes.
6. Very low-density lipoproteins (VLDL).
7. Dyslipidemia treatment.

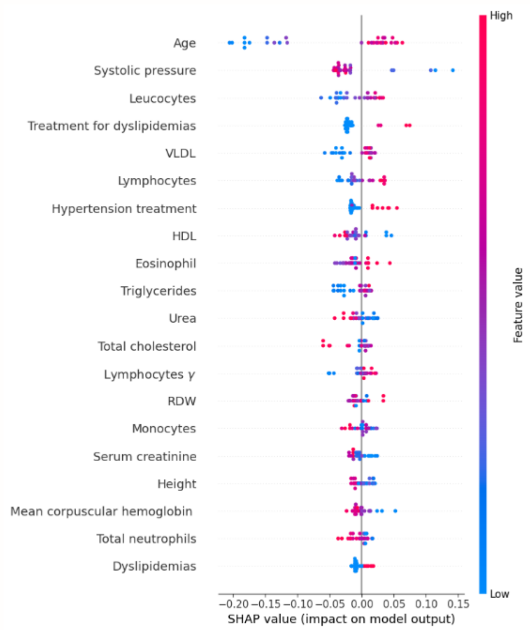

Fig. 3. Features selection with SHAP. "beeswarm plot" used to display an information-dense summary of the impact of the main features of a dataset on the model results. Each point represents an individual observation in the dataset, with colors indicating feature values (blue represents lower values and red represents higher values). The x-axis position reflects the impact of each variable on the model's output. A positive SHAP value suggests an increased likelihood of T2D, while a negative value indicates a reduced risk.

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3.2 Model comparison

Six ML algorithms (LR, RF, SVM, DT, KNN, and NB) were evaluated using multiple performance metrics. These metrics include the ROC curve, recall, specificity, accuracy, F1-score, and AUC.

Table 1 presents the evaluation metrics for different ML models in training and test sets. For the training set, the reported values correspond to the mean and standard deviation obtained from a 10-fold CV, ensuring a robust performance assessment. The test set results reflect the final evaluation of each model on unseen data.

For the training set, the results show that the RF model achieved the best overall performance, with an accuracy of 0.875 ± 0.077 (standard deviation), a recall of 0.850 ± 0.124, and an AUC of 0.937 ± 0.057, indicating a high ability to discriminate between positive and negative cases. Other models, such as SVM and LR, also showed good results, with F1-scores of 0.750 ± 0.121 and 0.739 ± 0.141, respectively. On the other hand, the NB model exhibited the lowest recall (0.493 ± 0.240), indicating a high false negative rate, while the DT model showed low specificity (0.562 ± 0.196), suggesting a high false positive rate.

Similarly, for the test set RF outperformed all models, achieving an AUC of 0.9793, a recall of 0.9545, and a specificity of 0.9090. It also had the highest accuracy (0.9318) and an F1-score of 0.9333, indicating its strong overall performance. SVM and LR also performed well, with AUCs of 0.9214 and 0.8925, respectively. SVM achieved an accuracy of 0.8863, a recall of 0.9545, and a F1-score of 0.8936, while LR showed a similar accuracy of 0.8181, a recall of 0.8636, and a F1-score of 0.8260. Although NB had the lowest accuracy (0.7727), its AUC of 0.8987 suggests reasonable classification performance, with a recall of 0.8636 and a F1-score of 0.7916. DT and KNN showed trade-offs in performance. KNN had a recall of 0.9545 but the lowest specificity (0.6818), an accuracy of 0.8181, and a F1-score of 0.8400. DT, with an accuracy of 0.8409, a recall of 0.7727, and a F1-score of 0.8292, demonstrated a balanced performance, though it did not perform as well as the other models. Overall, RF demonstrated the best balance between accuracy, sensitivity, specificity, and F1-score, making it the most effective model.

Table 1. Performance metric of ML models in training and test sets.

Train set + cross validation					
Model	**Accuracy**	**Recall**	**Specificity**	**F1- score**	**AUC**
LR	0.760±0.138	0.700±0.202	0.820±0.147	0.739±0.141	0.778±0.199
RF	0.875±0.077	0.850±0.124	0.896±0.171	0.854±0.105	0.937±0.057
SVM	0.764±0.116	0.766±0.187	0.758±0.105	0.750±0.121	0.866±0.113
DT	0.667±0.089	0.778±0.240	0.562±0.196	0.600±0.087	0.743±0.121
KNN	0.668±0.100	0.666±0.176	0.706±0.221	0.645±0.136	0.787±0.166
NB	0.665±0.131	0.493±0.240	0.843±0.119	0.578±0.229	0.767±0.080
Test set					
Model	**Accuracy**	**Recall**	**Specificity**	**F1-score**	**AUC**
LR	0.8181	0.8636	0.7727	0.826	0.8925
RF	0.9318	0.9545	0.909	0.9333	0.9793
SVM	0.8863	0.9545	0.8181	0.8936	0.9214
DT	0.8409	0.7727	0.909	0.8292	0.8667
KNN	0.8181	0.9545	0.6818	0.84	0.8698
NB	0.7727	0.8636	0.6818	0.7916	0.8987

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Fig. 4 presents the ROC curves and corresponding AUC values for the six ML models. The ROC curve provides a graphical representation of each model's ability to discriminate between T2D and non-T2D cases, with sensitivity plotted against 1-specificity.

The performance of RF model in training and test sets highlights its robustness, generalizability, and suitability for clinical applications in T2D risk assessment. Its superior AUC of 0.9793 indicates that RF effectively distinguishes individuals with and without T2D, making it the most reliable classifier in this study.

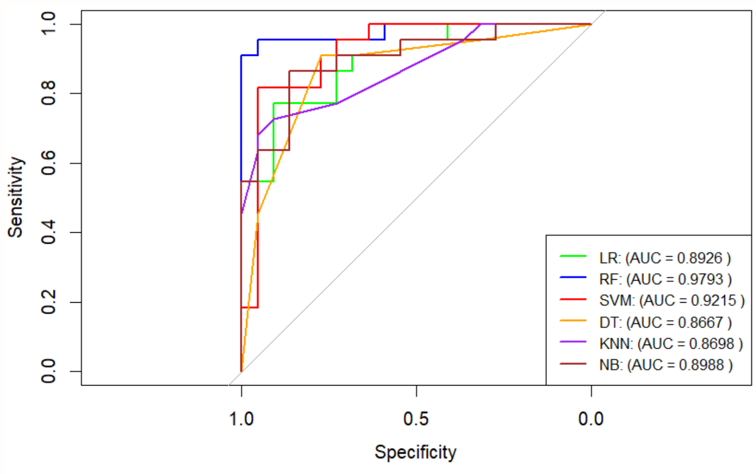

Fig. 4. ROC curve analysis and AUC values for T2D classification models.

3.3 App design

A Shiny-based R application was built, driven by the trained RF model to provide a user-friendly tool for preliminary T2D diagnosis. The app is divided into two main components:

Cover Page: This page includes essential project details, author information, institutional logos, and a disclaimer emphasizing that the tool is intended for educational purposes and not for definitive clinical diagnosis (**Fig. 5**).

1. Diagnostic Interface: Users can input relevant patient data (age, systolic blood pressure, leukocyte count, lymphocyte count, VLDL level) and specify whether treatments for hypertension and dyslipidemia are in use via drop-down menus. Data validation ensures completeness before a diagnosis is generated. Upon clicking "Perform Diagnosis," the RF model predicts the likelihood of T2D. Results are displayed in text form alongside an interactive pie chart (rendered with ggplot2) showing the probabilities for T2D and non-T2D. A "Reset" button enables easy clearing of inputs, facilitating multiple predictions in a single session (Fig. 6).

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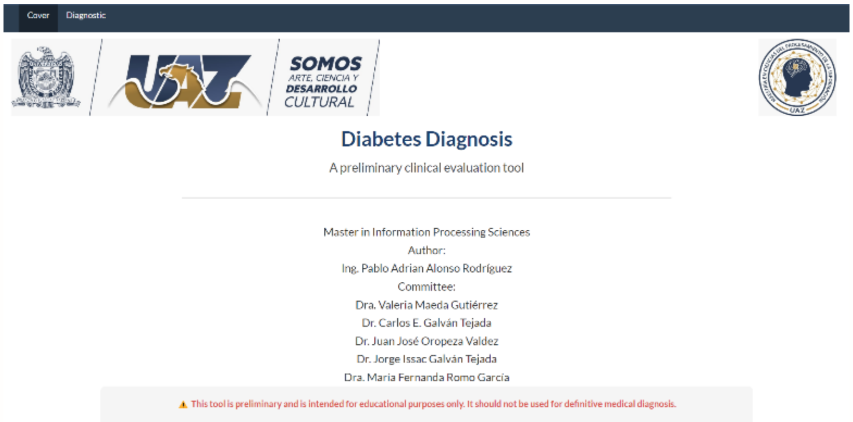

Fig. 5. Cover page of the Shiny application. It presents key project information, author details, institutional logos, and a disclaimer emphasizing the tool's educational purpose.

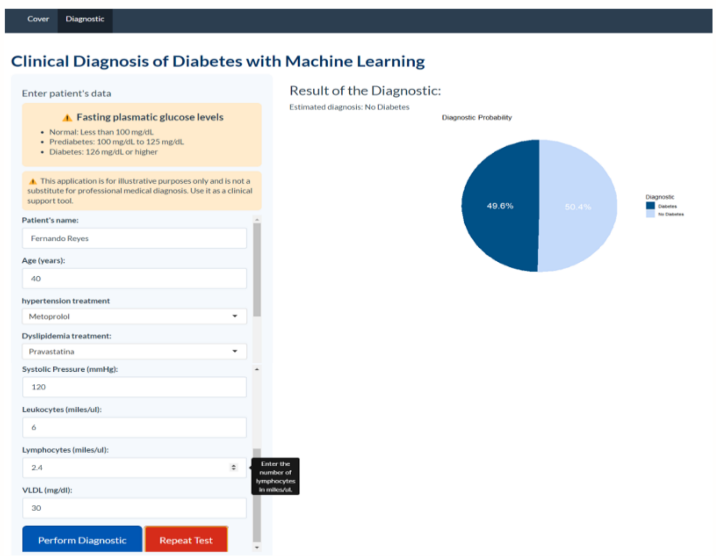

Fig. 6. Diagnostic interface of the Shiny application. Users can input relevant clinical data (e.g., age, blood pressure, and blood counts), specify treatments, and receive a preliminary T2D diagnosis. Results are displayed in text form and as an interactive pie chart of classification probabilities.

4 Conclusion and discussion

In this study, feature selection was a fundamental step in improving the performance of ML models for T2D detection. This process reduces the number of variables without compromising information while optimizing computational resources. The SHAP method identified the most relevant variables for disease prediction, notably age, where a correlation between aging and T2D was observed. This aligns with research linking older age to insulin resistance. For example, in the United States (2005–2008), diabetes prevalence increased with age: 3.7% among individuals aged 20–44, 13.7% for those aged 45–64, and 26.9% for those over 65 [17]. Systolic blood pressure was another key factor, with studies showing that each mmHg increase correlates with a 1%-4% higher risk of T2D [18]. Inflammatory markers, specifically leukocyte and lymphocyte levels, were relevant to T2D. Chronic inflammation in T2D involves dysfunctional leukocyte activity, contributing to disease progression [19]. Additionally, pro-inflammatory shifts in T lymphocytes and macrophages, along with increased TNF-α, IL-6, IL-1β, and IL-17, impair insulin signaling, damage pancreatic β-cells, and promote chronic hyperglycemia [20]. Another characteristic is that VLDL levels are often elevated in patients with T2D, as studies have shown. This overproduction of triglyceride-rich VLDL is linked to excess free fatty acids, hyperglycemia, obesity, and insulin resistance [21]. It has been found that in patients with well-controlled T2D and no history of ischemic heart disease, certain medications, such as fibrates, can improve dyslipidemia and reduce vascular complications, particularly in cases of diabetic dyslipidemia [22]. Once these features were selected, the performance of various machine learning algorithms was compared.

Compared with another study that analyzes various machine learning models to predict diabetes, it is essential to emphasize the significance of performing feature selection. Additionally, it is worth noting the effectiveness of models such as RF, which, as demonstrated in this study, proved to be one of the most suitable for classifying T2D [13]. Finally, the implementation of the model, in alignment with the ISO 9241-210:2010 standard for user-centered design in clinical applications, is essential for its adoption in medical environments. The effectiveness of such a tool relies not only on its accuracy in detecting diabetes, but also on its usability. Future research could enhance the model by integrating additional data sources and validating its performance in real-world clinical settings, thereby increasing its value in the prevention and early diagnosis of diabetes

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Development of a Virtual Tour for the University Campus and its Sculpture Park

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Abstract. Digital tourism in 360 degrees has experienced significant growth, allowing users to explore tourist destinations virtually from the comfort of their homes using mobile devices, desktop computers, or vir-tual reality headsets. This type of tourism stands out for its accessibility, offering an effective solution for those who cannot travel physically. The objective of this project is to develop an immersive 360° experience for the Lircay campus of the anonymous University, making it accessible to people with mobility difficulties, prospective students, and alumni. The virtual experience also allows users to explore the campus and discover details about points of interest, including 3D models of sculptures gen-erated through photogrammetry. A total of 24 panoramic images and 4 interactive 3D models were implemented using the 3D Vista engine. User testing yielded positive results, with students and individuals fa-miliar with the campus appreciating the hidden details revealed, while those unfamiliar with the location valued the effectiveness of the virtual tour.

Keywords: Tour 360°, Photogrammetry, Methodology, Mobile App, Virtual Reality, Virtual tourism.

1 Introduction

Planning a trip often faces barriers such as distance, costs, and available time. As an alternative, 360° tourism offers an accessible experience to explore desti-nations virtually. Stappung et al. (2023) have worked on this type of tourism in Chilean national parks [1] and served as the primary basis for the development of this project.

The anonymous campus of the anonymous University is a place of interest for students and the general public, but some people do not have the opportunity to visit it. This location spans across hectares, blending a rich variety of history and culture, reflected both in its infrastructure and in the emblematic Sculpture Park, making it an important public point of interest. Additionally, it is of great interest to new students, who often find it challenging to navigate its vast and diverse environment.

In this context, accessibility becomes a key challenge, especially for people with reduced mobility. Spaces such as the Botanical Garden or the Arboretum, with uneven terrain and wide distances, can represent significant obstacles to travel. This limits the ability to fully explore and enjoy these environments, highlighting the need for inclusive solutions that allow all visitors to experience the campus in an equitable manner.

Among the background studies related to 360° tourism, notable examples include:

- A tour conducted at the Emperador Hotel in the city of Ambato [2], which demonstrated the effectiveness of these technologies in the tourism sector, increasing the hotel's clientele and the number of tourists in the area. Fur-thermore, the implementation of the 360° virtual tour enhanced the hotel's digital presence, allowing potential guests to explore its facilities remotely and make informed booking decisions. This strategy not only improved cus-tomer engagement but also positioned the hotel as an innovative leader in the local hospitality industry, fostering competitiveness and long-term growth.

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- The proposal for a virtual tour of the laboratories at the Universidad del Valle de Guatemala [3], developed using web programming in JavaScript and HTML, aims to allow users to explore the facilities remotely from any device with internet access. The project involves studying user needs and interests, capturing 360° photographs of the facilities, compiling essential information about each space, and integrating this data into the virtual tour. An added value of the tour is the information section, where users can interact with available equipment on campus through information icons; with a single click, they can access content about the equipment or space of interest.
- A study conducted by a local university in Germany on a farm [4] revealed that mobile devices have greater acceptance in the use of these technologies. Additionally, the research found that while both virtual reality (VR) glasses and tablets were effective in providing insights into pig husbandry, tablets were preferred due to their ease of use and familiarity. Participants appreci-ated the ability to explore the farm environment virtually, highlighting the potential of these tools to enhance transparency in agricultural practices and improve public perception of livestock farming.

According to the researched data, the implementation of virtual tours sig-nificantly improves tourism in the area. In this context, this work proposes an immersive virtual solution using 360° images captured at different points on ca pus, integrated with information about the locations to enrich the user experi-ence. Additionally, the project seeks to incorporate 3D models into these tours, a relatively new and underutilized tool in this field. The digitization methodol-ogy employed will be similar to that used in museums [5], aiming to enhance interactivity and exploration, representing an innovative research approach to virtual tourism in the area.

2 Methodology

For the development of this project, the Design Science Research (DSR) method-ology was used, which includes the following steps: Awareness of Problem, Sug-gestion, Development, Evaluation, and Conclusion [6].

- **Awareness of Problem:** Identifying and understanding a problem or op-portunity in the field of study that requires a solution. This involves com-prehending the context and dynamics of the problem, which includes data collection and a critical analysis of the current situation. This phase is crucial as it lays the foundation for future actions.
- **Suggestion:** Once the problem has been diagnosed, an action plan is devel-oped. This involves defining clear and specific objectives, as well as design-ing strategies to address the problem. In this phase, different alternatives are considered, and the most suitable one is selected, taking into account available resources and possible resistance.
- **Development:** In this phase, the action plan is implemented. This may include introducing changes in practice, training participants, or creating new policies. It is an active process where planned interventions are carried out, and their development is observed in practice.
- **Evaluation:** After implementing the action, the results are evaluated. This phase involves analyzing the effects of the interventions using empirical meth-ods to measure their impact. The goal is to determine whether the objectives established during the planning phase have been achieved and what changes have occurred in the problematic situation.
- **Conclusion:** Finally, the process and results are reflected upon. In this phase, lessons learned are documented, best practices are identified, and considerations are made regarding how these insights can be applied to fu-ture research or actions. This phase is essential for consolidating acquired knowledge and improving future practice.

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3 Development

3.1 Awareness of Problem

There are people, both locals and from other cities, who wish to explore the campus due to personal connections, such as having friends, family members, or acquaintances studying there, being future students, having been alumni, or simply out of curiosity. However, they do not always have the means or op-portunities necessary to visit. The main problem identified is the inability of some people to physically access the campus, due to factors such as economic, demographic, physical or time constraints [7].

The core issue lies in the challenges faced by the general public in accessing the campus, as it is located on the outskirts of the city, which limits access for those residing within it. Additionally, the campus hosts a large number of students from other cities, making it difficult for their close circles—or even the students themselves—to have prior knowledge of the facilities. Furthermore, the campus spans vast areas of considerable size, which also presents a challenge for students, particularly those visiting for the first time, as they may struggle with orientation.

3.2 Suggestion

The proposed solution to this issue involves the creation and implementation of a 360° virtual tour, allowing the community to virtually visit the Lircay campus of the anonymous University.

Table 1. General use case for the virtual tour.

Use Case	**360° Virtual Tour of anonymous University**
Actors	Visitors (prospective students, current students, alumni, general public)
Preconditions	Users must have a device with internet access (PC or mobile).
Flow of Events	The user accesses the virtual tour through a web platform. The system loads a panoramic 360° view of the campus, allowing navigation through various points of interest. Users can interact with hotspots to display additional information about locations and facilities. The system provides 3D models of sculptures, enabling rotation and zooming for better visualization. Users can switch between different sections of the campus using a virtual map. If applicable, users provide feedback through a survey on the expe-rience.
Postconditions	The user gains knowledge about the campus layout, facilities, and avail-able resources. The university collects insights into user engagement and potential improvements for future updates.

To achieve this, the process for creating virtual tours described by Stappung et al. [1] and Jegó et al. [5] was followed. This process includes the implementation of 360° images captured using the methodology described in this work [8] and processed with 3DVista Pro software [9]. Additionally, a feature allowing in-teraction with 3D

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objects within the experience was implemented. The creation of these models is based on the method used for the digitization of museum objects [5], which was previously also utilized by Mauletec.

To accomplish this, an action plan consisting of three phases was imple-mented:

- 360° Image Capture
- Object Digitization
- Software Development

3.3 Development

As mentioned earlier, the development of this project was divided into three phases, which are explained below:

- **360° Image Capture**: In this phase, a route through the campus was planned, including a total of 24 points of interest that users can navigate through. The selection of the sites was based on several factors, including their historical and cultural value, their popularity among the university community, and the frequency with which they are visited by students. It is important to note that the route initially considered was reduced due to the limited duration of the semester assigned to the degree project.

Fig. 1. Route formed by connecting all the points where photographs were taken to create the panoramas.

A Canon Rebel T6 camera equipped with a 10-20 mm wideangle lens was used to capture the images. In addition, a tripod with a stabilizer was used to ensure greater sharpness in the shots. Following this configuration, images were captured every 30° in a horizontal plane, covering angles of 45°, 90° and 135°

Once the images are captured, they are processed using the PTGui software to perform the stitching process, which automatically merges the images through control points generated from similarities found between them.

Fig. 2. Demonstration of the stitching process.

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Once this process is completed, details are adjusted and the tripod is removed using 2D image editing software, such as Photoshop in this case.

- **Digitization of Sculptures**: Due to a new feature incorporated into the 3DVista engine, it is now possible to integrate 3D models into the developed virtual tours. This significantly enhances the understanding of the elements present in the virtual environment, making the experience more didactic and engaging [10].

As mentioned earlier, the time available for the development of this exploratory work was limited. Therefore, on this occasion, only four models of campus statues were developed, selected in some cases based on their size, as this factor influences the point cloud generation process, which will be explained in greater detail later in this document.

The sculptures selected for 3D modeling were:

1. El Beso
2. Mesa II
3. Cohabitación VI
4. Todos los días

To achieve accurate photogrammetry, multiple images are captured from various angles, focusing on a specific point, such as the sculptures. Due to the size of some sculptures, a drone was used to obtain aerial shots. Then, the images are processed using the specialized software Agisoft Metashape, which analyzes the similarities between them and generates a point cloud that serves as the basis for creating the 3D model.

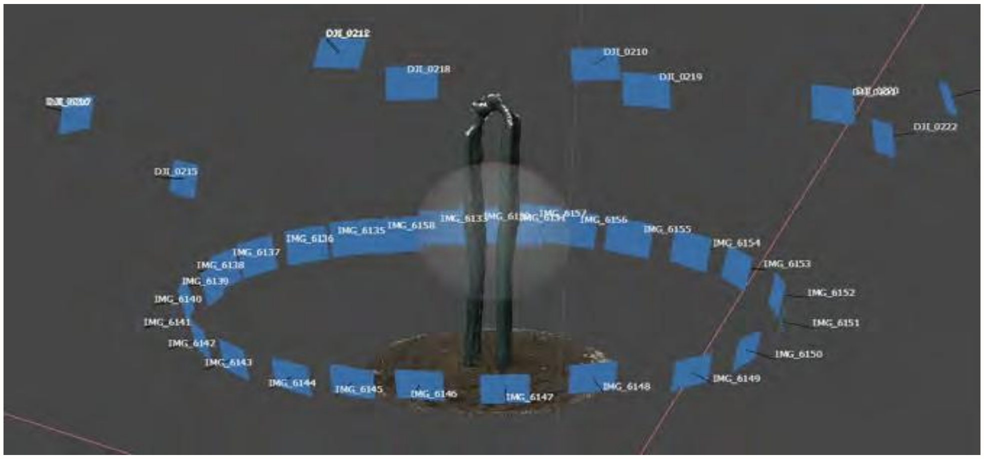

Fig. 3. Demonstration of point cloud creation from photographs.

In this phase, difficulties arose due to the size of some sculptures and the presence of blind spots that the camera could not capture. To address this, during the Optimization phase, these issues were corrected through Retopol-ogy, which reduced the number of polygons in the models, and Baking, which transferred the texture details without losing quality.

The impact of retopology varied depending on the size and complexity of each sculpture. In smaller pieces, the optimization was carried out without significant loss of detail, preserving the fidelity of the original textures and shapes. However, for larger sculptures, especially "Todos los días", several sections had to be recreated due to missing information in certain areas of the model. In "El Beso", although the impact was less pronounced, a par-tial reconstruction of the figures' heads was necessary, using digital editing techniques in Photoshop to maintain the consistency of the final model.

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Table 2. Polygon count comparison table by model.

Model	Polygons Pre-baking	Polygons Post-baking
El Beso	344,183	3,796
Mesa II	3,342,689	1,478
Cohabitación VI	3,269,889	1,762
Todos los días	2,402,566	1,154

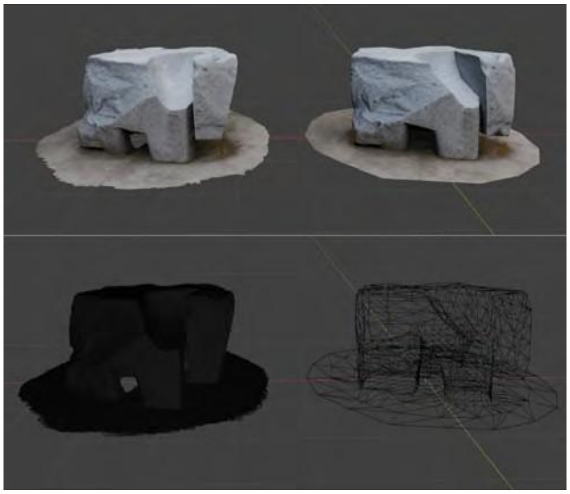

Fig. 4. Comparison of models and polygon density of the sculpture Mesa II.

– **Implementation in 3DVista Engine**: With the most important elements completed, work on the virtual tour itself can begin. For this purpose, the 3DVista engine was used, a tool specifically designed for this task. Some of the key features of this engine include the presence of Skins, which allow for a responsive interface adaptable to any screen size. Another relevant feature is the implementation of Hotspots, editable elements such as buttons, signs, text, among others, that enable users to interact with them or use them as indicators.

For the implementation, the following aspects were addressed within the engine:

– Aesthetics: The tour design follows the style of the Tui anonymous app, using a red and white color palette to facilitate future updates of the anonymous University application.
– Panorama Implementation: Integrating panoramas is straightforward, but adjustments were made such as setting the starting point (centering the camera upon entry) and configuring zoom settings (adjustments to zoom degree, speed, and limits).
– 3D Model Implementation: The 3D models were imported in .glb for-mat. Parameters such as environment (background color) and lighting (uniform ambient light) were adjusted.
– Functionalities: The tour allows interaction with elements such as sculp-tures and points of interest through skins (adaptive interface) and hotspots (interactive elements).

3.4 Evaluation

The evaluation was conducted with a total of 30 participants, with an average age of 28 years, using the System Usability Scale (SUS) methodology [11], which measures effectiveness, efficiency, and satisfaction through 10 questions rated on a numerical scale from 1 to 5. Additionally, an open-ended question was included to gather suggestions for improvement or notable aspects highlighted by participants during the experience.

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Once the questions were answered, the SUS methodology proposes an eval-uation formula that generates a score. This score can be interpreted using the table shown in **Figure 5**, which, according to a study conducted on more than 500 websites and applications [12], indicates that the average score is 68. Results below this value suggest that there are several aspects that require improvement.

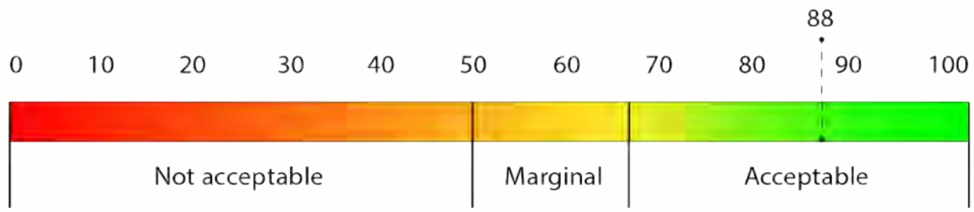

Fig. 5. Representation of SUS results.

The average score obtained using the SUS scale was 88. To arrive at this value, it is necessary to separate the results by user type. On one hand, mobile users achieved an average SUS score of 89.7, while PC users obtained an average of 86.25. A difference of 6.6% was observed between the devices used, indicating that the mobile version had better acceptance among participants. This suggests that the interface and user experience were more satisfactory on mobile devices compared to the PC version.

The median score was 91 points, showing that most evaluations exceeded this score, while only two were below the average, with scores of 57.5 and 65. These results demonstrate an overall success of the project, with minor areas for potential improvement based on user feedback.

4 Conclusions and future work

The 360° image capture methodology described in [8] was successfully applied, allowing the creation of 24 high-quality panoramic images. Although the process was relatively fast per image, the total number of images generated a considerable workload.

The photogrammetry technique [5] also produced good results by generating 3D models of four sculptures on campus. However, the accuracy of the model

was affected in large sculptures such as "Todos los días" due to the quality of the images taken from a long distance. Despite this, the irregularities in the model were satisfactorily corrected.

The integration of these elements into the 3DVista engine enabled the cre-ation of a high-quality interactive tour, with functionalities that enhanced the navigation experience. This tour effectively represented the key areas of the cam-pus and was positively evaluated by both users familiar with the place and new visitors.

The final result, validated by participant feedback, demonstrates that the project successfully met the hypothesis initially proposed.

The observations from participants and the time-limited tasks in this study suggest the following improvements for future work:

- **Expansion of the university tour**: It is proposed to expand the tour to include all areas of the campus and improve navigation.
- **Digitization of more sculptures**: It is suggested to digitize most of the sculptures, excluding some large ones, to create a more comprehensive ex-perience.
- **Adaptation to virtual reality (VR)**: Although not a complex process, it is recommended to adapt the experience to VR using the 3DVista engine to make it more immersive.

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Enhancing the User Experience of PlanTEA: A Support Tool for Planning and Anticipation for Individuals with ASD

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Abstract. In individuals with Autism Spectrum Disorder, skills related to planning and mental flexibility are often impaired. Therefore, having applications that allow them to anticipate everyday and unavoidable situations can be highly beneficial in helping them face these activities with reduced stress and anxiety. To support this need, the PlanTEA application was developed. PlanTEA is a mobile application based on the use of pictograms that supports the anticipation and planning of activities and routines. This application has several versions, the latest of which (PlanTEA 3.0) incorporates a series of features and functionalities aimed at improving accessibility and better adapting to the specific characteristics and needs of the target user group. This article describes these features, as well as an evaluation conducted to validate them. The results of this evaluation indicate favorable acceptance levels, with notable strengths in usability and functionality. However, it also highlighted the need to address cognitive load, error control, and guidance issues to improve accessibility for less tech-savvy users and enhance the overall user experience. The feedback provided by respondents offers valuable insights for further development and enhancement of the application.

Keywords: Autism Spectrum Disorder (ASD), Design and evaluation, personal autonomy, Planning and routine anticipation, Usability and Accessibility, User experience.

1 Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition with a strong genetic basis that emerges in early childhood. It is characterized by deficits or delays in skill acquisition across various domains. Individuals with ASD often display stereotyped behaviors, rigid routines, and restricted, repetitive interests. Moreover, persistent impairments are also observed in social interaction, communication, and socialization [1]. ASD is one of the most prevalent emerging neurodevelopmental disorders in early childhood. However, it also significantly affects individuals beyond the pediatric population and impacts their surrounding environment.

Over the past four decades, the prevalence of ASD diagnoses has risen substantially [2]. According to a recent report from the World Health Organization, ASD affects approximately 1 in 160 children worldwide (0.63%), though prevalence rates vary by country and its diagnostic capacity. The condition's high degree of variability, known as the "spectrum", depends on the severity of impairment [3], with each individual presenting unique characteristics. These variations are influenced by factors such as developmental progress, available support, comorbid conditions (e.g. psychiatric disorders, intellectual disability) [4], and language development. Thus, individualized support is essential, particularly in assisting individuals with ASD in managing daily activities more effectively [3], a challenge that remains central for the scientific community [5].

For individuals with ASD, unfamiliar environments and situations can lead to significant anxiety. Tasks like shopping, attending medical appointments, or traveling can be particularly stressful for both individuals with ASD and their families [6]. To assist with such challenges, "anticipation notebooks" break down activities into sequential steps using visual representations (pictograms) and descriptive phrases, thus easing comprehension and reducing anxiety [7].

Technology has shown promise in supporting individuals with ASD, particularly in enhancing communication skills, social interaction, and autonomy [8]. While there has been an increase in the software

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applications for the ASD population, few focus on planning and anticipation of daily tasks. Furthermore, most fail to address the specific characteristics of ASD individuals, such as preference for visual processing, differences in sensory perception, attention to detail, preference for a certain routine or order, as well as certain sounds, objects, and people. As a result, many existing applications cannot effectively adapt to the unique needs, preferences, and requirements of each individual with ASD [9]. Several technological tools support individuals with ASD through pictogram-based communication and routine planning, each offering specific features. However, while some tools offer specialized functionalities—such as Doctor TEA and DictaPicto in medical contexts, or Araword with text-to-pictogram translation—most lack comprehensive planning capabilities or support for multimedia integration.

To address this gap, PlanTEA [10], an Android mobile application, was created to aid family members, therapists, and healthcare professionals in planning activity sequences and facilitating communication, particularly in clinical settings, through the use of pictograms. Its main objective is to provide "digital anticipation notebooks", thereby addressing the practical challenges associated with traditional methods, such as searching for pictograms, printing, cutting, and pasting. Since its inception, the PlanTEA application has evolved significantly, with several versions released. The initial version (PlanTEA 1.0) adhered to specific design guidelines tailored for individuals with autism (AutismGuide) [11]. It was evaluated with the participation of family members, caregivers, and experts in autism, software development, and usability [10]. Based on the findings of this evaluation, PlanTEA 2.0 was developed to address identified limitations and broaden its applicability beyond clinical settings. This version was evaluated by therapists, ASD experts, and usability specialists [12]. PlanTEA 2.0's user Experience (UX) was assessed using a methodology and UX tools specifically designed for ASD users [13][14]. Insights from both evaluations and feedback from experts in ASD from various Spanish associations (FESPAU, AUTRADE, and FACLM), contributed to the development of PlanTEA 3.0 [15]. This version represents a substantial improvement over its predecessors, incorporating features that enhance usability, accessibility, personalization, and adaptation to the unique needs of individuals with ASD. Experts from the collaborating associations have played a key role in the design of PlanTEA.

Therefore, this paper aims to describe the new functionalities and features of the latest version of PlanTEA, along with the results of the evaluation conducted by experts in usability and accessibility. To that end, the rest of the document is structured as follows: Section 2 describes the features and functionalities of PlanTEA's latest version; Section 3 outlines the evaluation process and presents the findings from the assessment. Finally, Section 4 discusses the main conclusions and potential directions for future work.

2 Functionalities of planTEA's latest version

The latest version of PlanTEA introduces a set of essential functionalities, developed and validated through the expertise of professionals from collaborating associations and the evaluation results of its previous versions [10][12]. As a result, it preserves the successful features and functionalities of earlier versions, ensuring a seamless transition between applications [15]. Thus, PlanTEA 3.0 supports two types of roles: planner and user with ASD. The user with the planner role will be responsible for creating and managing the plans, which are an ordered sequence of pictograms representing the steps to follow in a daily situation (Figure 1.a). On the other hand, users with ASD will be able to anticipate the situations represented in the plans through their visualization, simulation, and tracking (Figure 1.b).

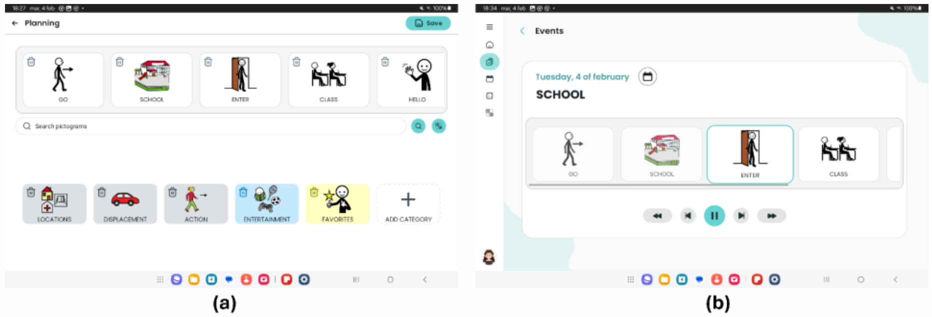

Fig. 1. (a) Planning editing functionality, available for the user with the planner role. (b) Appearance of the planning in the interface available for the user with ASD, with playback/simulation options.

The following subsections will describe in detail the main features of the latest version of PlanTEA, with a focus on those that enhance aspects related to usability, accessibility, personalization, and user adaptation.

2.1 Flexible and customized planning creation and editing

The application allows for the flexible creation and editing of plans, using a set of pictograms organized into categories.

PlanTEA 3.0 includes a pictogram search engine that searches into the ARASAAC repository. Thus, given a word, the application returns a set of pictograms to represent it, allowing the user to change until finding the one he/she is most interested in. The user can also create customized pictograms from the set of available pictograms (Figure 2.a), including images or real photos stored in the device's gallery and identifying it with the desired text, which allows for the inclusion of visual representations of people, places, or objects familiar to the user with ASD [16].

Moreover, PlanTEA 3.0 supports the selection of pictograms as "Favorites" as well as the creation of groups of them in customized categories. Both functionalities enable planners to quickly locate and use the most frequently used or preferred pictograms. It is also possible to associate text with the pictograms so that the planner can specify behavioral guidelines or social recommendations that will help the user with ASD in the depicted situation (Figure 2.b).

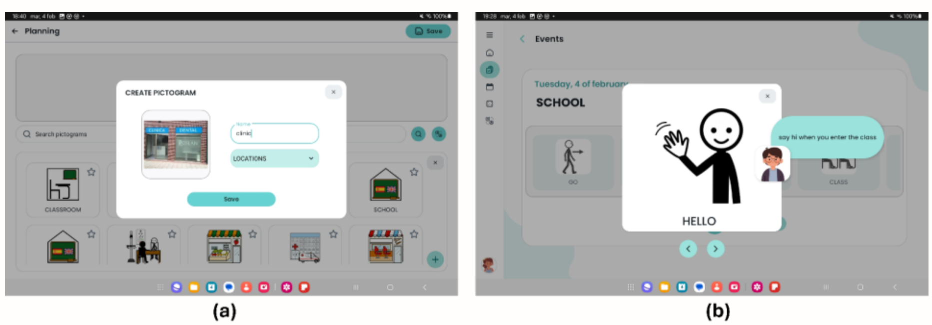

Fig. 2. (a) Functionality that allows adding custom images to the planning. (b) Functionality that allows associating recommendations and social guidelines to the pictograms.

The application also facilitates a very flexible editing of plans, since it supports the modification and deletion of steps (pictograms) in the sequence, as well as their reorganization, by means of direct manipulation techniques (drag-and-drop).

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2.2 Text-to-pictogram translation

A text-to-pictogram translator has been added to streamline the planning design process. It converts user-entered phrases into pictograms word by word. If multiple pictograms are available for a word, the user can select the most suitable one by clicking through the options provided (Figure 3).

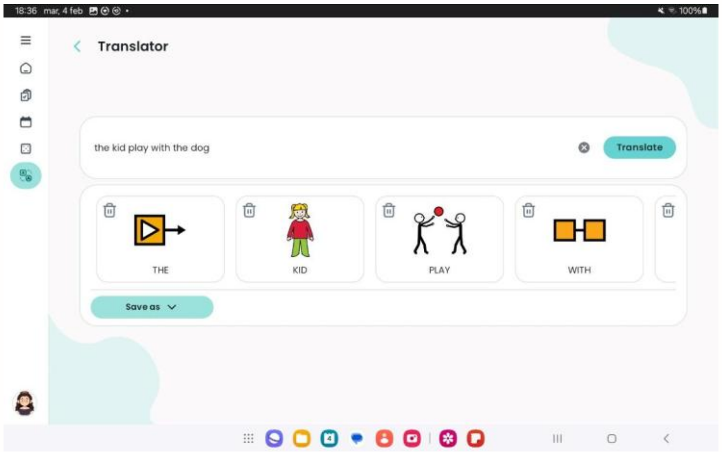

Fig. 3. User interface of the text-to-pictogram sequence translation functionality.

The application allows users to listen to the translated phrase for a more accessible experience. It also enables saving the translation as a plan for easy access and future reference.

2.3 Accessibility features

The development of the latest PlanTEA version focused on accessibility, applying design and evaluation strategies based on the Web Content Accessibility Guidelines (WCAG) from the W3C [17]. Additionally, specific design guidelines for applications aimed at the ASD users were considered [11][14].

The accessibility guidelines implemented in the latest version of PlanTEA adhere to the principles of perceivability, operability, understandability, and predictability. These principles ensure that information is easily identifiable, readable, comprehensible, and manageable for all users. Regarding perceivability, emphasis was placed on maintaining adequate contrast between text and background in key elements such as titles and labels. Additionally, a dark mode was incorporated into the interface (Figure 4.a) to enhance visual accessibility. A thorough review of the color palette used in previous versions allowed for improved differentiation and contrast, achieving a contrast ratio of 7.6:1, thereby complying with WCAG guideline 1.4.6. Furthermore, text and pictogram sizes were adjusted to optimize legibility. Another significant improvement was the integration of content descriptions (contentDescriptions) to enhance compatibility with screen readers such as TalkBack, along with hints to describe on-screen elements.

In terms of operability, the interface was designed to facilitate intuitive navigation and interaction through basic actions such as clicking and dragging, minimizing the need for complex gestures. Additionally, all touch elements were standardized to a minimum dimension of 48 pixels, ensuring ease of interaction for all users.

To enhance understandability and predictability, the application employs simple and clear language, avoiding technical jargon that could hinder comprehension. A consistent and repetitive structure was also maintained across screens and buttons, promoting ease of use and allowing users to anticipate interactions more effectively.

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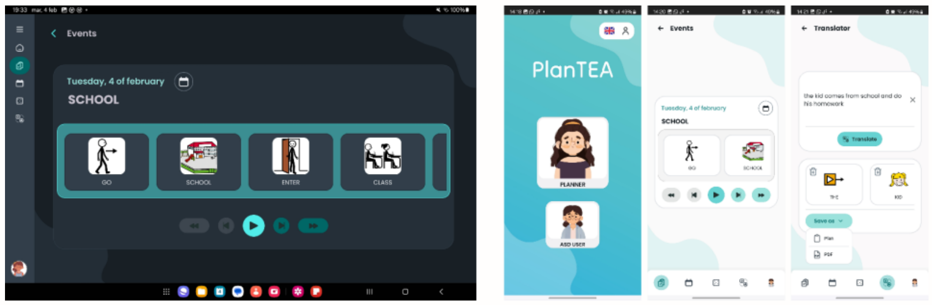
Furthermore, significant improvements have been made in multi-device deployment (portability). The previous version of PlanTEA was limited to tablet devices, restricting accessibility. The new version addresses this limitation by ensuring full compatibility with Android smartphones (Figure 4.b), expanding its usability across multiple devices.

As a result of these enhancements, the application now meets AA-level compliance with WCAG 2.2 standards, ensuring broad accessibility. Overall, these measures have strengthened the clarity and robustness of the interface, providing a more inclusive and user-centered experience.



(a) (b)

Fig. 4. (a) User interface appearance of PlanTEA in dark mode. (b) Application appearance on a mobile device (smartphone).

3 Assessing planTEA 3.0

To assess the latest version of PlanTEA, with a particular focus on usability, customization support, and accessibility, an evaluation was carried out involving 59 students from a Human-Computer Interaction course. These students possessed prior knowledge of usability, accessibility, and evaluation of both aspects.

In this evaluation, inspection (usability heuristics) and inquiry (subjective perception questionnaires) techniques were combined.

3.1 Purpose of the study and research questions

This study aims to explore key aspects of the evaluated system's usability and user perception. Specifically, the following research questions were formulated:

RQ1. Which usability and accessibility aspects are the most and least effectively supported in the PlanTEA app?

RQ2. How do participants perceive the usefulness of the interaction, flexibility and customization techniques supported by PlanTEA?

RQ3. To what extent are the visual metaphors used in the PlanTEA interface appropriate and effective?

RQ4. What is the users' subjective perception of PlanTEA's acceptance in terms of usefulness, ease of use, and intention to use?

Addressing these questions will provide valuable insights into the system's strengths and areas for improvement. The following subsection describes how the experiment was conducted, as well as the measurement instrument designed to evaluate PlanTEA.

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3.2 Experiment and measurement instrument

To address the research questions, an experiment was conducted in which participants first attended a lecture and seminar focused on the needs of individuals with ASD. Following this, the developers of PlanTEA, along with the lead researchers of the project, provided a detailed explanation of the primary functionalities of the application. Participants then completed a subjective opinion questionnaire, administered via a web-based form. The questionnaire was organized into several sections:

- **Previous experience**. This section included four initial questions regarding participants' prior knowledge in the following areas: Use of mobile applications for tablets (PE1); Use of applications designed for individuals with ASD (PE2); Design and programming of mobile user interfaces (PE3) and Knowledge of usability (PE4). Participants were asked to rate their familiarity with these aspects on a Likert scale from 1 to 5.
- **Usability and accessibility aspects of PlanTEA**. Based on Nielsen's heuristics [18], participants were asked to rate (on a 1 to 5 scale) various usability and accessibility aspects of the application (HU1 to HU12). These aspects included: Suitability for tasks (design of pictogram-based plans); Ease of learning; Feedback and system status visibility; Consistency and standardization; Flexibility and efficiency of use (e.g., deleting pictograms, drag-and-drop, etc.); Visual design and aesthetics of the app; Error control and prevention; Portability; Accessibility; Personalization/adaptation to the profile of the user; User assistance or guidance during tasks and Cognitive load or need for memorization.
- **Usefulness of PlanTEA's main functionalities**. This section assessed the perceived usefulness of PlanTEA's core functionalities, which provide flexibility and support for adaptation and customization (FUNC), as outlined in section 2.
- **Evaluation of visual metaphors in PlanTEA (Figure 5)**. Participants were asked to rate (on a 1 to 5 Likert scale) the appropriateness of the visual metaphors (icons) used in four key areas of the application (METAF): (1) PlanTEA navigation menu; (2) Defining an event; (3) Additional information for a pictogram and (4) Associating plans with specific days of the week.
- **Acceptance of PlanTEA**. Participants were asked to rate, on a Likert scale (from 1 to 5) the three dimensions of the Technology Acceptance Model (TAM) [19]: Perceived Ease of Use (PEU); Perceived Usefulness (PU) and Intention to Use (ITU), whether they would use the tool and whether they would recommend its use.
- **Open-Ended Questions**. The questionnaire concluded with three open-ended questions designed to gather feedback on the strengths and weaknesses of the application, as well as suggestions for improvement.

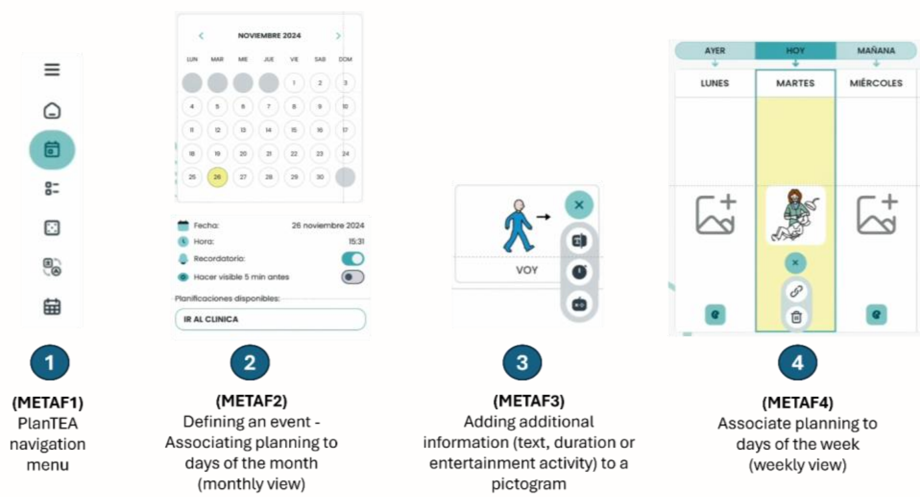

Fig. 5. Sets of visual metaphors used in PlanTEA.

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This structured instrument provided a comprehensive assessment of PlanTEA's usability, perceived usefulness, overall acceptance, and the specific aspects that users found most and least effective.

3.3 Data analysis and results

This section presents the analysis of the data collected during the study. A total of 59 participants took part in it, the majority of whom were male (84.75%), followed by females (13.56%), with a small percentage (1.69%) who preferred not to disclose their gender. The participants' familiarity with mobile applications for tablets (PE1) had a mean score of 4.00, indicating a high level of usage. In contrast, their experience with applications designed for individuals with autism (PE2) was relatively low, as reflected by a mean score of 1.56. The participants' knowledge of mobile user interface design and programming (PE3) had a mean score of 2.83, suggesting a moderate level of familiarity. Finally, their understanding of usability principles (PE4) was fairly high, with a mean score of 3.51.

RQ1. *Which usability and accessibility aspects are the most and least effectively supported in the PlanTEA app?*

The analysis of the usability aspects (HU1 to HU12) presented in Table 1 offers valuable insights into the participants' perceptions of the application's strengths and areas requiring improvement.

Among the highest-rated aspects were task adequacy (HU1) and personalization/adaptation to the profile of the user with autism (HU10), both receiving a mean score of 4.44. These results indicate that participants found the application particularly effective in supporting the design of schedules based on pictograms and offering personalized features tailored to the needs of users with autism. Additionally, the visual design (HU6) of the application was well-received, with a mean score of 4.42, suggesting that participants appreciated the aesthetics and overall appearance of the application.

Table 1. Descriptive statistics related to usability aspects in PlanTEA.

Variable	Usability aspect	Mean	Standard Deviation	Median	Mode
HU1	Task adequacy (design of plans based on pictograms)	4.44	0.62	5.0	5
HU2	Ease of learning	4.15	0.76	4.0	4
HU3	Feedback. System status visibility	4.12	0.70	4.0	4
HU4	Consistency and standardization	4.25	0.76	4.0	4
HU5	Flexibility and efficiency of use (deleting pictograms, drag-and-drop, etc.)	4.34	0.80	5.0	5
HU6	Visual design. App aesthetics	4.42	0.77	5.0	5
HU7	Error control and prevention	3.75	0.78	4.0	4
HU8	Portability	4.12	0.89	4.0	5
HU9	Accessibility	4.37	0.74	5.0	5
HU10	Personalization and customization based on the	4.44	0.68	5.0	5

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	profile of users with ASD				
HU11	User help or guidance during tasks	3.95	0.84	4.0	4
HU12	Cognitive load or need for memorization	3.36	1.06	3.0	4

Conversely, some usability aspects received relatively lower ratings, highlighting areas that may require further attention. The cognitive load or need for memorization (HU12) was the lowest-rated aspect, with a mean score of 3.36. This suggests that participants found the application somewhat demanding in terms of cognitive effort, implying the need to simplify tasks and reduce the mental load on users. Similarly, error control and prevention (HU7) and user guidance during tasks (HU11) received mean scores of 3.75 and 3.95, respectively, indicating potential areas for improvement in helping users avoid mistakes and providing clearer guidance throughout the application.

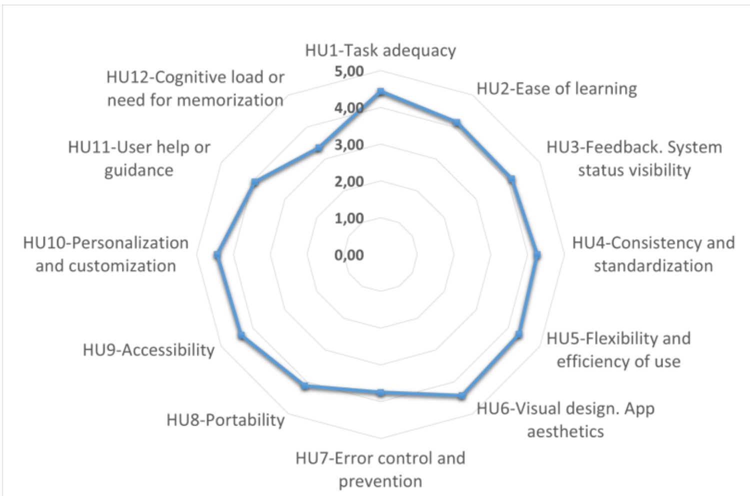

Fig. 6. Radar chart displaying the usability and accessibility ratings of the PlanTEA app.

Overall, the results underscore (Figure 6) the strengths of the application in terms of task adequacy, personalization, and visual design, which were highly valued by participants. However, they also highlight the importance of addressing cognitive load, enhancing error control, and improving user guidance to further enhance the overall usability of the application. By focusing on these areas, the application can provide an even more user-friendly and supportive experience for individuals with ASD.

RQ2. *How do participants perceive the usefulness of the interaction, flexibility and customization techniques supported by PlanTEA?*

The analysis of the functionalities (FUNC1 to FUNC6) presented in Table 2 reveals a highly positive perception of the evaluated functionalities, with all mean scores above 4.4 on a 5-point scale. The median and mode are consistently 5, suggesting that most participants rated these features at the highest level. Additionally, the low standard deviations (ranging from 0.54 to 0.77) reflect a strong consensus among users regarding the usefulness of these functionalities.

Text-to-pictogram translation (FUNC5) emerged as the highest-rated functionality, with a mean of 4.68 and a low standard deviation of 0.54, highlighting its perceived value and consistent support among respondents. Direct manipulation techniques for editing pictograms (FUNC6) followed closely with a mean of 4.61, suggesting that drag-and-drop editing is also highly appreciated, though with slightly more variation in responses (0.70 standard deviation). Additionally, integration with an external pictogram database (FUNC1) and the ability to create custom pictograms (FUNC2) received strong ratings (4.58 and 4.53, respectively).

Table 2. Descriptive statistics related to the usefulness of customization support functionalities in PlanTEA.

Variable	Customization support functionalities	Mean	Standard Deviation	Median	Mode
FUNC1	Connection/Integration with an external database for the search of standard pictograms (ARASAAC)	4.58	0.65	5.0	5
FUNC2	Ability to create custom pictograms using the ARASAAC library or the device's gallery	4.53	0.68	5.0	5
FUNC3	Ability to create custom categories of pictograms (e.g., to group pictograms about family members)	4.44	0.77	5.0	5
FUNC4	Ability to mark frequently used pictograms as "Favorites"	4.46	0.73	5.0	5
FUNC5	Text-to-pictogram translation	4.68	0.54	5.0	5
FUNC6	Direct manipulation techniques (drag-and-drop) for the editing/modification of pictograms	4.61	0.70	5.0	5

While marking frequently used pictograms as favorites (FUNC4) and creating custom pictogram categories (FUNC3) had the lowest mean ratings (4.46 and 4.44, respectively), they were still highly valued, with their median and mode at 5—showing that most users rated them at the highest level. The low standard deviations across all functionalities suggest a general agreement, reinforcing the idea that these features are widely regarded as essential.

Overall, the findings (Figure 7) indicate a strong user preference for customization, with text-to-pictogram translation and direct manipulation techniques standing out as the most favored functionalities.

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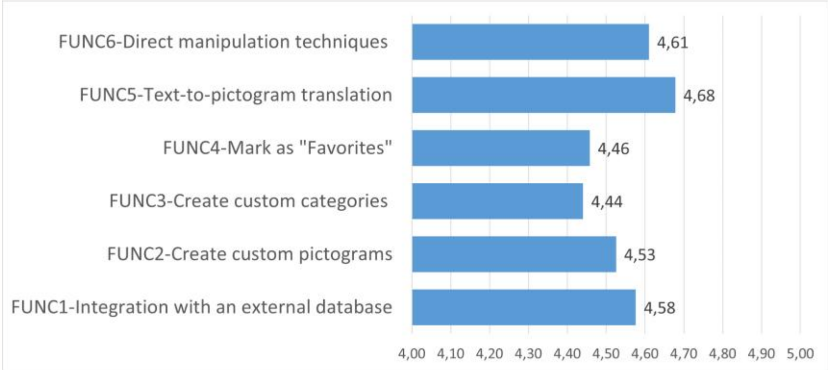

Fig. 7. Bar chart displaying the functionalities ranked by their usefulness in supporting customization, with higher bars indicating stronger perceived value in enabling personalized features.

RQ3. To what extent are the visual metaphors used in the PlanTEA interface appropriate and effective?

The results for the four variables METAF indicate a high level of adequacy in the metaphors used in these areas of the interface (Figure 5). METAF2, METAF3, and METAF4 stood out with median and mode values of 5, reflecting a high level of user satisfaction with these functionalities. These aspects were consistently rated highly by the majority of participants, suggesting the effectiveness of the metaphors in enhancing user understanding and interaction within the interface. However, METAF1 had a slightly lower mean score of 4.02 and the highest standard deviation (0.94), indicating greater variability in user responses. While it was still rated positively, this suggests that some users were less satisfied with this aspect compared to the others. This variability may indicate areas for further improvement to enhance the consistency of user experience.

In summary, while the overall feedback on the usability aspects was positive, there is room for improvement, particularly with METAF1. By addressing this area, it may be possible to achieve a more uniform and satisfactory user experience across all evaluated features.

RQ4. What is the users' subjective perception of PlanTEA's acceptance in terms of usefulness, ease of use, and intention to use?

The results for the variables PEU (Perceived Ease of Use), PU (Perceived Usefulness), ITU1, and ITU2 (Intention to Use) indicate a positive reception of the system among participants (Table 3).

The data indicates a strong perception of usefulness, with PU receiving the highest mean score (4.61) and a low standard deviation (0.56). This suggests that users find the tool highly beneficial, and there is a strong consensus on its value.

However, PEU has the lowest mean (4.25) and the highest standard deviation (0.76), indicating more variability in user opinions. While most users find the tool easy to use, some may encounter difficulties or require additional support. The mean score for PEU is 4.25 (sd = 0.76), suggesting that participants generally find the system easy to use. The intention to use the system is reflected in the scores for ITU1 and ITU2. The mean scores for ITU1 and ITU2 are 4.70 and 4.72, respectively, showing that participants are likely to use the system themselves and recommend it to others. The median and mode values for both ITU1 and ITU2 are also 5.00, indicating strong positive intentions towards using the system.

Table 3. Descriptive statistics related to the subjective perception of PlanTEA's acceptance in terms of usefulness, ease of use, and intention to use.

Variable	Item statement	Mean	Standard Deviation	Median	Mode
PEU	I find this system easy to use.	4.25	0.76	4.0	5

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PU	I believe this system helps create plans targeted at users with ASD.	4.61	0.56	5.0	5
ITU1	If I needed to plan and anticipate daily life situations for people with ASD, I would use this system.	4.46	0.73	5.0	5
ITU2	I would recommend using this system to people who need to plan and anticipate daily life situations for individuals with ASD.	4.64	0.66	5.0	5

Overall, these results (Figure 8) demonstrate that the system is well-received by participants in terms of ease of use, usefulness, and intention to use.

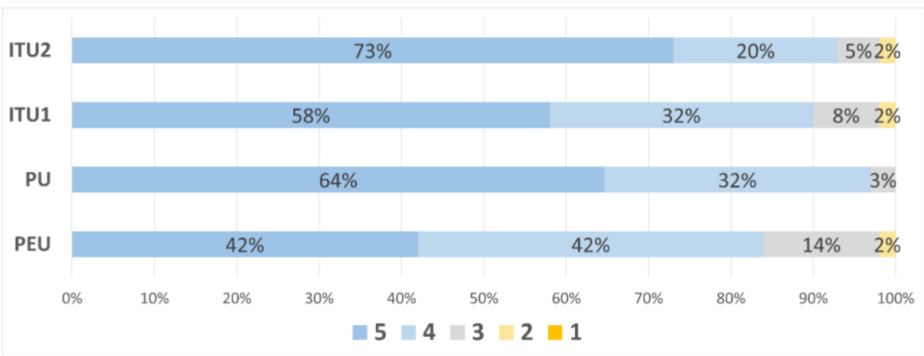

Fig. 8. Stacked bar chart showing the distribution of Likert scale responses for the variables Perceived Usefulness (PU), Perceived Ease of Use (PEU), and Intention to Use (ITU).

Strengths, weaknesses and proposals for improvement

The open-ended questions in the evaluation provided valuable insights into the strengths, weaknesses, and suggestions for the PlanTEA app. Here are some key points from the responses:

Strengths (OQ-Strong). Participants highlighted several strengths of the PlanTEA app. Many praised its simplicity and ease of use, noting that the app is intuitive and user-friendly. The integration with external databases and the translation of text to pictograms were also mentioned as significant advantages. Additionally, the app's visual design and the ability to facilitate communication for individuals with autism were frequently cited as strong points. Overall, the feedback indicates that users appreciate the app's functionality and its potential to improve the lives of its target audience.

Weaknesses (OQ-Weak). Despite the positive feedback, some participants identified areas for improvement. A common concern was the steep learning curve for new users, particularly those who are not tech-savvy. Some users also mentioned that the app could be overwhelming due to the need to memorize

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numerous icons. Additionally, there were comments about the design, suggesting that it could be further refined to enhance user experience. These points highlight the importance of making the app more accessible and user-friendly for a broader audience.

Proposals for improvement (OQ-Propos). Participants provided various suggestions to enhance the PlanTEA app. Some recommended adding audio features to assist users with auditory preferences. Others suggested ensuring that updates and improvements remain intuitive and do not overload the app with unnecessary information. There were also proposals for improving the design to make it more appealing and easier to use. Additionally, participants expressed a desire for the app to continue helping individuals with autism and their families, emphasizing the importance of maintaining its core functionality while exploring new features.

In summary, the open-ended responses reveal that while the PlanTEA app is highly valued for its simplicity, ease of use, and functionality, there are opportunities for improvement in terms of accessibility, design, and user support. The suggestions provided by participants offer valuable guidance for future updates and enhancements to better meet the needs of its users.

4 Conclusions and future work

The PlanTEA application arises to meet the planning and anticipation needs of people with ASD. This application has undergone several evolutions and has been subjected to multiple evaluations. The latest version (PlanTEA 3.0) aims to provide better support for accessibility and content customization for users with ASD. This paper describes the evaluation conducted on the features and functionalities incorporated to support this need.

The evaluation of the PlanTEA app demonstrates its overall effectiveness and positive reception among users. High scores in perceived usefulness, ease of use, and intention to use indicate that the app successfully meets the needs of its target audience. Participants particularly valued features such as integration with external databases and text-to-pictogram translation, highlighting their role in improving accessibility and usability. The app's simplicity, intuitive design, and functionality were well received, emphasizing its potential to enhance communication and planning for individuals with autism and their families.

The availability of an app like PlanTEA, which easily enables individuals with ASD to anticipate situations that deviate from their usual routines, carries important practical implications. By providing a clear understanding of what to expect next or what will occur in the future, the app can significantly reduce anxiety levels. This predictive capability helps individuals with autism navigate daily challenges more effectively, fostering a sense of control and stability in environments that may otherwise be overwhelming or unpredictable. Consequently, it supports both their emotional well-being and overall adaptability to change.

Despite these positive results, the study also identified areas for improvement. Some users reported challenges related to cognitive load, error control, and user guidance, suggesting that the app may be overwhelming for new or less tech-savvy users. Additionally, there were recommendations for refining the design to enhance the overall user experience. Addressing these concerns, particularly by reducing cognitive load and improving navigation, will be crucial to making the app more accessible to a broader audience. Therefore, future work should focus on incorporating user feedback to enhance functionality and usability. Key improvements will focus on reducing cognitive load by refining the interface, introducing audio support, expanding language options, and providing comprehensive tutorials to assist new users. Thus, the adaptability of PlanTEA's cognitive load to user needs reinforces its role as a valuable support tool for individuals with ASD, enhancing their ability to navigate daily life with greater ease and confidence.

On the other hand, the study's real-world relevance is limited by the fact that it is based on students rather than users with ASD or caregivers. Future work will consider evaluating the application with target users to improve its impact on assistive technology research [13][20].

Ultimately, this study establishes a foundation for future research on tailored and accessible user interfaces, and the broader implementation of such tools within inclusive frameworks for ASD people.

Acknowledgments

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Hacia el Mejoramiento de la Usabilidad y la UX de la Fototeca Digital de la Universidad de La Habana

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Resumen. El presente trabajo resume los resultados de las primeras aproximaciones al mejoramiento de la usabilidad y la experiencia de usuario de la Fototeca Digital de la Universidad de La Habana. En esta primera fase, se realizó la implementación del *System Usability Scale* (SUS) para determinar el nivel de usabilidad desde la perspectiva de los usuarios finales. Para ello, se abordaron aspectos teóricos y metodológicos relacionados con la evaluación de fototecas digitales como servicio bibliotecario desde una perspectiva centrada en la experiencia del usuario. En este sentido se consideraron dos indicadores principales: 1) La facilidad de navegación, y 2) La eficacia de las opciones de búsqueda avanzada. Los resultados preliminares indicaron que los participantes percibieron una curva de aprendizaje relativamente baja para el uso de la plataforma, lo cual puede ser un aspecto positivo para facilitar su adopción y uso por parte de los potenciales usuarios, determinado por el rango etario dominante.

Palabras Clave: Experiencia de Usuario, Servicio Bibliotecario, Fototeca Digital, Usabilidad, System Usability Scale.

1 Introducción

La era digital ha transformado radicalmente la forma en que accedemos y gestionamos la información, de forma tal que las bibliotecas digitales han emergido como una herramienta fundamental y un recurso invaluable para la preservación y acceso a colecciones de imágenes históricas y contemporáneas. La llegada de las Tecnologías de la Información y la Comunicación (TIC) y la digitalización de los servicios ha hecho posible que las fototecas encuentren su espacio en el mundo digital. Sin embargo, la efectividad de estos servicios depende en gran medida de su usabilidad y la facilidad con la que los usuarios pueden interactuar con ellos para encontrar, acceder y utilizar la información que contienen.

La creación de productos y servicios digitales que sean intuitivos, eficientes y satisfactorios para los usuarios depende en gran medida de la usabilidad y la experiencia de usuario. La facilidad de navegación, la rápida localización de la información y la ejecución sin dificultades de tareas, son aspectos clave que influyen tanto en la satisfacción del usuario como en la eficacia de estos servicios.

Según Nielsen [1], "la usabilidad es un atributo de calidad que evalúa lo fáciles que son las interfaces de usuario de usar". Está definida por 5 componentes de calidad: apreciabilidad, eficiencia, memorabilidad, errores y satisfacción. Mientras en la norma ISO 9241-11, la usabilidad hace referencia a la medida en que un producto puede ser utilizado por determinados usuarios para el alcance de sus metas específicas con efectividad, eficiencia, y satisfacción en un contexto específico de uso.

La usabilidad y la experiencia de usuario, también conocida como UX (del inglés *User Experience*) son conceptos fundamentales en el diseño y la evaluación de productos y servicios digitales. Mientras que la usabilidad de los servicios bibliotecarios y de las fototecas digitales se centra en la facilidad con la que los usuarios pueden interactuar con un sistema, producto o servicio, la experiencia de usuario abarca la impresión general que una persona tiene al utilizar dicho producto o servicio.

Como las bibliotecas académicas ofrecen servicios, tanto tradicionales como digitales, estas pueden evaluarse a través del enfoque de la experiencia de usuario y la usabilidad para identificar posibles problemas

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y áreas de mejora. La usabilidad de servicios bibliotecarios digitales, basados en [2, 3, 4, 5], es entendida como la capacidad que poseen sus prestaciones digitales para realizar las funciones de búsqueda y recuperación de información para las que fueron diseñadas, sin errores, en un tiempo establecido y satisfaciendo las expectativas de los usuarios.

La Biblioteca Central de la Universidad de La Habana, ha desarrollado informes sobre satisfacción de sus usuarios, como es el caso de la tesis de diploma de Salazar Tamayo [6]. Si bien esta investigación no aborda las fototecas digitales, ni la usabilidad, hace referencia a la importancia de implementar servicios bibliotecarios de forma digital para estar en correspondencia con los cambios tecnológicos actuales.

Entre los servicios de más reciente implementación de la Biblioteca Central de la Universidad de La Habana se encuentra la fototeca digital universitaria. Para contextualizar la investigación, primeramente, se define la fototeca digital como un "espacio o un sistema que permitirá a los usuarios hacer consultas de la colección fotográfica a través de sus computadoras, tabletas, teléfonos inteligentes, ya que el material está totalmente en formato digital, lo que facilitará su consulta y difusión, ya que no será necesario para acceder al material ir a la sede física, sino que podrá ser consultada a través del sistema" [7]. A pesar de que este servicio lleva un año de implementación aún no ha sido objeto de evaluación, por ello este trabajo se traza como objetivo determinar el nivel de usabilidad de la Fototeca Digital de la Universidad de La Habana.

Este trabajo forma parte de una investigación más amplia cuyo objetivo es proponer acciones de mejora para la experiencia de usuario en la Fototeca Digital de la Universidad de La Habana a partir del estudio de su usabilidad. Los resultados presentados en este trabajo son los obtenidos en la primera fase de esta investigación.

2 Métodos y técnicas

En el marco de esta investigación, la usabilidad es la variable que se utiliza para evaluar la experiencia de usuario en la Fototeca Digital de la Universidad de La Habana, a través de una encuesta aplicada a sus usuarios potenciales con el objetivo de comprender mejor su percepción sobre la usabilidad de este servicio y su satisfacción en general.

La Escala de Usabilidad del Sistema o *System Usability Scale* (SUS por sus siglas en inglés), es "*el cuestionario estandarizado más utilizado para la evaluación de la usabilidad percibida*" [8]. Brooke [9] afirma que esa herramienta permite obtener datos cuantitativos sobre la facilidad de uso y la eficacia de los servicios digitales, lo que proporciona información valiosa para evaluar y mejorar la experiencia del usuario; a lo que Lewis & Sauro [10] añaden que proporciona una medida global de la satisfacción con el sistema y subescalas de usabilidad y facilidad de aprendizaje.

Esta es una herramienta de uso extendido en los estudios de experiencia de usuario debido a su facilidad de aplicación, ya que brinda datos cuantitativos sobre la usabilidad, facilitando la comparación entre diferentes sistemas y que puede aplicarse para evaluar la usabilidad de todo tipo de sistemas y servicios digitales [11,12, 13].

La evaluación se realizó con una muestra de 51 usuarios, compuesta por estudiantes (64.7%), profesores e investigadores (29.4%) y técnicos en servicios de información (5.9%). El grupo etario más representado fue de 18 a 30 años (72.50%).

Los participantes completaron una encuesta que incluía 10 preguntas, con siete opciones de respuesta que iban desde "Totalmente en desacuerdo" hasta "Totalmente de acuerdo". Las encuestas se aplicaron *in situ*, y los participantes fueron instruidos sobre el uso de la fototeca digital antes de comenzar la evaluación.

A todos los encuestados se les solicitó la ejecución de las siguientes tareas: 1) Acceder al sitio de la fototeca digital (https://accesoabierto.uh.cu/s/creatiiif), 2) realizar búsquedas en el sitio, 3) hacer clic sobre un ítem y evaluar si es suficiente la descripción detallada que se ofrece, 4) Acceder al mismo sitio desde sus dispositivos móviles y expresar sus inconformidades. Previamente se les informó que se tomarían notas sobre su interacción con la plataforma y se contó con su autorización para hacerlo. Durante la realización de las tareas específicas,

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antes mencionadas, además de la observación de la interacción de los usuarios con la plataforma y se registraron las manifestaciones de inconformidad e insatisfacción de los usuarios.

Entre los indicadores utilizados para evaluar la usabilidad se encuentran: facilidad y velocidad de acceso, estado del sistema, consistencia y estándares, prevención de errores, flexibilidad, facilidad de uso, eficiencia de uso, estética y tipo de diseño, niveles de ayuda al usuario y sistema de recomendación.

Para el análisis de las respuestas a las 10 preguntas realizadas, se tuvieron en cuenta las 7 opciones de respuesta posibles: FD: Totalmente en desacuerdo, D: En desacuerdo, MD: Moderadamente en desacuerdo, I: Ni de acuerdo, ni en desacuerdo, MA: Moderadamente de acuerdo, A: De acuerdo y FA: Totalmente de acuerdo.

3 Análisis y discusión de los resultados

3.1 Resultados de la observación durante la interacción con la plataforma

El 100% de los usuarios coincidieron en que la plataforma cuenta con una arquitectura simple que facilita la navegación y que la búsqueda funciona correctamente, aunque les sería útil poder contar con una búsqueda más intuitiva que les recomiende términos de búsqueda, términos más buscados, ítems más visitados o descargados. Sin embargo, los investigadores en las páginas de resultados buscaron filtros para limitar los resultados de manera eficiente pero la plataforma no los provee.

Tanto investigadores como técnicos, se mostraron satisfechos con la organización temática del sitio y con la posibilidad de encontrar información como título, autor, fecha, descripción al hacer clic sobre un ítem. Sin embargo, señalaron como una ausencia importante metadatos técnicos que proveen información sobre especificaciones de la cámara o escáner, la resolución de las imágenes.

Durante la interacción fue posible registrar otros aspectos relevantes sobre la visualidad, funcionalidades para compartir y trabajar con las imágenes y de uso en general que contribuyen a mejorar la usabilidad de la fototeca. Un resumen de las fortalezas y oportunidades de mejora identificadas a partir de la observación de la interacción de los usuarios con la plataforma se presenta en la Tabla 1.

Tabla 1. Fortalezas y oportunidades de mejora de la plataforma Fototeca Digital de la Universidad de La Habana.

Fortalezas	**P/I**	**E**	**T**
Acceso a metadatos que permiten el uso ético del recurso a partir de la correcta citación y que además posibilitan contextualizar su uso académico.	x		x
Organización temática que facilitan la exploración inicial de materiales.	x		x
Búsqueda por palabras clave, barra de búsqueda muy visible y funcional que permite localizar recursos usando términos específicos.	x	x	x
Simplicidad de navegación.	x	x	x
Enlaces a colecciones destacadas	x	x	x
Acceso gratuito y abierto, no requiere autenticación.	x	x	x
Oportunidades de mejora	**P/I**	**E**	**T**
Falta ofrecer más información técnica como resolución, lo cual es clave para utilizar las imágenes en publicaciones académicas.	x		x
No hay opciones para refinar resultados por fecha exacta, tipo de medio (foto, negativo) o resolución.	x		
Aunque se permite ampliar las imágenes, no hay herramientas para comparar fotografías en paralelo o descargar versiones en alta resolución.	x		
Algunos elementos se ven desajustados en pantallas pequeñas.	x	x	x
No se sugieren términos relacionados al escribir en la barra de búsqueda.		x	

Falta de guías o tutoriales que expliquen cómo aprovechar mejor la plataforma, indicaciones sobre cómo citar las imágenes en trabajos académicos.	x	x	
La estética visual es funcional pero no es muy atractiva.		x	
No hay opciones para compartir imágenes en redes sociales o crear galerías personalizadas	x	x	x

Leyenda: P/I: profesor/Investigador, E: estudiante, T: Técnico en servicios de información

El análisis por cada uno de los grupos de usuarios nos releva prioridades que deben ser atendidas: los investigadores, profesores y técnicos buscan funciones avanzadas para refinar búsquedas y metadatos técnicos; los estudiantes, profesores e investigadores necesitan orientación y prefieren una visualidad más atractiva y 100% responsive, que no están completamente disponibles. Los usuarios además podrían necesitar acceso móvil, compartir imágenes y descargas en alta resolución, funcionalidades que algunas están parcialmente desarrolladas, pero no son óptimas.

3.2 Resultados de la encuesta posterior a la interacción

Ante la pregunta sí utilizarían la fototeca digital frecuentemente, el 90% de las respuestas reflejaron algún grado de acuerdo con la posibilidad de utilizar el servicio frecuentemente (ver Fig. 1), lo cual indica un nivel significativo de interés y disposición por parte de los usuarios hacia la Fototeca Digital. Además, puede inferirse que la comunidad universitaria encuestada percibe la necesidad de hacer un uso frecuente de este servicio lo cual podría conllevar altas probabilidades de que una vez que el usuario utilice el servicio vuelva a usarlo.

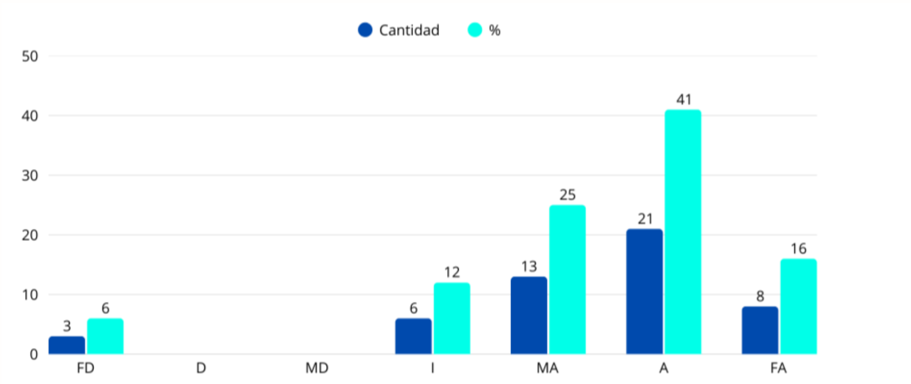

Fig. 1. Interés por el uso de la Fototeca Digital de la Universidad de La Habana (https://accesoabierto.uh.cu/s/creatiiif/).

En total, el 84.4% de los usuarios no consideró que la plataforma fuera incómoda de usar, lo cual sugiere que el diseño y la usabilidad del sistema fueron bien recibidos por los encuestados, y que la experiencia general de los usuarios fue positiva. Aunque el 13.7% estuvo moderadamente de acuerdo en que las interacciones con la plataforma son complejas, y el 3,57% se mostró neutral.

El 72.6% de los usuarios expresaron diferentes grados de confianza en el uso de la plataforma, lo cual sugiere que el diseño, la funcionalidad y la experiencia general del sistema les generó una sensación de seguridad y control durante su interacción. Al preguntarle a aquellos que se sintieron confiados sobre el esfuerzo que realizaron para aprender a usar la plataforma, el 89.74% de ellos (35 de 39) refirió que fue fácil.

Sin embargo, incluso para los que no se sintieron confiados, se percibe en el 60% de los casos (6 de 10) que la curva de aprendizaje es relativamente corta y no se observaron diferencias significativas por rango de edad.

El 81,08%, de los encuestados menores de 30 años, se muestran con algún grado de acuerdo sobre la facilidad de uso de la plataforma. Mientras al realizar similar análisis en el rango de edad que supera los 30 años, se obtuvo que el 57,14% considera que el servicio es fácil de usar.

Respecto a considerar si necesitan ayuda o soporte técnico para el uso de la plataforma, el 44,74% de los encuestados que consideraron fácil de usar el sistema refieren que sí la necesitan en alguna medida. En general e independiente a su respuesta a la pregunta sobre la facilidad de uso, la necesidad de asistencia técnica fue más percibida por los encuestados menores de 30 años (61,11%) que por el resto de los grupos etarios encuestados.

Estos resultados pueden deberse a que los de más experiencia en el mundo académico están más habituados a interactuar con funcionalidades avanzadas de sistemas digitales de búsqueda y recuperación como las que ofrece el servicio evaluado. También esta experiencia acumulada puede conllevar a mayor exigencia en la evaluación de la facilidad de uso pues poseen un mayor número de referencias de servicios similares con los cuáles comparar y mayor conocimiento sobre sus usos potenciales.

El 54.9% de los encuestados percibieron que las diferentes funcionalidades de la plataforma se encontraban bien integradas entre sí, lo cual puede ser un indicador positivo de la calidad y usabilidad del sistema. Por otro lado, el 35.3% consideran que la fototeca constituye un servicio consistente.

La interfaz intuitiva y fácil de usar ha permitido a los usuarios navegar por la fototeca digital de manera eficiente, encontrar rápidamente las imágenes deseadas y acceder a la información asociada sin dificultades. En general, los usuarios percibieron una curva de aprendizaje relativamente baja para dominar el uso del servicio digital, lo cual puede ser un aspecto positivo para facilitar su adopción y uso por parte de los potenciales usuarios, determinado por el rango etario dominante.

Asimismo, se pudo corroborar que la complejidad de las interacciones se corresponde con la complejidad de la tarea a desarrollar en la plataforma. Los estudiantes constituyen la categoría de usuario en la cual deben centrarse las mejoras en la plataforma al ser estos los que expresaron más necesidad de asistencia técnica para hacer un uso más óptimo.

3.3 Discusión

Los resultados de la observación y de la encuesta muestran que la Fototeca Digital Universitaria cumple con la función básica de repositorio de imágenes en acceso abierto, y aunque los hallazgos de este estudio inicial muestra que se satisfacen cuestiones elementales de usabilidad resultan oportunidades de mejora: la implementación de filtros avanzados, mayor disponibilidad de metadatos técnicos, diseño visual más atractivo y totalmente responsive, integración de funcionalidades de análisis y comparación de imágenes y la inclusión de recursos educativos que le permitan a sus usuarios sacar mayor partido a la plataforma.

4 Conclusiones

Los resultados muestran que la Fototeca Digital Universitaria cumple con la función básica de repositorio de imágenes, pero carece de elementos de experiencia de usuario ajustados a las tendencias actuales de diseño web y funciones específicas adaptadas a cada grupo de usuarios.

Entre las acciones inmediata para potenciar la usabilidad de la fototeca se encuentra la implementación de un proceso de evaluación heurística. A través de ese estudio, se podrá identificar problemas específicos de la interfaz que pudieron no ser evidentes en el análisis mediante el SUS, incluyendo: la detección de inconsistencias, problemas de navegación y barreras en la accesibilidad. Al abordar estos problemas, se espera una mejora significativa en la eficiencia y satisfacción del usuario al interactuar con la Fototeca Digital.

En este sentido, se espera que los resultados de ambos estudios contribuyan a lograr una comprensión holística de la experiencia del usuario, reflejándose en recomendaciones prácticas que faciliten el rediseño de la interfaz de la Fototeca Digital, promoviendo un entorno digital más intuitivo y accesible. Esto, a su vez, fomentará un aumento en la aceptación y el uso de la Fototeca, contribuyendo a su éxito y relevancia como recurso académico y cultural.

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Conflicto de Intereses. Los autores A, B y C formaron parte del equipo responsable del diseño, implementación y/o gestión operativa de la Fototeca Digital. A pesar de la relación institucional de los autores con el objeto de estudio, se garantiza que el artículo sigue los principios de transparencia, honestidad académica y equilibrio crítico. Los datos y hallazgos se presentan sin omitir limitaciones o desafíos identificados durante el proceso de mejora. El autor D declara que no existen conflictos de intereses.

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Heuristic Evaluation for Improving Usability in LMS Platforms: A Study at CEVEC Virtual College

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Abstract. Information and Communication Technologies in education have established virtual learning environments as pivotal tools for continuous personal and professional development. This study uses Nielsen's heuristics adapted to educational contexts to evaluate the usability of Comfacauca's Virtual Business Education Center and its Learning Management System. Using a mixed methods approach within the User-Centered Design framework, the platform's usability was evaluated through a System Usability Scale questionnaire, think aloud protocols, and heuristic evaluations. Participants, mainly adult learners, accessed educational materials and participated in forums while their interactions were observed and analyzed. An empathy map was developed to contextualize user needs, revealing learners' specific challenges. The results identified that the Learning Management System achieved a high score of 73.9, significantly above the threshold of acceptable usability, indicating a strong level of perceived usability. In addition, problems were identified, such as navigational inefficiencies and design flaws, which hindered the learning experience. The results indicate that usability is a determining factor in the success of Learning Management Systems, as it allows users to focus on educational content rather than grappling with platform complexities. This study contributes to the domain by proposing a heuristic evaluation framework specifically for evaluating Learning Management System platforms, especially for adult learners, and highlights the potential of usability improvements to indirectly increase academic retention and performance.

Keywords: Usability, Learning Management System, User-Centered Design, Adult Learners.

1 Introduction

Information and Communication Technology (ICT)-mediated education has established itself as a cornerstone of the young and adult population's continuous personal and professional development, facilitating the completion of basic and secondary education for individuals who did not complete it in previous stages of their lives [1]. In 2021, the global value of the ICT-mediated education market was estimated to reach $315 billion, with a projected annual growth rate of 9.1% [2]. Likewise, the COVID-19 pandemic acted as a significant catalyst for the growth of ICT-mediated education, affecting more than 90% of students worldwide due to the closure of educational institutions, driving the adoption of e-learning solutions and causing a boom in this type of education [3].

In this context, the Centro Educativo Virtual Empresarial Comfacauca (CEVEC) in Popayán, Cauca, Colombia, is an innovative and accessible solution for young people and adult education. Using the Moodle Learning Management System [4], widely recognized in virtual education, CEVEC offers students the opportunity to continue their education through a flexible and meticulously structured online learning environment. Since its implementation two years ago, CEVEC has trained teachers to create educational content and adopted the ADDIE instructional design model [5] to structure the platform, ensuring a solid pedagogical foundation. To date, 458 students have enrolled, and 132 have graduated, demonstrating this initiative's efficacy and scope.

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As the platform expands, ensuring its usability meets users' expectations and needs is important. Furthermore, usability is considered a determining factor for the success of any Learning Management System (LMS) [6]. This allows users to navigate and use the system efficiently and smoothly, facilitating teaching and learning. Thus, users can concentrate on the educational content rather than struggling with how to use the platform [7].

Several studies have assessed users' perceived usability of LMSs in this context. For example, Orfanou et al. in [6] conducted a study with the participation of 769 students who evaluated two LMSs, eClass and Moodle, concluding that the perceived usability is satisfactory. Similarly, Gomes in [8] performs a state-of-the-art review on the adaptability and usability of an academic LMS based on WAMMI usability factors. Finally, specific tools have been developed, such as the frameworks mentioned in [9], which propose a practical tool to identify the usability determinants in designing more efficient LMS.

Given the importance of usability evaluation in LMS platforms for ensuring quality standards, this study employs Nielsen's heuristics for platform usability assessment. Furthermore, in line with the User-Centered Design (UCD) paradigm [10], we proceeded to characterize the profile of adult users belonging to CEVEC, allowing us to adapt the particularities of the evaluation approach to this specific group. For data collection during usability testing, the think aloud protocol was implemented, which allowed users to express their thoughts and mental processes while interacting with the platform [11]. The resulting empirical data were fundamental for understanding the adult population's specific needs and, subsequently, for adapting the Nielsen heuristics to this specific user population.

Finally, the main objective of this research is to optimize the user experience within the CEVEC virtual learning environment by evaluating its LMS. Additionally, it seeks to provide a reference framework for evaluating usability in similar educational platforms aimed at the adult population. Therefore, this research differs from similar research in that it proposes an adaptation of Nielsen's heuristics to support the improvement of the learning experience of adults in this type of platform.

2 Materials and methods

To evaluate the usability of the CEVEC virtual learning environment, a mixed methods approach [12] based on UCD principles was employed (Figure 1). This approach integrated quantitative and qualitative data collection and analysis techniques, enabling a complete understanding of the user experience. Relevant prior studies in the domain were also consulted, as the study by Orfanou et al. in [6].

The evaluation framework comprised several key elements. First, System Usability Scale (SUS) questionnaires [13] quantified user perceptions. Second, think aloud protocols [14] captured users' real-time interactions and cognitive processes during task performance. Finally, a heuristic evaluation, adapted for educational contexts and based on Nielsen's principles [15], identified potential design flaws from the user's perspective.

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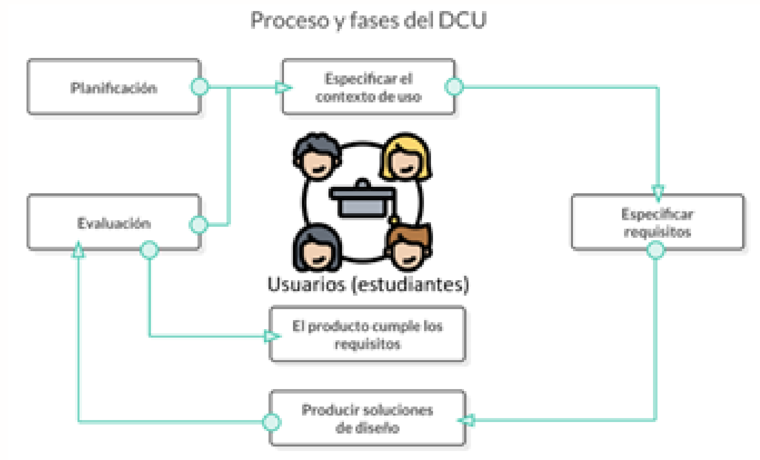

Fig. 1. Methodological structure used in the research is based on the UCD method.

2.1 Description of the methodological process employed

The case study applied the UCD method, focusing on understanding the school's students, who represent the research's unit of analysis. The information-gathering process is based on agile methods (LEAN) to obtain as much data as possible. To this end, an empathy map was constructed with the student's profile, which is presented in Figure 2.

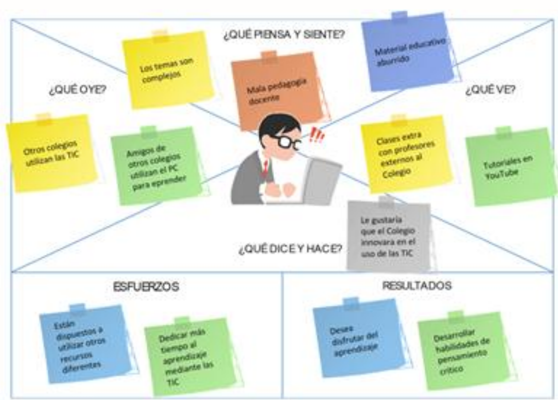

Fig. 2. Empathy map summarizing the profile and context of CEVEC student users.

In this context, the present research was structured in five fundamental phases.

- Phase 1. Diagnosis: Using the CEVEC Learning Management System, a series of tests and surveys were conducted to identify adult learners' difficulties and specific needs. These included semi-structured interviews and usability questionnaires adapted from the SUS. In addition, a think aloud protocol was used to capture users' thoughts and mental processes during interaction with the platform.
- Phase 2. Planning: Specific tasks were designed for participants to perform on the platform, such as accessing the platform, accessing educational materials, answering questionnaires, and participating in forums, among other recurring user activities in the LMS.
- Phase 3. Creativity: A usability evaluation methodology based on Nielsen heuristics was employed, adapted to better address the specific needs of adult CEVEC users. A set of heuristics was explicitly developed for educational LMSs targeting adults.

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– Phase 4. Implementation: Usability evaluation was conducted on the CEVEC platform through direct observation of participants as they performed the planned tasks. Observers took detailed notes on the usability problems encountered and collected user suggestions for improvements [16]. Subsequently, interviews were conducted to gain insight into the users' experiences.
– Phase 5. Analysis: The results derived from implementing the usability evaluation methodology were examined. This included statistical analysis of quantitative data collected through the SUS questionnaires and qualitative analysis of interviews and think-aloud session observations. Patterns were identified, and potential improvements were suggested.

2.2 Experimental design

The experiment was conducted with the participation of 50 CEVEC students, who had an average age of 28 years and an age range from 16 to 60 years old. This age distribution allowed us to observe the experiment's impact on a broad age spectrum because education at CEVEC is organized in school cycles, making it possible to group students according to their educational level. In this experiment, students from all cycles were included: Cycle III (grades 6 and 7), Cycle IVA (grade 8), Cycle IVB (grade 9), Cycle V (grade 10), and Cycle VI (grade 11). Likewise, the sampling was random in principle because all the students of the mentioned cycles were invited, employing a non-probabilistic sampling by convenience.

The experimental period covered May 28 to June 10, 2024. During this time, various activities and evaluations were implemented to estimate the students' usability of the platform. The experimental units were the CEVEC students themselves, who actively participated in all phases of the experiment and were treated as individual units of analysis.

For data collection, a questionnaire adapted to the institutional context was used, substituting the term "system" for "platform" (a colloquial term familiar to participants). The data were collected using a digital form and distributed among the participants from different school years. Finally, it is important to indicate that the Figures in this text are presented in Spanish because they represent the specific artifacts of the study's context.

2.3 Description of the think aloud protocol

The study's objective was to evaluate the usability of the CEVEC platform using the think-aloud protocol to identify problems with navigation, comprehension, and use of the LMS. Students were randomly selected, with special emphasis on adults who are representative of the target audience, to obtain a variety of perspectives. Testing was conducted in a controlled, distraction-free environment with access to the platform and pre-prepared test questionnaires.

The tasks evaluated included platform registration, course navigation, and quiz completion, typical activities within educational contexts. The study protocol comprised an introduction, think-aloud instructions, platform overview, task execution, follow-up questions, data recording, and conclusions.

The data collected during the evaluation sessions were analyzed to identify recurring patterns and specific problems, which were classified according to their severity and priority for correction. Finally, a report of results was prepared that included the results obtained, specific recommendations, and suggested actions to improve the usability of the CEVEC platform.

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Fig. 3. The SUS questionnaire applied to CEVEC students.

2.4 Adaptation of Nielsen heuristics

Nielsen's usability heuristics, widely recognized in the field of human-computer interaction, were adapted and contextualized for the specific evaluation undertaken in this research to address the particularities of the educational environment. In this sense, while Nielsen's original heuristics focus on general usability, the adapted heuristics presented here incorporate pedagogical principles and considerations of learning, teaching, and access to education.

The main modification lies in expanding the scope of the evaluation from assessing conventional usability to including pedagogical relevance of content, assessment of interactivity and active participation, accessibility, and educational equity, among other elements. In addition, new heuristic categories are introduced, such as Relevance of educational content, Accessibility and educational equity, and Personalization of learning (Table 1).

In this sense, applying these adapted heuristics provides a relevant methodological framework for usability evaluation within this educational context, facilitating the identification of strengths and weaknesses in the LMS's design and functionality.

Table 1. Accessibility and educational equity, and Personalization of learning.

Heuristics	Metric
Adaptability to the educational environment	The site provides a user-friendly interface suitable for the educational environment. The navigation and design elements are designed with the specific needs of students and teachers in mind.
Relevance of educational content	Site content is aligned with educational and curricular objectives.

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	Diversified and updated content covering various topics and educational levels is provided. The site offers educational resources in different formats to suit various learning styles.
Interactivity and participation	Active interaction between students and teachers is encouraged through forums, chats, or collaborative activities. Students can actively participate in learning through hands-on activities, exercises, and interactive assessments. Immediate and personalized feedback is provided to facilitate learning and continuous improvement.
Accessibility and educational equity	The website is accessible to users with different abilities and special needs. Personalization and customization options are provided to ensure an inclusive educational experience for all students. Educational equity is promoted by providing all users with free or affordable educational resources.
Security and data protection	The site implements robust security measures to protect users' privacy and personal data. Clear and transparent policies are established regarding collecting, storing, and using user information. Guidance and resources are provided to educate users about safe online practices and protecting personal information.
Personalization of learning	The site offers customization options that allow students to tailor the content and pace of learning to their individual needs. Content and educational resource recommendations are provided based on each student's progress and preferences.
Collaboration and educational community	Collaboration between students, teachers, and parents is encouraged through dedicated tools and spaces for discussions, group projects, and joint activities. The site facilitates the creation and participation in online learning communities where users can share resources, ideas, and educational experiences.
Aesthetics and minimalist design	The information is relevant, the content is well-classified, the content is well-organized and the content is well distributed throughout the site.
Evaluation and progress monitoring	Varied and meaningful assessment tools allow teachers to measure student progress and performance effectively. Students can track their progress and receive continuous feedback on their performance and areas for improvement.
Resources and support for	The site provides a wide range of educational resources, tutorials, and guides that enable students to learn autonomously and self-directedly.

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autonomous learning	Tools and strategies are offered to develop study, organization, and time management skills that support independent learning.
Integration of educational technology	Innovative technological tools and platforms enrich the learning experience and promote creativity and active student participation. The site provides guidance and resources to train teachers and students to use educational technology effectively in the classroom and beyond.
Speed and media	The site content can be accessed only in text form . The media (images, video, sound) take too long to load the site. The size of the files is indicated when downloading files from the site is possible. The technical quality of videos, images, and sound is acceptable. The media used reinforces the content of the message. Global rating of the platform.

3 Results

This section presents the main results obtained from the survey applied to the individual CEVEC study units, focusing on the level of satisfaction with the usability of the LMS platform.

3.1 Survey results (Adapted SUS Questionnaires)

In reviewing the results of the surveys (Figure 4), it was observed that the promise of responses on the odd statements was 15.24, while on the even statements, it was 14.32. This resulted in a calculated SUS score of 73.9. According to the available literature, a score equal to or above 68 indicates acceptable usability, while a score below 68 suggests significant deficiencies in usability. Therefore, it can be inferred that the CEVEC silver-form LMS exceeds the average threshold, evidencing above-average usability.

In this sense, 85% of users intend to use the platform regularly. In addition, 90% rated the interface as intuitive and accessible, suggesting a reduced learning curve. 88% considered that the platform does not require technical support or additional complex operations. In addition, 87% of respondents noted cohesion between functions and facilitating navigation, and 89% estimated that most users acquire operational competence with the LMS in less than half an hour. Additionally, areas for improvement were identified, such as the need to implement more confirmation and feedback messages, especially when completing critical tasks, according to 75% of users. In addition, 80% recommended including options such as "save and continue later" and a progress bar in the questionnaires.

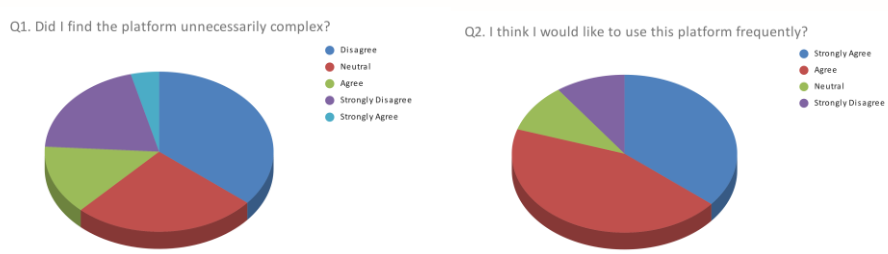

Fig. 4. Results of some of the heuristics are estimated in the usability evaluation of the platform.

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These results indicate a general positive trend towards frequent use of the platform, with most students showing a favorable predisposition towards its use. Most responses suggest that the platform is not complex, reflecting a positive perception of simplicity and ease of navigation. In addition, the survey reveals that technical support is not considered necessary to use the platform, suggesting an adequate learning curve and an intuitive interface.

Some students perceive the platform's functionalities to operate cohesively, suggesting a well-designed information architecture and smooth user experience. The consistency between the different functions and the ease of learning reinforces the idea that the platform is intuitive and accessible to a broad audience, considering the age range of the users.

In this line, the platform was perceived as safe and reliable, providing consistency and clarity in its use and the learning environment. Students tend to value usability aspects positively, such as ease of use, simplicity, consistency, and integration of functions. In addition, the perception is that neither an extensive learning curve nor constant technical support is required to reinforce the positive assessment of the platform.

3.2 Think aloud protocol in measuring LMS usability

The literature establishes that the SUS questionnaire is a reliable tool for evaluating the usability of web platforms. However, it is essential to complement this evaluation with qualitative methods that allow observing how tasks are carried out on the website under study. For this purpose, the think aloud protocol was used, providing qualitative results and insights into using the LMS platform. This study was conducted with the CEVEC units of study and applied to students, including activities such as greetings and introductions, think aloud instructions, and executing tasks on the platform by all participants in the protocol. Fifty students participated in the think aloud protocol, ranging in age from 16 to 60 years, and had experience in the use of technology ranging from one year to more than ten years.

Fig. 5. Participants in the think aloud protocol.

The results of the think aloud protocol revealed that the platform's use was straightforward. The mandatory fields were clearly labeled, facilitating the task's understanding. However, the lack of a successful registration confirmation message was noted, which could detract us from the user experience.

Participants felt that navigation through the course was straightforward and that the modules were clearly labeled. However, messages indicating the following steps and confirmation at the end of each course section were identified as needed, which could provide more explicit guidance and reduce uncertainty during navigation.

The questionnaire's completion was considered intuitive, and the instructions were clear. However, the lack of a confirmation message at the end of the questionnaire was highlighted. In addition, an option to save and

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continue later was suggested, as well as a progress bar to indicate completed and remaining questions, which improved the user experience by providing greater control and visibility over progress.

Participants described the tasks as simple, intuitive, quick, and straightforward. The evaluated tasks did not present navigation problems, but the need for messages providing status information at the end of a task was identified. It was also recommended that an option to save and continue later, a feature considered but not implemented in the prototype, and a progress bar should be included when completing the questionnaire to indicate completed and remaining questions.

4 Discussions of the results

The results of this research provide findings on the usability of Virtual Learning Environments (VLEs), exemplified by the case of the Comfacauca CEVEC LMS. The high SUS score of 73.9, which significantly exceeds the acceptable usability threshold of 68 proposed by Bangor et al. in [17], demonstrates that the CEVEC platform achieves a high level of usability, being noteworthy given the variability of the target demographic group, students, who often have different levels of digital literacy and may face challenges in adopting new technologies [18]. In this regard, the results are in line with those proposed in other research, such as that of Orfanou et al. in [6], who reported satisfactory levels of usability for Moodle-based LMS platforms, suggesting that the CEVEC base in Moodle contributes to its strong usability benchmark.

In this regard, positive feedback obtained through quantitative (SUS questionnaires) and qualitative (think aloud protocols) methods reinforces this claim, as users find the platform intuitive, easy to navigate, and require minimal technical assistance. Ease of use is crucial in adult education contexts [19], where learners prioritize efficient access to educational content and practical learning experience, minimizing distractions from the platform itself [7]. The perception of a short learning curve and adequate LMS functionality indicate a successful user-centered design for CEVEC. These results demonstrate the effectiveness of the ADDIE instructional design model employed during the development of CEVEC, which emphasizes structured, user-centered planning [20].

Notably, the study's methodological approach, based on UCD principles and employing mixed methods, is a strength. The initial diagnostic phase, which focused on understanding the specific needs and challenges of CEVEC students, was important in contextualizing the usability evaluation. In addition, adapting the Nielsen heuristic to incorporate pedagogical considerations, accessibility, and specific student needs represents a contribution to the domain, which goes beyond generic usability principles and offers a more specific framework for evaluating educational platforms such as LMSs.

Finally, the think aloud protocol provided important qualitative data, revealing specific areas for improvement despite the overall positive usability. The identified need for confirmation messages (e.g., successful registration, section completion), features such as "save and continue later," and progress indicators are helpful ideas for future platform iterations. These adjustments can improve the user experience, especially in mitigating uncertainty and fostering a sense of control during learning activities [21].

5 Conclusions

This study evaluated the usability of CEVEC's LMS, an online learning platform built on Moodle, by adapting Nielsen heuristics for educational environments. Integrating qualitative methods, such as the think aloud protocol, with standardized tools, such as the SUS and the UCD framework, provided a specific assessment of the platform's effectiveness, efficiency, and user satisfaction. The results indicate that the CEVEC LMS is perceived as intuitive and easy to navigate, with clearly labeled modules and required fields that facilitate user interaction. These attributes align with the needs of adult learners, who prioritize efficient access to educational resources and minimal technical assistance, as corroborated by previous research in this area.

Despite the strengths, the evaluation identified areas for improvement, including minor inconsistencies in the navigation flow and the need for additional user guidance in specific platform sections. These findings underscore the value of adapting the Nielsen heuristic to the specific requirements of LMSs, where usability goes beyond functionality to encompass and support pedagogical effectiveness and learner engagement. Positive feedback from participants on the simplicity and accessibility of the platform reaffirms the potential of Moodle-based systems to support distance learning, particularly for adult populations seeking to complete basic and secondary education.

This research contributes to the growing scientific knowledge about usability in virtual learning environments by demonstrating the effectiveness of applying Nielsen's heuristic adaptations to identify strengths and actionable improvements. Future studies could extend these results by incorporating longitudinal data to assess the sustained impact of usability improvements on student outcomes such as retention and academic performance. In addition, comparative analyses across various LMS platforms could further refine the applicability of these tailored heuristics.

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Implementation of an Electronic Data Acquisition System for Integration into the Development of Educational Platforms

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Abstract. Data acquisition systems (DAQ) play a crucial role in the collection and analysis of real-time information for a wide variety of applications. These systems allow the conversion of physical signals, such as temperature, pressure, or motion, into processable digital data. As technologies advance, the accuracy, speed, and flexibility of data acquisition systems continue to improve, opening new possibilities for the creation of interactive and dynamic platforms in different fields. This paper presents the implementation of a data acquisition system, which will be the technological basis for the development of various platforms applied in the educational field. The software of this system consists of a graphical control interface developed in the Python programming environment from various widgets such as frames, buttons, scales, labels, displays, among others. In the hardware instrumentation of the system, various elementary components were used, such as an electronic card for reading and writing signals, analog sensors, buttons, and various types of actuators. This first prototype uses a serial communication protocol, achieving a data transfer rate of 115,200 bauds/second (sampling rate = 2.5 KHz.). Incorporating these types of DAQ systems into educational platforms makes it possible to design tools that promote hands-on learning, experimentation, and problem-solving. These are key aspects of teaching STEM subjects (Science, Technology, Engineering, and Mathematics). This article explores how implementing data acquisition systems can transform the design and functionality of educational devices, enhancing the learning experience and enabling greater interaction between content and learner.

Keywords: Data Acquisition Systems (DAQ), Educational Technology, Educational Platforms, STEM Methodology, Educational Data Analysis, Interactive Devices.

1 Introduction

Over the course of technological evolution in education, data acquisition systems (DAQs) have emerged as a fundamental tool for improving practical education. These systems enable the capture and processing of physical signals through sensors and actuators, facilitating the creation of dynamic and experimental learning environments. DAQs provide an effective way to link theory with practice, allowing students to observe physical phenomena in real time and apply theoretical concepts to real-life situations [1]. This is particularly valuable in disciplines such as physics, biology, and engineering, where experimentation is essential for a deep understanding of principles. The use of data acquisition technologies in educational contexts not only facilitates access to practical experiences but also encourages active and collaborative learning. Educational platforms that integrate these systems offer a problem-based approach, enhancing student participation and engagement [2]. Furthermore, DAQs allow for personalized learning by providing real-time data that can be analyzed and discussed, which supports informed decision-making regarding the educational process. The implementation of these technologies in schools and universities also opens up new possibilities for the creation of interactive educational devices. Designing educational platforms using DAQ systems has the potential to transform the way students interact with knowledge, making learning more accessible, flexible, and inclusive [3].

Chapter 2 addresses the state of the art regarding the application of data acquisition systems in the educational field. Chapter 3 describes the architecture and development of the data acquisition system implementation presented in this article. Chapter 4 presents the results obtained through the graphical interface implemented,

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and the accessibility level of the prototype system's user interface . Finally, Chapter 5 offers a reflection on the results obtained and presents the final conclusions.

2 State of the art on the application of DAQs in education

Data acquisition systems (DAQs) have transformed the way teaching and learning occur in educational environments. This article provides a state-of-the-art review of the application of DAQ systems in education, exploring their evolution, benefits, and challenges. Recent research was reviewed, highlighting the impact of these systems on learning, accessibility to emerging technologies, and their integration with tools such as sensors, analysis software, and interactive platforms. Current and future trends are also analyzed, including the incorporation of artificial intelligence and machine learning into educational processes.

An example is described in [4], where university-level students apply DAQs in the development of "Internet of Things" platforms. The practical results indicate that students significantly improved their emotional level, knowledge level, and innovation level after studying the course.

The work mentioned in [5] describes the use of DAQs by elementary school students to develop their programming and computational thinking skills. The results show that in recent years, smart toys concern special sciences (programming) and some 21st century skills (STEM and computational thinking). In contrast, in the first 20 centuries, interest focused more on transverse skills, such as collaboration, emotional thinking, symbolic thinking, storytelling, and problem solving.

DAQs have also been used in the development of augmented reality systems, as mentioned in [6], where high school students are developing an initial phase of experimentation with this technology.

The platforms with DAQs most used in education are robotic systems, two examples are described in [7] and [8], respectively where primary school students use educational robotics combining storytelling, results show that an increase in computational thinking is evident after the intervention of robotics-based storytelling activities also the results demonstrate the positive influence of project-based teaching using educational robots on the development of student competencies, especially the important key competencies for solving problems. Another example is described in [9] where students of different levels carried out the implementation of electric robotic ground vehicles; the results highlight good practices during the various implementation stages of electric robotic ground vehicles that can serve realistic agricultural tasks. The work presented in [10] mentions how high school students use DAQs in conjunction with EUROPA's software infrastructure which is based on Robot Operating System (ROS); results show that EUROPA software easy to use interfaces for robot control and interaction with users and thus can easily be incorporated in Science, Technology, Engineering and Mathematics (STEM) and robotics classes. In [11], the application of DAQs in the work of engineering students is presented, which consisted of developing a non-linear control system of a Ball-Plate, as a result was obtained the process of designing, fabricating, assembling, programming, and optimizing a prototype non-linear mechatronic BallPlate System (BPS) as a laboratory platform for engineering education STEM. DAQs also have application in preschool education, as described in [12], about Robotics education using robotics kits, result of this study suggests clarifying and specifying robotics-intensified knowledge, skills, and attitudes in defining robotics education in connection with computer science education.

Table 1 shows some learning approaches where data acquisition systems have been applied and the academic level of the students who have participated in the educational experiences integrating these systems.

Table 1. Learning approaches where data acquisition systems have been applied.

Article	Learning Approach	Education Level	Results
[4]	Internet of Things	University (Engineering)	The practical results indicate that students significantly improved their

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			emotional level, knowledge level, and innovation level after studying the course.
[13]	Electronic-textiles-based art	High School	The findings reveal how making became a means of personal, artistic expression with quite literal layering of coded meanings, and how maker activities can integrate art.
[14]	Programming	High School	The results of training local teens to become maker-mentors allowed teens to explore areas of making that were in line with their interests while still being a part of a larger community of practice.
[5]	Programming and computational thinking	Elementary School; University	The results show that, in recent years, smart toys have focused on specific sciences (programming) and some 21st-century skills (science, technology, engineering, and mathematics, and computational thinking). In contrast, interest has shifted toward soft skills such as collaboration, emotional thinking, symbolic thinking, storytelling, and problem-solving.
[15]	AI-Thinking	University (Engineering)	In applying AI to think discursively, the AI-Thinking from the STEAM learners can improve their AI literacy, which in turn enables them to ask better questions to solve problems.
[6]	Augmented Reality	High School	Initial phase: Teacher Professional Development (TPD).
[7]	Educational robotics combining storytelling	Elementary School	Results show that an increase in computational thinking is evident after the intervention of robotic-based storytelling activities is implemented.
[9]	Implementation of electric robotic ground vehicles	Elementary School; High School; University	The results highlight good practices during the various implementation stages of electric robotic ground vehicles that can serve realistic agricultural tasks.
[16]	Graph Theory in Autonomous Motion of Robots	University	The contribution of this study is a change in the approach to teaching graph theory and a greater interconnection of individual areas of STEM to achieve better learning outcomes for science students.

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[8]	Programming educational robots	Elementary School	The results of the study clearly demonstrate the positive influence of project-based teaching using educational robots on the development of student competencies, especially the important key competencies for solving problems.
[10]	Programming in EUROPA's software infrastructure (based on Robot Operating System – ROS)	High School	The results show that EUROPA software provides easy-to-use interfaces for robot control and interaction with users and thus can easily be incorporated in Science, Technology, Engineering and Mathematics (STEM) and robotics classes.
[17]	Cartesian Coordinate System (CCS) through a Two-Dimensional Cartesian Coordinate System Educational Toolkit (2D-CACSET)	University	As a result, the Educational Mechatronics Conceptual Framework (EMCF) enables constructing knowledge at concrete, graphic, and abstract levels.
[11]	Control non-linear of a Ball-Plate	University (Engineering)	As a result, the process of designing, fabricating, assembling, programming, and optimizing a prototype nonlinear mechatronic Ball-Plate System (BPS) is obtained as a laboratory platform for engineering education STEM.
[12]	Robotics education using robotics kits	Pre School	The result of this study suggests clarifying and specifying robotics-intensified knowledge, skills, and attitudes in defining robotics education in connection to computer science education.

This study seeks to provide a comprehensive view of the role of data acquisition systems in teaching, identifying opportunities to improve educational quality and foster more dynamic, experimentation-based learning.

3 Architecture and development of DAQs

In general terms, a DAQ system consists of the following key elements: Sensors and actuators, signal conditioning, Analog-to-Digital converters (ADC), data acquisition module (DAQ Hardware), data processing and storage, communication interface, visualization and analysis software. The data acquisition system described in this research work was developed in the Python environment. This system integrates a graphical interface developed with the Tkinter library, and that allows bidirectional data transfer (writing and reading). Two types of data inputs were configured: analog input (continuous signals) and digital input (discrete signals). Two types of data outputs were also configured: digital output (binary signals) and PWM (Pulse Width Modulation) output. The block diagram presented in Fig. 1 shows the architecture of the data acquisition system presented in this article. Each of the elements that make up the proposed data acquisition system are detailed in this chapter.

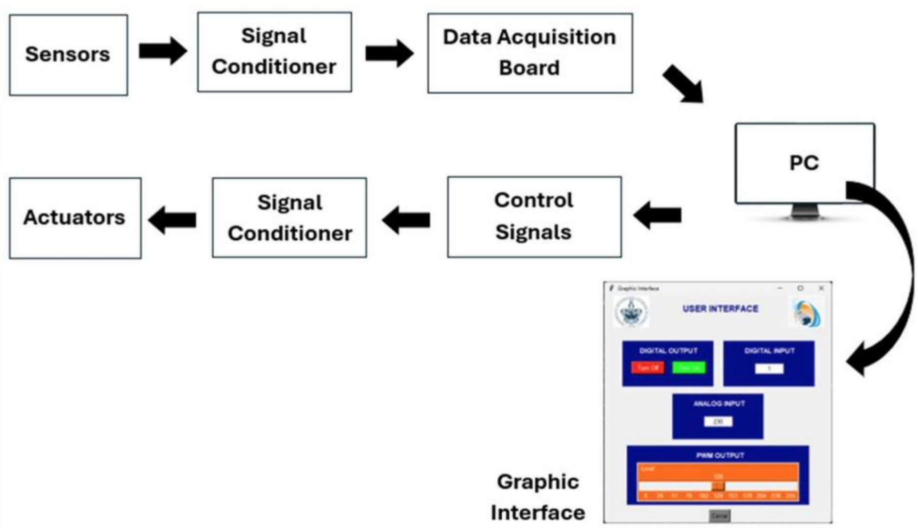

Fig. 1. Data acquisition system architecture.

3.1 Data reading stage

The data reading stage in a DAQ system includes the detection of the physical magnitude by the sensors, the conditioning of the signals to improve their quality, and the conversion and digitization of those signals through a DAQ card for subsequent analysis or control.

- **Sensors**. Sensors are devices that detect physical quantities, such as temperature, pressure, speed, humidity, among others, and convert it into an electrical signal. Depending on the type of sensor, the output can be analog (voltage or current) or digital (pulses or binary signals). In this work we include temperature sensors and pressure sensors (buttons).
- **Signal Conditioning**. Sensor signals are often weak, noisy, or difficult to interpret, so they require conditioning before processing. Signal conditioning aims to prepare the signals, so they are suitable for subsequent analysis and digital conversion. Two signal conditioning actions were implemented in this work:
- **Filtering**. Unwanted noise or interference that could affect the measurement was removed.
- **Signal Conversion**. Continuous signals were converted to discrete values.
- **Data Acquisition Board**. The data acquisition (DAQ) card is the device responsible for converting conditioned signals into digital data that can be processed by the computer or control system. The main functions of the DAQ card are:
- **Analog-to-digital conversion (ADC)**. Converts analog signals from sensors (after being conditioned) into digital signals that can be understood by the computer.
- **Signal sampling:** The DAQ card captures signals at specific time intervals (sampling rate).
- **Communication with the control system**: Transmits digital data to software or a control system for processing, analysis, or visualization. Serial communication was implemented for this work.

3.2 Data writing stage

The data writing stage in a DAQ ensures that the control signal is properly conditioned so that the actuators receive the correct signal and perform the expected action in the system.

- **Control Signals**. Control signals are signals generated by the control system or computer to influence the behavior of an actuator. These signals can be digital or analog and are used to execute actions. The

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actions performed by the system presented in this work were: turning devices on/off and adjusting the speed of a motor.

– **Signal conditioning**. Signal conditioning in the data writing stage is the process of transforming control signals into a form suitable for the actuators to interpret correctly.

The signal conditioning implemented in this system includes:

– **Amplification**. If the control signal is very weak, it is amplified to ensure it arrives with adequate power.
– **Actuators**. Actuators are devices that receive conditioned control signals and perform physical action within the system. These are the elements responsible for modifying the state of a process or system.

The actuators used in this system were:

– **Electric actuators**: Electric motors, relays, LED indicators.

4 Results of system accessibility

The graphical interface implemented for the data acquisition system presented in this paper is shown on Fig. 2. The elements it contains are:

– **Digital Output:** The widgets in this frame (Button on and Button off) control a digital output that activates or deactivates a device.
– **Digital Input:** The widget in this frame (Label Display) displays the input data from a pressure sensor (push button).
– **Analog Input:** The widget in this frame (Label Display) displays the input data from a continuous signal sensor (temperature sensor).
– **Analog Output:** The widget in this frame (Scale) controls a PWM (Pulse Width Modulation) digital output that drives the velocity of a motor.

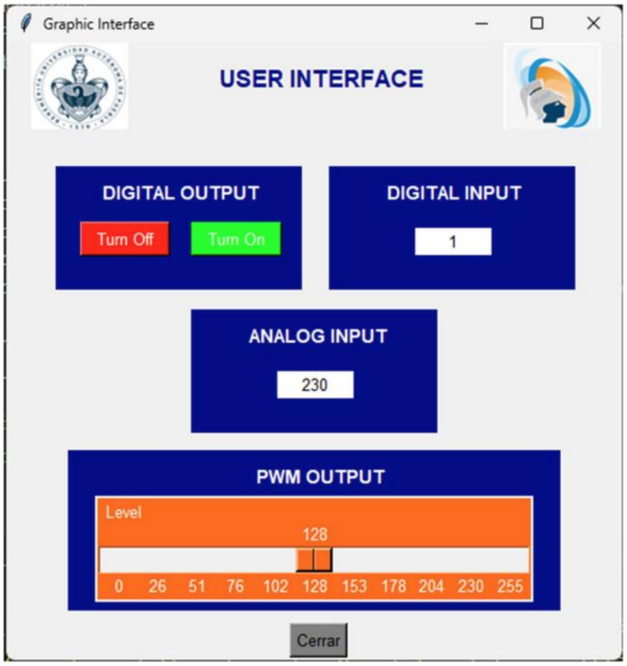

Fig. 2. Graphical interface of the data acquisition system.

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An instrument was applied to evaluate the level of accessibility of the user interface of the system prototype [18], [19].

In the system development process it is relevant to consider the evaluation stage of the User Interface (UI) so that it is easy to understand and pleasant for the user, in this way it is proposed to use the Accessibility test based on Web Content Accessibility Guidelines (WCAG) 2.1 its objective is to evaluate if the colors and widgets comply with accessibility, to satisfy the needs of different groups and situations, three levels of conformity are defined: A (minimum), AA and AAA (maximum).

Below are the results of applying for the WCAG test with the accessibility verification tool Color Contrast Checker (https://accessibleweb.com/color-contrast-checker/) according to the first widget that contains two buttons (Fig. 3).

Fig. 3. First widget: "Digital Output".

For the combination of the first button (Fig. 4) it indicates a ratio of 3.42:1 determining that the combination is not viable with small text, but because it is a button the contrast of the combination of the text in the button is analyzed again (Fig. 5) a contrast of 3.79:1 is obtained, both combinations suggest reaching the minimum contrast, it is possible to consider the combination of the "Turn off" button is clear and highlights the objective of turning off by identifying it with the red color, but an image of a switch could be used as a proposal for change.

Fig. 4. First result of contrast widget: "Digital Output" "Turn off" button.

Fig. 5. Second result of contrast widget: "Digital Output" "Turn off" button.

For the combination of the second button (Fig. 3, right) it indicates a ratio of 9.52:1 determining that the combination is viable with small and large text (Fig. 6), in this sense being a button it stands out and it is possible that intuition recommends a "start" or in this case "turn on", subsequently the contrast of the combination of the text in the button is analyzed (Fig. 7) a contrast of 1.42:1 is obtained, although both results are contrasting since the color of the green button stands out with the background of the widget, it is observed that the white text is lost in the green button, so it is considered to improve this color combination of the button text following the WCAG guide. For the second button combination:

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Fig. 6. First result of contrast widget: "Digital Output" "Turn on" button.

Fig. 7. Second result of contrast widget: "Digital Output" "Turn on" button.

For the third button corresponding to the second UI widget (Fig. 8), a single button is shown that will accept the input data for processing by the system. The evaluation result (Fig. 9) is 13.32:1, which exceeds the minimum contrast requirement, and the content is clearly and accurately displayed.

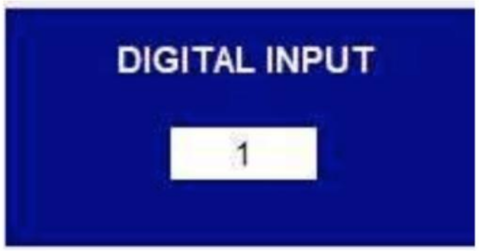

Fig. 8. Second widget: "Digital Input".

Fig. 9. Result of contrast widget: "Digital Input".

The third UI widget (Fig. 10) has a scroll bar that will take the data to be processed by the system. The evaluation result (Fig. 11) is 6.55:1, which exceeds the minimum required contrast for the bar in the widget. However, the second evaluation (Fig. 12) of the text in the bar yields a 1.86:1 ratio. As seen in the image, this ratio is visible but requires some visual effort. Therefore, it is considered necessary to verify this combination in the scroll bar.

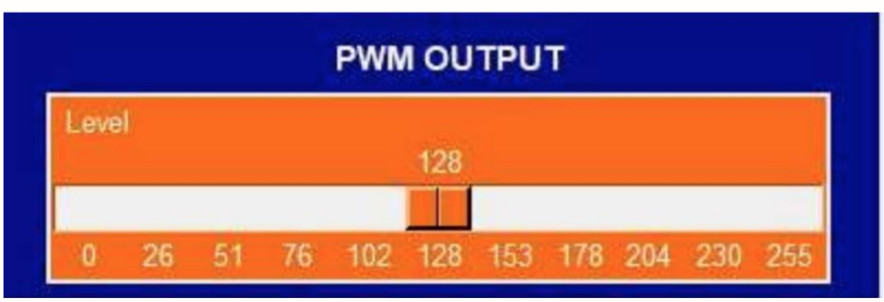

Fig. 10. Third widget: "PWM Output".

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Fig. 11. First result of contrast widget: "PWM Output".

Fig. 12. Second result of contrast widget: "PWM Output".

As a first version of the system UI prototype, there is a clear set of contents in the three presented Widgets, in which it is possible to integrate a combination that meets the minimum required 4:5:1, it is possible to integrate icons that respond to the user's intuition such as a switch and possibly add alternative text in a second version of the UI.

5 Conclusions

The implementation of this data acquisition system represents a significant advance in the integration of innovative technologies within the educational field. By combining this tool with different technological platforms, the goal is to optimize the collection and analysis of information, providing educators and students with more effective learning resources. This approach will allow for better personalization of educational experiences, improving decision-making and facilitating access to valuable data in real time.

The sampling frequency achieved for the data acquisition system (2.5 kHz) allows for reading and writing signals without any desynchronization with the devices implemented so far. However, more input signals (sensors) will be enabled and new control signals will be sent, so the system's performance will be evaluated after these implementations.

The accessibility evaluation of the graphical interface allows us to direct design improvements for the implementation of a second version of the data acquisition system. Integration with various technological platforms enhances the system's potential, contributing to the creation of a more dynamic, interactive, and user-friendly educational environment.

The impact of the development of this graphical interface has motivated students and teachers to generate several sensor reading systems on multiple platforms. Furthermore, there has been a constant search for new widgets and features to display information on dynamic dashboards.

Finally, as future work, various platforms will be developed that use this data acquisition system in their operation, for application in learning experiences in the classroom.

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Systematic Mapping for the Characterization of Non-Functional Requirements and Architectures for Artificial Intelligence

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Abstract. Artificial intelligence is a branch of computer science that seeks algorithms capable of learning, reasoning, adapting, and performing tasks in a similar way to how a human would do them. These algorithms are part of software that meets the needs of users. The software is determined by a set of functional (FR) and non-functional requirements (NFRs). NFRs, such as scalability, security, performance, and usability, define how a system should work beyond its basic functionalities. The architecture must be designed to meet these non-functional requirements, ensuring that the system is efficient and reliable, while maintaining a flexible and modular structure. Within the NFRs there are some that are related to HCI, which are necessary to improve the user experience in terms of adaptability, influencing these systems to dynamically adjust their behavior. As mentioned earlier, project-specific requirements, technological advancement, and domain greatly affect the variety of NFRs and architectures that will be essential for building AI-based systems. This systematic mapping aims to provide what non-functional requirements and architectures have been used in AI-based systems. The evidence collected shows that there is a tendency in NFRs to use security, scalability and precision. On the other hand, with this architecture there is a tendency like microservices and lambda architecture.

Keywords: Artificial Intelligence, Non-functional requirements, Software Architecture, Systematic Mapping.

1 Introduction

Artificial intelligence (AI) is a branch of computer science that seeks to create algorithms capable of learning, working, adapting, and performing tasks in a human-like manner. The term AI is used to refer to any machine that uses any type of algorithm or statistical model to perform perceptual, cognitive, and conversational functions typical of the human mind, such as speech, visual recognition, problem solving, and reasoning [1][2]. AI algorithms make part of software to satisfy the needs of users [2].Software products are determined by a number of functional and non-functional requirements. Functional requirements (FRs) specify the behavior of the software product, while non-functional requirements relate to quality attributes and standards the product must satisfy. Non-functional requirements (NFRs) play a fundamental role in the design of any system, according to ISO/IEC 25010 standard for the assessment of quality attributes in traditional software products [3], [4].

Another fundamental aspect of a software system is its architecture [5], as it affects the abstraction of heterogeneous hardware components, ensures smooth transactions between network protocols, and contributes to the overall quality of the system. A system's architecture has an impact on functional requirements, outlining tools and components that can be used, and this in turn has an impact on non-functional requirements [6]. The

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design of a system's architecture must aim to satisfy its NFRs, ensuring efficiency and reliability while keeping the structure flexible and modular [7].

Non-functional requirements specify how the system should perform beyond its basic functionalities [4]. Some NFRs relate to human-computer interaction (HCI), in so far as they aim to ensure that the system is intuitive, accessible, and user-centered [8]. The attention here is directed towards NFRs relating to user experience, including usability, accessibility and response time. A well-designed architecture must adopt HCI principles from the beginning, allowing for the smooth integration of optimized user interfaces and ensuring a positive experience in terms of both technical compliance and user expectations [9]. Designing AI-based systems requires a balance between the choice of attributes and architectures. Project-specific requirements, technological advancement, and domain greatly affect the variety of NFRs and architectures that will be essential to building AI-based systems, and this problem can also be observed in the Internet of Things (IoT). These NFRs critically impact the software architecture, making it a challenging task to satisfy these NFRs in order to have a flexible and modular structure. Among the challenges mentioned for NFRs and architectures are the following: (i) AI tends to encompass a wide range of ideas and practices, ranging from the details of the technology used to even how it is defined, (ii) Traditional mechanisms such as replication and multi-version programming might not work in intelligent systems, and so this field is in its nascent stage, (iii) All programs, including AI systems, can be hacked by malicious users, (iv) A human agent is replaced by an AI-based agent to perform a critical task in healthcare, military, or other mission-critical situations. In these situations, any type of decision must be explainable, (v) If the size of data collected by AI-based systems increases, efficient algorithms are essential for data analysis and decision making [10].

As mentioned earlier, project-specific requirements, technological advancement, and domain greatly affect the variety of NFRs and architectures that will be essential for building AI-based systems. Thus, this systematic mapping focuses on providing what non-functional requirements and architectures have been used in AI-based systems because they are vital for: (I) identifying patterns, (ii) replicability of solutions in the context of AI, (iii) establishing quality standards and (iv) making informed architectural decisions.

The paper is organized as follows: Section 2 presents related works, Section 3 the systematic mapping methodology adopted. Section 4 describes the state of the art in the domain of artificial intelligence. Section 5 presents our findings and the answer to the research questions posed in Section 3. This is followed by a discussion of our findings in Section 6, and conclusions in Section 7.

2 Related works

Few works have been found that relate NFRs and architectures, which enhances the importance of our work, these studies are listed below. This study analyses functional and non-functional requirements for artificial intelligence (AI) systems. The paper highlights that traditional approaches do not fully address the unique challenges of AI-intensive applications. Through a systematic mapping, Ahmad et al. [11], identified primary studies in order to explore methodologies, tools and techniques for specifying requirements in AI systems. One of the most important findings was that although some frameworks such as UML and domain-specific modeling languages are useful, current approaches are not adaptive enough for the needs of AI-based systems.This is due to unique characteristics such as uncertainty, data-driven decisions, and the need to incorporate ethical principles, explainability, and trust.

Among the challenges identified are the difficulty in defining clear requirements, handling trade-offs between conflicting objectives (such as accuracy vs. privacy). This work indicates that there is an urgent need to develop approaches adapted to the changing requirements of AI-driven software engineering. Abdullahi et al. [12], conducted a systematic mapping study on quality models for artificial intelligence (AI) systems, software, and components. The aim of the present study was to critically analyze, classify, and evaluate existing models. It was found that, although there are proposals for AI-intensive systems and software, there are no specific models for software components, such as those based on machine learning. The identified gap lies in the fact that there are few complete and specific quality models for software components in AI, as well as the need for metrics that allow quantitative and objective evaluations.

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Habiba et al. [13], address requirements engineering (RE) for artificial intelligence (AI)-based systems, where they highlight the complexities added by the adaptive and probabilistic nature of these systems. A systematic mapping is performed in order to identify existing practices, challenges, and research gaps. It is observed that most works focus on requirements analysis and specification, with challenges such as explainability. The gap lies in the lack of mature methodologies and standard tools to address the particularities of AI, indicating an urgent need for adaptation in traditional RE practices. Kaur and Kaur [14], perform a systematic mapping between the years 2012 and 2023, applying machine, deep and transfer learning techniques in requirements classification. The analysis includes methods such as SVM, CNN, and evaluation metrics such as accuracy and completeness.

Further investigation of some of the research directions is planned with an emphasis on the integration between application reviews and software architecture by using AI techniques. Sofian et al. [15], perform a systematic mapping on the use of artificial intelligence (AI) techniques in software engineering (SE). It examines studies published between 2015 and 2021, identifying phases of the software lifecycle where these techniques, such as machine and deep learning, have been applied to improve activities such as testing, development and maintenance. The analysis highlights the increasing use of AI, especially in automation and prediction, but identifies a gap in the homogeneous adoption of these techniques in all phases of SE, underlining the need for future research in real-world contexts and less explored phases, such as design and deployment. Regarding the identified gaps, it can be identified that a generalized architectural framework that covers multiple domains and quality requirements has not been achieved, which limits adaptability, an essential attribute of AI.

3 Methodology

In this work, a systematic mapping was carried out following two approaches: (1) the guide for systematic reviews in software engineering proposed by Kitchenham [16] and (2) the guide for conducting systematic mapping studies in software engineering proposed by Petersen *et al* [17].

3.1 Research questions

Quantum computing research currently offers countless areas for exploration. In this paper we address two specific aspects, non-functional requirements and architecture, based on the following questions, respectively:

1. What are the non-functional requirements used in AI-based systems?
2. What architectures are used in AI-based systems?

3.2 Search string

To create the search string, the main terms and possible synonyms were identified in order to obtain as many relevant primary studies as possible. The following main search strings were identified: "Non-Functional Requirements", "Software Engineering", "Quality Characteristics", "Software Architecture", "Artificial Intelligence" and "AI-based systems". The alternative terms "NFRS" and "Architecture" were also identified. Table 1 summarizes the identified search strings.

Table 1. Search string.

Main Terms	Alternatives Terms
Non Functional Requirements	(Software Architecture)
Software Engineering	AND ((non-functional requirements)
Quality Characteristics	OR (NFRs)

Software Architecture Artificial Intelligence	OR (Quality Characteristics) AND (Artificial Intelligence) OR (AI-based systems))

3.3 Search strategy

The following digital repositories were consulted: Scopus, Science Direct, IEEE Xplore and Springer. Search strings were applied to the fields Title, Abstract and Keywords. The documents considered in this study include research articles, conference proceedings, books, technical reports and graduate papers in English and Spanish published between 2019 and 2024. Table 2 summarizes the elements of the search strategy.

Table 2. Search strategy.

Item	Alternatives Terms
Repositories:	Scopus, Sciencedirect, IEEE Xplore y Springer.
Publication type:	Research papers, Conference papers, Books, Technical reports, Technical reports and Degree works.
Search fields:	Title, Abstract y Keywords.
Language:	Studies written in English or Spanish.
Publication period:	2019 - 2024

3.4 Inclusion and exclusion criteria

The search only considers academic and professional studies carried out in conferences, journals, technical reports or graduate works. This work excludes personal blogs, web pages or works written in Spanish, with the exception of some works in Spanish that were included due to their contribution to the research, as shown in Table 3. Works that do not focus on software engineering, non-functional requirements and architectures for artificial intelligence are not considered. Workshop abstracts and duplicate papers from the same search in different repositories were excluded.

Table 3. Inclusion and exclusion criteria summary.

Criteria	Rules
Inclusion Criteria	Terms included in the search string. Studies reported in articles, conferences, books, technical reports or degree works. Studies written in English and Spanish. Publications from 2019 to 2024. Studies that establish software engineering, non-functional requirements and architectures for AI-based systems.
Title and abstract Inclusion and exclusion criteria	Studies that do not address software engineering, non-functional requirements and architectures for AI-based systems. Studies that only present abstracts or slide content. Content from web pages, personal blogs or brochures.
Exclusion criterion for full text	Studies presenting workshop abstracts

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According to Petersen et al. [17], quality assessment is most essential in systematic reviews to determine the rigor and relevance of the primary studies. In systematic mapping it is not necessary, although it is recommended, to perform a quality assessment. The use of the classification of research types according to the category of proposed solutions mentioned in Wieringa et al. [18] would contain studies without empirical or scientific evidence. Although the latter are not usually included in systematic reviews, they are important in systematic mappings, as they help to detect trends in the topics worked on. For this reason, findings with and without empirical evidence were included in the present study. To refine the selected studies, we used the checklist proposed by Zarour et al. [19], reproduced in Table 4. For each item there are three possible answers: Yes = 1 point, No = 0 points and Partially = 0.5 points. Using the first quartile (6/3 = 2) as the cut-off point, if a publication obtains a score lower than 2 it is excluded from the list of final studies to avoid low-quality papers.

Table 4. Quality criteria checklist.

#	Question
QA1	Is the objective of the study sufficiently well explained?
QA2	Is the idea, approach and limitations presented clearly explained?
QA3	Are threats to validity taken into account?
QA4	Is there an adequate description of the context in which the study was conducted?
QA5	Are the results of the research clearly established?
QA6	The study was designed to achieve these objectives?

4 Results of the systematic mapping

By applying the search strings mentioned above to the selected repositories, a total of 2376 results were obtained. These results were filtered by title, abstract and conclusions shown in Table 2, and as result, 180 articles were selected. Subsequently, the inclusion and exclusion criteria defined in Table 3 define which articles exclude.

Also, there is another criterion based on the quality of the work and is defined in Table 4. With these two criteria applied, 32 results were selected (Table 5). Sections 4.1 and 4.2 describe the articles selected in the previous filter.

Table 5. Summary of results after applying the search strategy.

Search String	Repositories	Results	Title, Abstract and Conclusions	Selected with Quality Criteria
1	Scopus	694		
	Science Direct	422		
	IEEE Xplore	487		
	Springer	773		
	Total	**2376**	**180**	**32**

4.1 Non-functional requirements in AI-based systems

Iván Haro [20] analyzes the use of Large Language Models (LLMs), such as ChatGPT and Gemini, developing a specialized model to recommend and apply design patterns, in order not to depend on human validation, for example, Rubén Alonso, Rodolfo E. Haber et al. [21], analyze how interoperable software platforms can integrate AI in the industry. While Daole et al. [22], propose OpenFL-XAI, a software for federated learning

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(FL) of explainable artificial intelligence (XAI) models, using a system based on fuzzy rules. In contrast Ranit Chatterjee et al. [23], propose to identify and classify ASFRs to avoid expensive refactoring processes using a model based on deep neural networks. Habibullah et al. [24], analyze the challenges that ML systems face in managing NFRs, using interviews and surveys to identify key differences in how NFRs are defined and measured for ML systems. However, Bajraktari et al. [7], propose a framework for documenting ML-specific NFRs to improve accuracy and consistency in documenting these NFRs. Muccini and Karthik [25], present ML-based systems and aim to highlight current architectural practices and propose improvements for the development of these systems using ML, IoT, and statistical optimization techniques. Martin Heyn et al. [26], propose a compositional architectural framework to address the challenges of (AI) systems embedded in the (IoT), their objective is to create a framework that enables collaborative and integrated design, addressing quality aspects such as security, robustness, and efficiency.

Nascimento et al. [27], study the performance of software engineers in specific tasks with AI, and also evaluate performance, efficiency, and reuse in ChatGPT and IoT in complex contexts. Martínez García et al. [28] , propose a solution based on convolutional neural networks (CNN), to improve the classification of non-functional requirements (NFR), using natural language processing techniques and pre-trained matrices such as Word2Vec and FastText. Lu, et al. [29] aim to understand how AI developers perceive and implement ethical principles. Through interviews with 21 experts, they identify common problems, such as the lack of mechanisms for continuous monitoring of AI systems. Rocha de Sousa [30], proposes a software architecture for NFRs in intelligent systems that process large amounts of data generated in distributed environments, implementing NFR monitoring tools that manage resources and detect quality of service violations. Haldorai, and Ramu [31], examine how AI can predict software reuse. They make use of neural networks and the Flexible Random Fit algorithm to optimize the reuse prediction of software components in service mesh systems. Kaur and Kaur [14], performed a systematic analysis for NFRs. Their study reviews current applications to optimize requirements identification in big data and application reviews, highlighting improvements in accuracy and promising results. Liubchenko [32], assesses the risks associated with NFRs, particularly those influenced by AI/ML components, uses a requirements tree-based approach, mapping dependencies between requirements to perform more accurate risk assessments.

Seungkyu Park et al. [33], present a methodology for designing architectures, based on (AI), the objective of their study is to provide a clear structure, called IMO (Input-AI Model-Output), that facilitates the identification of the NFRs necessary to develop AI models.

4.2 Adopted architectures in AI-based systems

Vajpayee et al. [34], establish scalable data architectures for AI applications. The research faces the limitation of balancing between scalability and architectural simplicity. Haindl et al. [35], seek to develop a reference architecture to optimize collaboration between humans and AI systems in smart manufacturing environments. Graef and Georgievski [5], implemented a service-oriented software architecture to improve AI-based planning systems using a Service-Oriented Architecture (SOA). Lo et al. [36], conduct a study on the architectural design of federated learning systems, employing an approach based on systematic literature review and real-world applications, classifying categories and aggregating models. Aksakalli, et al. [37], identified deployment and communication patterns in microservices architectures. Through a review, they made a multi-phase selection process to ensure relevance and quality. Alves et al. [38], specified a framework for the orchestration of (ML) workflows applied to (IoT) data, using a microservices architecture. Borelli et al. [39], propose a classification of architectural patterns for the development of IoT applications, their objective is to address the complexities of designing IoT architectures that integrate sensors, actuators, and data processing components.

Martín et al. [40], offer an end-to-end solution for managing ML pipelines in continuous data environments by integrating technologies such as Apache Kafka and Docker containers. Runpakprakun and Washizaki [41], explore architectures that can optimize both the response speed and consistency of ML models by deploying Lambda and Kappa in applications with high accuracy requirements facing challenges in result consistency between batch and real-time processing layers. Altintas et al. [42], present a dynamic composition approach for heterogeneous systems in remote sensing, employing federation of Kubernetes clusters and microservices.

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Nazir [6], investigated challenges, best practices, and key architectural design decisions in ML systems, on the main architectural decisions that could guide the design in large-scale projects. Elhabbash et al. [43], address a microservices architecture designed for predictive maintenance in Industry 4.0 environments, using incremental learning to dynamically adapt to changes in machine operating data. Jayesh Rane et al. [44], investigate scalable and adaptive deep learning algorithms for ML systems.

The study focuses on optimizing the use of deep learning algorithms in applications that handle large volumes of real-time data. Laurens Martin [45]. represent workflow independence consistently and technologically, simplifying the integration and deployment of ML solutions in serverless environments. Mills [46], focuses on the design of hyper-automated AI platforms for complex digital time-spaces, that maintain their effectiveness under changing conditions without human intervention. Shah Zeb et al. [47], analyze how next-generation (NextG) wireless networks and computational intelligence (CI) use multi-tenant service architectures and patterns based on microservices and service-oriented architecture (SOA), to facilitate the provision of customized services for various industrial applications.

5 Findings

5.1 What are the non-functional requirements used in AI-based systems? (Q1)

As can be seen in table 6, the Non-Functional Requirements (NFR) indicates that there is a notable trend in scientific texts that address the topic of artificial intelligence, such as scalability and security, with 8 appearances in the consulted resources. Also frequent are the requirements of precision, with 6 appearances, and explainability, with 5 appearances. Likewise, the requirements addressed in the bibliography were those of adaptability, reliability, and interoperability, with 3 appearances each. Another requirement addressed was performance efficiency.

Table 6. Frequency of non-functional requirements in the analyzed publications.

NFR	Scalability	Security	Accuracy	Explainability	Adaptability	Reliability	Interoperability	Performance efficiency
Frec.	8	8	6	5	3	3	3	1
Ref.	[7], [20]–[26]	[7], [21], [24], [26]–[30]	[22]–[24], [27], [31], [32]	[7], [22], [24], [26], [28]	[7], [24], [27]	[22], [24], [26]	[7], [22], [23]	[28]

5.2 What architectures are used in AI-based systems? (Q2)

From the articles consulted, it is observed that the number of architectures discussed in the context of artificial intelligence is extensive, since 7 different patterns could be found, in which the microservices architecture stands out with 9 mentions, followed by the Lambda architecture with 5 appearances in the articles consulted. The infrequent architectures are the SOA pattern and the Federated Learning pattern with 2 mentions each. Other architectures mentioned are Data Pipeline, Workflow orchestration and Layered pattern.

Table 7. Frequency of different architectures in the analyzed publications.

NFR	Microservices Pattern	Lambda Pattern	SOA Pattern	Federated learning Pattern	Layered Pattern	Data Pipeline Pattern	Workflow orchestration Pattern

Frec.	9	5	2	2	1	1	1
Ref.	[6],[34], [37],[38], [41]–[43]	[34],[35], [40], [41],[46]	[5], [47]	[36], [44]	[39]	[41]	[45]

6 Discussion

The advancement of emerging technologies based on artificial intelligence (AI) poses key challenges, among which is the correct choice of NFRs and software architectures that enable efficient performance aligned with the requirements of project leaders. Key conditions such as project focus; user requirements and current technology market conditions directly influence the decisions that will be made beforehand. When analyzing current approaches, there is a notable preference for certain architectures and attributes that are widely used in modern AI-focused projects in the technology sector. Among the most visible Nfrs are scalability, security and accuracy, which are critical for programs that operate in real time, such as the Internet of Things (IoT) or machine learning (ML) systems. For example, in high data traffic applications, scalability is a crucial attribute to handle high system demands and implement updates without affecting the user experience, while, in commercial or financial applications, reliability and security are vital to protect sensitive data. However, attributes such as interoperability and efficiency are important, they tend to be less visible in certain scenarios, particularly in those projects where resources do not limit the process or where the system does not integrate with multiple platforms. Current trends in the technology market have shown that reliability and adaptability are also of greater importance, especially in ML systems, where applications must adapt quickly to large data sets and system demand. On the other hand, each attribute is determined by customer requirements, the development environment and the methodologies used. In continuous development environments, for example, attributes such as performance efficiency may be less of a priority in the face of the need to deliver fast, scalable products.

Regarding the most widely used software architectures in AI-based systems, the most dominant ones are those that facilitate scalability and flexibility. Microservices architecture has established itself as one of the most widely used alternatives thanks to its modularity, which facilitates the implementation and maintenance of complex systems. This architecture allows updating and scaling individual modules without altering the overall operation of the system, which is especially useful in AI and ML-based projects. On the other hand, Lambda Architecture is widely implemented in Big Data and real-time processing projects, as it combines batch and streaming processing, efficiently handling large volumes of data. More classical architectures, such as monolithic systems or SOA, have lost importance in modern applications due to their reduced ability to adapt to new technologies, and their maintenance cost makes them less of a priority in an IA environment. Even so, SOA is still functional in corporate systems that require high interoperability, although its adoption has been largely replaced by architectures that allow handling large databases and modularity in modern applications. The implementation of an architecture is also influenced by aspects such as project complexity, team experience and community support. Although architectures such as Lambda are ideal for real-time analysis, their development can be demanding for teams with limited experience in distributed environments. Similarly, less commonly used patterns, such as Workflow Orchestration and Data Pipeline, are essential in systems where accuracy and traceability are required, such as in the automation of specific processes. The relationship between attributes and architectures is clear once you identify the most widely adopted patterns, such as microservices and Lambda, as they are closely related to attributes such as scalability, security and reliability, which are crucial for modern systems. As technology continues to evolve, these NFRs and architectures are likely to remain dominant, but tailored to the specific demands of growing industries. For example, federated learning systems, which prioritize decentralization and privacy, are already beginning to influence how architectures must adapt to complex scenarios. The design of AI and ML-based systems requires a balance between the choice of attributes and architectures. The most visible attributes, such as scalability and security, along with flexible architectures such as microservices and lambda, reflect current market needs. However, project-specific requirements and technological advancement greatly impact the variety of NFRs and architectures that will be essential for building AI/ML-based systems. NFRs are vital aspects to consider when implementing systems that interact with users. In the HCI domain, these NFRs not only impact system performance, but also significantly impact the user experience. For example, scalability and interoperability are essential to ensure that the system can be kept up to date and can integrate with other modules. Reliability and security ensure that users have confidence in the system. Explainability and accuracy are crucial in interfaces where system decisions must be easy for users to understand. Likewise, adaptability facilitates experiences aligned to user expectations, while performance efficiency ensures 24/7 operation, which improves the level of user satisfaction. On the other hand, architectures, such as those based on microservices, play a fundamental role in HCI by enabling adaptive and scalable systems that optimize user interaction in applications such as IoT, offering fast responses. Architectural patterns such as Lambda and Data Pipeline help manage data by presenting information efficiently, so that the user can understand it in a better way, facilitating decision making and reducing mental fatigue. The relationship between HCI and architectural patterns focuses on how software architectures improve the experience through user-centered design. Patterns such as Model-View-Controller allow separating the user interface from control logic and data management, simplifying quick adjustments based on user interaction. Architectures such as Federated Learning and Workflow Orchestration in ML systems optimize workflows and protect privacy. Thus, the integration of NFRs and software architectures with HCI will contribute to the creation of robust, easy and user-friendly systems.

7 Conclusions

This systematic mapping allowed us to identify the NFRs and architectures most commonly used in AI and ML-based projects. As for architectures, we observed a tendency favoring the microservices and Lambda architectures, mainly as a function of their scalability, modularity, and adaptability. These architectures have prevailed due to their capability to manipulate large amounts of data and their compatibility with developing technologies such as machine learning. Despite being less prevalent, other approaches such as the monolithic and SOA architectures remain important in specific contexts. Regarding the analysis of the impact of NFRs, we observed that scalability, security and accuracy are essential in the majority of consulted works. In ML-based systems, each of these attributes relate to the need to process large volumes of data in real time, ensure data protection, and provide accurate results, respectively. Other quality attributes such as adaptability and reliability also play an important role, especially in systems that seek flexibility towards a changing environment. For HCI, adaptability is a vital issue because it enables AI-intensive systems to dynamically adjust their behavior, interface, functionality, or context variables and preferences based on user needs, improving usability, satisfaction, and accessibility through more personalized and intuitive interaction. Finally, our mapping also highlights the implementation of designs for high-interactivity, user-centered systems, where the adoption of HCI principles is crucial. These systems pose additional challenges. Quality attributes such as usability, accessibility and response time are critical, especially in the case of applications for non-technical users or in contexts where user experience affects competitivity. As for future work, it would be interesting to research the benefits and challenges of the IA powered System and a generalized architectural framework that covers multiple domains and quality requirements that have not been achieved.

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Visualización de Riesgos en Infraestructura Ciclista: Un Sistema en Desarrollo para la Presentación de Datos a los Usuarios

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Resumen. La planificación de infraestructura ciclista segura enfrenta desa-fíos debido al manejo de grandes volúmenes de datos sobre mo-vilidad y accidentes. La visualización de datos facilita la interpre-tación de esta información para ciclistas, urbanistas y tomadores de decisiones. Este estudio desarrolla un sistema basado en ma-pas de calor interactivos para identificar zonas de alto riesgo en ciclovías, priorizando la comunicación efectiva de la informa-ción a los usuarios. La metodología incluye la recopilación y procesamiento de datos geoespaciales de accidentes, representados mediante Folium y HeatMap para generar una visualización interactiva de la densi-dad de incidentes. Como resultado preliminar, se han identifica-do áreas de alta siniestralidad, aunque persisten desafíos como la optimización del sistema, la integración de datos en tiempo real y la incorporación de modelos predictivos.

Palabras Clave: Visualización de Datos, Mapa de Calor, Ciclovías, Movilidad Ur-bana, Análisis Geoespacial, Seguridad Vial.

1 Introducción

El crecimiento de la movilidad urbana sostenible ha impulsado la necesidad de desarrollar infraestructura ciclista segura y eficiente [1, 2]. Sin embargo, la planificación de ciclovías enfrenta desafíos debido a la dificultad de analizar grandes volúmenes de datos sobre movilidad y siniestralidad vial [3, 4]. En este contexto, la visualización de datos ofrece una oportunidad para mejorar la toma de decisiones en infraestructura ciclista, facilitando la identificación de patrones de riesgo y la implementación de estrategias de mitigación.

Los mapas de calor han demostrado ser eficaces en la identificación de zonas críticas con alta siniestralidad, permitiendo resaltar la concentración de accidentes [5, 6]. Estas visualizaciones optimizan la toma de decisiones al proporcionar una representación clara de la distribución de incidentes, lo que ayuda a priorizar intervenciones en infraestructura [7, 8, 9].

Este estudio desarrolla un sistema interactivo basado en mapas de calor para identificar zonas de alto riesgo en ciclovías, con un enfoque en la comunicación efectiva de la información a los usuarios. Utilizando Folium y HeatMap, se generan mapas dinámicos que facilitan la exploración de patrones de accidentes según variables como ubicación, horario y tipo de siniestro.

El sistema busca no solo optimizar la identificación de áreas de riesgo, sino también mejorar la interacción con los datos [10, 11]. Como resultado preliminar, se ha generado una visualización que destaca zonas de alta concentración de accidentes, facilitando la toma de decisiones basada en datos. Sin embargo, el sistema aún enfrenta desafíos técnicos, como la integración de datos en tiempo real, la incorporación de modelos predictivos y la adaptación de la interfaz a distintos perfiles de usuarios.

Este trabajo presenta los avances en el desarrollo del sistema, evaluando sus limitaciones y oportunidades de mejora en la visualización de información sobre seguridad ciclista.

La estructura del artículo es la siguiente: la Sección 2 describe la metodología de recopilación, procesamiento y visualización de datos. La Sección 3 presenta los resultados preliminares y su impacto en la identificación de

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zonas de alto riesgo. Finalmente, la Sección 4 aborda las conclusiones, destacando los avances logrados, las limitaciones identificadas y las futuras direcciones de investigación.

1.1 Trabajos relacionados

Diversos estudios recientes han abordado la visualización de riesgos aplicando técnicas de análisis espacial y Big Data. Figueres-Esteban et al. [12] exploraron la visualización de riesgos en el contexto ferroviario mediante Big Data Risk Analysis (BDRA), resaltando el desafío de simplificar grandes volúmenes de información para audiencias especializadas. Frigerio et al. [13] desarrollaron plataformas WebGIS como WebRiskCity y MultiRISK Visualisation Tool, enfocadas en la comunicación de riesgos naturales mediante bases de datos multi-escala y sistemas interoperables. Por su parte, Liu et al. [14] propusieron un sistema interactivo basado en mapas de calor para visualizar el riesgo de incendios urbanos, utilizando bases de datos históricas geoespaciales.

En contraste, nuestra propuesta se centra en una solución ligera y accesible para la visualización de riesgos en infraestructura ciclista, priorizando la interacción sencilla y la interpretación inmediata por parte de usuarios no técnicos, mediante la integración de Folium y HeatMap en un entorno Python.

2 Metodología

El desarrollo del sistema interactivo basado en mapas de calor para la identificación de zonas de alto riesgo en ciclovías se realizó en tres etapas: (1) recopilación y procesamiento de datos, (2) generación de mapas de calor y (3) presentación de la información a los usuarios.

2.1 Recopilación y Procesamiento de Datos

Se recopilaron datos de accidentes en ciclovías, incluyendo coordenadas geográficas, fecha, hora, municipio y tipo de siniestro. Se utilizó Python y Pandas para limpiar y organizar los datos, eliminando registros incompletos, normalizando coordenadas y asegurando la consistencia temporal. Como parte de la validación inicial, se inspeccionó la correspondencia entre las ubicaciones reportadas y su representación geográfica mediante herramientas de visualización en QGIS, contrastando visualmente los datos con mapas base de infraestructura urbana.

Para la conformación de la base de datos, se integraron tres fuentes principales:

- **Instituto Nacional de Estadística y Geografía (INEGI, México)**: Esta base nacional contiene 43 campos de información, incluyendo coordenadas geográficas (latitud y longitud), datos temporales (año, mes, día, hora y minuto), características del accidente (tipo, causa, condiciones de la vía), detalles de los vehículos involucrados (incluyendo bicicletas) y datos de víctimas (número de lesionados y fallecidos según tipo de usuario). La riqueza de esta información permitió un análisis detallado de los factores asociados a cada incidente.
- **Instituto de Información Estadística y Geográfica de Jalisco (IIEGJ, México)**: Esta fuente regional complementó la base nacional proporcionando información específica del área metropolitana de Guadalajara. Incluyó identificadores únicos de incidentes, detalles espaciales precisos (nombre de vialidades y cruces), tipología detallada de accidentes con énfasis en siniestros que involucraron ciclistas, y datos demográficos de los involucrados.
- **Programa GDL en Bici, Gobierno del Estado de Jalisco**: Se incorporó la cartografía oficial de la red de ciclovías en formato GeoJSON, que contiene geometrías exactas de las infraestructuras ciclistas, tipo de segregación vial, fecha de construcción o modificación, y características técnicas de diseño. Esta capa fue fundamental para contextualizar los accidentes en relación con la infraestructura ciclista existente.

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Estas bases fueron seleccionadas por su nivel de detalle, disponibilidad pública y pertinencia para el análisis de riesgos asociados a la movilidad ciclista urbana. Posteriormente, los datos fueron procesados utilizando Python, detectando patrones espaciales y clasificando zonas de alta y baja siniestralidad ciclista, sirviendo de base para el desarrollo de las visualizaciones interactivas presentadas en este trabajo.

2.2 Generación de Mapas de Calor

Se utilizó la biblioteca Folium en Python, junto con su módulo HeatMap, para crear un mapa interactivo que resalta las zonas de mayor concentración de accidentes. Esta elección respondió a la necesidad de una solución ligera, reproducible y fácilmente interpretable por usuarios no especializados en análisis geoespacial. El procedimiento incluyó:

- Extracción de coordenadas geográficas.
- Aplicación de la función HeatMap para representar la densidad de siniestros.
- Ajuste de opacidad y radio de influencia para mejorar la legibilidad del mapa.

2.3 Presentación de la Información

El mapa de calor generado permite visualizar la distribución geoespacial de accidentes en ciclovías sin necesidad de análisis estadísticos avanzados o plataformas GIS complejas. A diferencia de sistemas más robustos pero menos accesibles, el enfoque adoptado facilita la interpretación de datos por parte de urbanistas, gestores de movilidad y ciclistas. Actualmente, el sistema no incorpora filtros interactivos ni segmentaciones adicionales, pero proporciona una representación clara de los puntos críticos de siniestralidad. Finalmente, el mapa se exporta en formato HTML para su visualización independiente, como se muestra en la Fig. 1.

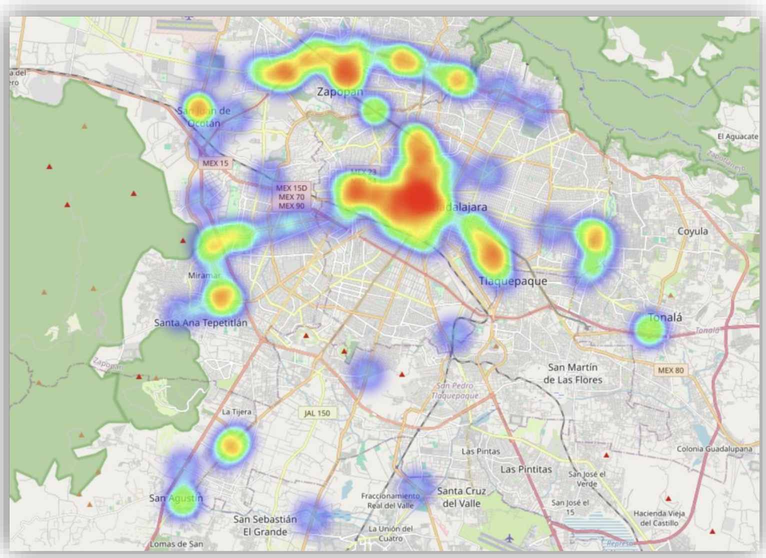

Fig. 1. Mapa de calor generado a partir del análisis de datos de accidentes viales en la Ciudad de Guadalajara, México.

El sistema se encuentra en una fase de desarrollo (work in progress) y no integra aún funciones avanzadas como predicción de riesgos o análisis dinámicos en tiempo real. Sin embargo, representa un primer paso hacia la creación de herramientas accesibles que apoyen la planificación y mejora de infraestructura ciclista basada en evidencia geoespacial.

3 Resultados y discusión

La implementación del mapa de calor interactivo ha permitido identificar zonas de alto riesgo en la infraestructura ciclista, facilitando la toma de decisiones basada en datos.

3.1 Identificación de zonas críticas

El análisis revela que los accidentes no están distribuidos homogéneamente, sino que se concentran en áreas específicas, especialmente en intersecciones y tramos compartidos con el tráfico vehicular. Además, se identifican diferencias en la siniestralidad según la hora del día y el día de la semana, lo que sugiere la influencia de patrones de movilidad.

3.2 Impacto en la planificación de infraestructura ciclista

El sistema de visualización desarrollado apoya la toma de decisiones al permitir:

- Priorización de intervenciones: Focalizando recursos en zonas con mayor siniestralidad.
- Análisis de seguridad en intersecciones: Identificando la necesidad de infraestructura segregada o mejoras en señalización.
- Monitoreo de políticas de seguridad vial: Evaluando el impacto de intervenciones a lo largo del tiempo mediante la comparación de datos históricos.

3.3 Limitaciones y desafíos pendientes

A pesar de su utilidad, el sistema presenta desafíos como:

- Falta de segmentación temporal para analizar variaciones por hora o tipo de siniestro.
- Ausencia de datos en tiempo real, lo que limita su aplicación dinámica.
- Necesidad de validación con usuarios finales para evaluar su efectividad en la planificación urbana.

A pesar de estas limitaciones, el mapa de calor demuestra ser una herramienta intuitiva y accesible para urbanistas, gestores de movilidad y ciclistas, facilitando la identificación de zonas peligrosas y la formulación de estrategias de mitigación de riesgos.

4 Conclusiones y trabajo futuro

La planificación de infraestructura ciclista segura es un desafío en entornos urbanos, y la visualización de datos emerge como una herramienta clave para la toma de decisiones basada en evidencia.

La planificación de infraestructura ciclista segura sigue siendo un desafío en entornos urbanos, y la visualización de datos se presenta como una herramienta clave para la toma de decisiones basada en evidencia. Este estudio desarrolla un sistema interactivo de mapas de calor para identificar zonas de alto riesgo en ciclovías, facilitando la interpretación de la concentración geoespacial de accidentes por urbanistas, tomadores de decisiones y ciclistas.

Los resultados obtenidos han permitido identificar zonas críticas de siniestralidad, proporcionando información clave para la planificación y mejora de ciclovías. La visualización facilita la priorización de intervenciones en infraestructura y ofrece una alternativa accesible a los métodos tradicionales de análisis estadístico.

Para optimizar el sistema, se proponen futuras mejoras como la incorporación de segmentación temporal, la integración de datos en tiempo real, el desarrollo de herramientas interactivas, la evaluación con usuarios finales, y la exploración de modelos predictivos. Estas mejoras permitirán que el sistema evolucione de una herramienta descriptiva a una plataforma avanzada de análisis, ampliando su impacto en la seguridad ciclista y la planificación urbana.

El aporte principal de este trabajo radica en su enfoque centrado en la usabilidad y la comunicación efectiva del riesgo, mediante una interfaz interactiva mínima que prioriza la claridad visual sobre la complejidad analítica. Esta decisión permite llegar a un público más amplio, incluyendo usuarios no técnicos, y ofrece una base escalable para futuras mejoras.

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