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Web System for the Management and Administration of Neuropsychological Tests: Design and Development

Sistema Web para la Gestión y Administración de Pruebas Neuropsicológicas: Diseño y Desarrollo

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Resumen

Las evaluaciones neuropsicológicas son fundamentales en el diagnóstico de condiciones cognitivas y neurológicas. No obstante, los métodos tradicionales manuales presentan limitaciones significativas, como errores humanos en la captura de los datos, tiempos prolongados de evaluación y falta de estandarización en la administración de pruebas. Estas deficiencias pueden retrasar el diagnóstico y afectar la fiabilidad de los resultados. Para abordar estos desafíos, este estudio presenta el diseño y desarrollo de una aplicación web para la gestión y administración de pruebas neuropsicológicas, orientada a optimizar el proceso evaluativo en términos de eficiencia, precisión y estandarización. La aplicación web se enfoca específicamente en la batería BANFE-2, ampliamente utilizada en el contexto clínico.

El desarrollo del sistema se fundamentó en la metodología MPIu+a (Modelo de Proceso de Ingeniería de Usabilidad+Accesibilidad), que guió cada fase mediante principios de Diseño Centrado en el Usuario (DCU). Para la gestión del proyecto se incorporó el marco del trabajo ágil

Scrum, permitiendo ciclos iterativos con retroalimentación continua. Como resultado, se construyó una plataforma que permite a los especialistas administrar casos clínicos, aplicar pruebas digitalizadas, registrar resultados, consultar historiales, y generar reportes en formato PDF, contribuyendo a una mayor estandarización y control del proceso evaluativo.
La evaluación de usabilidad arrojó un puntaje del 86.1%, evidenciando una buena aceptación por parte de los usuarios. Aunque el sistema no incorpora actualmente técnicas de inteligencia artificial, su arquitectura está preparada para futuras integraciones que permitan análisis automatizados. Este trabajo contribuye al fortalecimiento de herramientas tecnológicas aplicadas a la neuropsicología, ofreciendo una solución escalable, accesible y adaptada a contextos clínicos locales. Los trabajos futuros se centrarán en optimizar las limitaciones identificadas para mejorar la usabilidad, ampliar la funcionalidad y aumentar la adaptabilidad del sistema a diversas necesidades clínicas y de investigación.

Palabras clave: Ingeniería de software, Pruebas neuropsicológicas, MPIu+a, Usabilidad, Aplicación web.

Abstract

Neuropsychological evaluations play a fundamental role in diagnosing cognitive and neurological conditions. However, traditional manual methods present significant limitations, such as human errors in data recording, prolonged evaluation times, and a lack of standardization in test administration. These deficiencies can delay diagnosis and compromise the reliability of results. To address these challenges, this study presents the design and development of a web-based application for the management and administration of neuropsychological tests, aimed at optimizing the evaluation process in terms of efficiency, accuracy, and standardization. The system focuses specifically on the BANFE-2 battery, which is widely used in clinical contexts. The development process was based on the MPIu+a methodology (Usability and Accessibility Engineering Process Model), which guided each phase through principles of User-Centered Design (UCD). For project management, the agile Scrum framework was incorporated, enabling iterative cycles with continuous user feedback. As a result, a platform was built that allows specialists to manage clinical cases, administer digitized tests, record results, consult patient histories, and generate PDF reports, contributing to greater standardization and control of the evaluation process. The usability evaluation yielded a score of 86.1%, indicating strong user acceptance. Although the system does not currently incorporate artificial intelligence (AI) techniques, its architecture is designed to support future integration of automated data analysis tools. This work contributes to the advancement of technological tools applied to neuropsychology, offering a scalable and accessible solution tailored for local clinical contexts. Future work will focus on addressing identified limitations to improve usability, expand functionality, and increase system adaptability to diverse clinical and research needs.

Keywords: Software engineering, Neuropsychological tests, MPIu+a, Usability, Web application.

1. Introduction

Neuropsychological evaluation is a fundamental tool for diagnosing and monitoring cognitive and neurological conditions, providing healthcare professionals with detailed insights into mental processes and their relationships with various pathologies. Despite its clinical importance, the administration of these evaluations faces challenges related to efficiency, information security, and timely access to results [1]. Traditionally, evaluations have relied on manual methods that, although effective, are prone to human error, delays in interpretation, and difficulties in standardizing and organizing clinical data.

Technological advancements have given rise to various tools that automate neuropsychological assessments, aiming to improve accuracy, consistency, and accessibility. However, many existing solutions face limitations when adapted to specific clinical contexts or when there is a need for open, flexible, and cost-effective platforms. This study focuses on the BANFE-2 battery, a validated instrument commonly used in Mexican clinical settings to evaluate executive functions such as working memory, cognitive flexibility, planning, and impulse control [6], [7], [8].

Given the complexity and operational burden of manually administering the BANFE-2—including risks of error and time constraints—there is a pressing need to leverage technology to centralize the evaluation process, reduce errors, and improve diagnostic efficiency. To address these challenges, this article presents the design and development of a web-based system intended to streamline patient management, digital test administration, and structured result reporting.

The system development followed the MPIu+a methodology (Usability and Accessibility Engineering Process Model), which emphasizes user-centered design through iterative development and continuous evaluation. Furthermore, the Scrum agile framework was employed to manage the project in short development cycles, allowing frequent feedback and rapid adaptation throughout the process.

2. Related Work and Benchmark Analysis

Over the past decade, multiple digital tools have emerged to automate neuropsychological evaluations, reducing human error, speeding processing, and increasing access to cognitive testing. One prominent example is the Cambridge Neuropsychological Test Automated Battery (CANTAB), a computerized suite of cognitive tests validated across diverse populations, including Mexicans [3]. While CANTAB demonstrates strong accuracy and scientific rigor, it is costly, narrowly focused, and limited adaptability to specialized clinical needs like BANFE-2.

Another example is PsicoTest, a proprietary commercial platform that enables clinicians to administer complete test batteries digitally and generate reports. Although functional, PsicoTest is closed-source, limiting customization and scalability, and its licensing may pose financial barriers for public institutions or resource-limited environments [2].

Innovative academic projects also exist, such as Chandler et al.'s mobile platform for neuropsychological monitoring in psychiatric populations using machine learning models to predict cognitive states [4]. Similarly, Gómez-Valadés et al. implemented a decision-support system employing Semantic Web Rule Language (SWRL) within an

ontology to automate test result interpretation [5]. However, such systems are often unavailable publicly, lack real-world clinical validation, or are not tailored to specific protocols like BANFE-2.

A common limitation among many tools is the lack of validated usability and accessibility principles, hindering clinician adoption and diminishing user experience. Few projects employ user-centered methodologies or conduct formal heuristic evaluations to refine interaction design.

The system proposed here addresses these gaps by combining several key features:

- Specific focus on BANFE-2, widely used and validated in Mexican neuropsychology.
- Development using open-source technologies, promoting scalability, flexibility, and affordability.
- Strong grounding in MPIu+a methodology, ensuring usability, accessibility, and user satisfaction.
- Comprehensive clinical functionality, including patient registration, test administration, results tracking, and PDF report generation.

This benchmark analysis highlights a significant gap in neuropsychological digital tools that combine local clinical relevance, open architecture, practical functionality, and validated usability/accessibility. The present work aims to fill that gap, contributing a valuable resource for applied neuropsychological assessment.

3. Tools and Technologies Used

The development of the APEN platform was grounded in a robust and well-structured technological approach, utilizing modern tools and frameworks to ensure functionality, usability, scalability, and security. The core backend of the system was built using the Django framework, a powerful and versatile Python-based solution. Django's adherence to the Model-View-Controller (MVC) architectural pattern facilitates a clear separation of concerns among business logic, presentation, and data management [11], [12].

For frontend development, standard client-side technologies such as HTML and CSS were employed to define the platform's structure and visual styling. These were complemented with JavaScript to provide dynamic interactivity. Additionally, Bootstrap, a widely adopted responsive design framework, was integrated to deliver a consistent and visually appealing user experience across a variety of devices and screen sizes [21].

PostgreSQL was selected as the relational database management system due to its reliability, efficiency in handling large datasets, and compatibility with diverse technological ecosystems. Its support for complex transactions and advanced security features ensures data integrity and protection—critical factors when handling sensitive neuropsychological information [13].

In addition to PostgreSQL's security capabilities, the Django framework provides built-in mechanisms that significantly enhance platform security. These include automatic protection against common web vulnerabilities such as Cross-Site Request Forgery (CSRF) through token validation, and Cross-Site Scripting (XSS) prevention by escaping output in templates. Django's robust authentication and authorization system securely manages user sessions and supports fine-grained access control through permissions and groups. Furthermore, Django's ORM (Object-Relational Mapping) prevents SQL injection attacks by using parameterized queries. The framework also

facilitates secure cookie management, supports HTTPS configurations including HTTP Strict Transport Security (HSTS), and enables security-related HTTP headers through middleware to mitigate risks like clickjacking and content injection [20].

By integrating these technologies and security features, the system not only automates tasks related to BANFE-2 administration but also adheres to high standards of technological quality and data protection. Its scalable architecture supports future expansions, while its focus on accessibility, performance, and security guarantees an optimized and safe user experience. This approach effectively reduces development time and delivers a modern, reliable solution tailored to the evolving needs of the neuropsychology field.

4. Methodology and Method

Currently, the use of computer systems and applications has become widespread, significantly expanding and diversifying the profile of users interacting with websites, desktop applications, and mobile applications. For a system to succeed, one of the key challenges is to develop applications that are not only useful and efficient but also provide a satisfying and accessible user experience.

With this objective in mind, this project developed a web application, APEN (Web Application for Neuropsychological Tests and Evaluations), aimed at automating neuropsychological assessments. The development process was structured using a hybrid approach that combined the MPIu+a model (Usability and Accessibility Engineering Process Model) [14] as the primary development methodology, with the agile framework Scrum for project management.

Below is an overview of the integration of User-Centered Design (UCD) activities within the interactive Scrum cycle (see Figure 1), which describes the key stages and their relationship with the employed methodology.

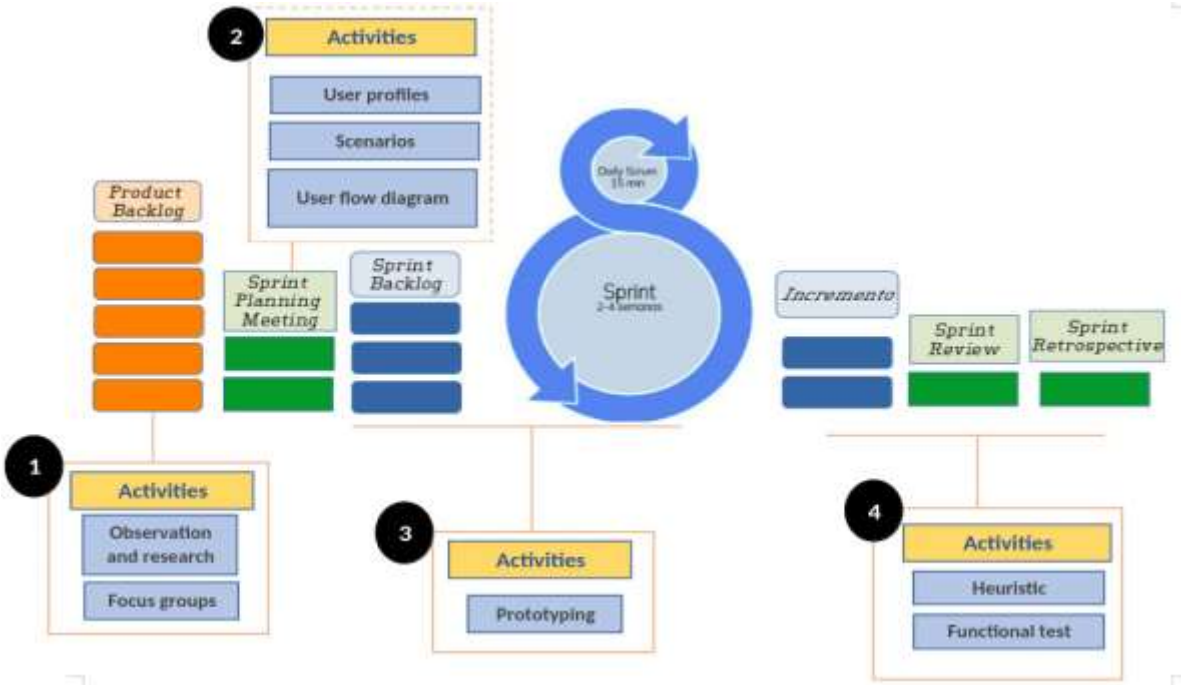

Figure 1. UCD Activities in Scrum.
Source: Own Elaboration.

MPIu+a Model as Development Methodology

The MPIu+a model was applied throughout all phases of the development cycle to ensure an optimal experience in terms of usability and accessibility. This model promotes an iterative user-centered process that integrates activities such as requirements gathering, prototype design, evaluation, and continuous validation of the interface.

The main activities performed during the development of APEN following MPIu+a included:

1. UX Backlog Storage: Consolidation of all planned activities addressing key user experience aspects throughout the Scrum lifecycle, focusing primarily on the needs of the clinical specialist.
2. Product Backlog Definition: Recording and prioritizing ideas and functionalities, applying a UCD approach to enhance usability and user satisfaction through intuitive and accessible interfaces.
3. Prototyping: Iterative development and refinement of interactive prototypes, with collaboration from the Scrum team and the Usability Owner to ensure compliance with standards.
4. Evaluation: Conducting continuous testing and assessments to validate that the system meets usability and accessibility criteria, enabling informed adjustments and ongoing improvements.

Scrum Framework for Project Management

Scrum was used exclusively as an agile framework to organize tasks, manage the product backlog, plan deliveries, and facilitate communication among the multidisciplinary team. It is important to clarify that Scrum was not applied as a software development methodology, but as a management tool complementing the use of MPIu+a.

During development, two-week sprints were conducted, in which specific tasks such as user interface design, implementation of functional modules, and integration of automated tests were defined and prioritized. Trello was used to manage the backlog, and regular meetings were held to monitor progress and adjust plans.

Requirements Analysis

To ensure the APEN platform addresses the real needs of its users, a thorough requirements analysis phase was conducted as part of the UX Backlog definition. This stage involved both contextual inquiry and focus groups, following a user-centered approach to gather functional and non-functional requirements.

Contextual Inquiry

Field observations revealed critical limitations in the traditional application of the BANFE-2 battery. Key issues included:

- High error rates in manual data collection.
- Excessive paper usage and related inefficiencies.
- Tedious and error-prone manual transcription of results into analysis software.
- Inability to apply the test to multiple subjects simultaneously due to limited physical resources.
- Limited collaboration and data accessibility when working with paper-based results.

These findings highlighted the need for digital solutions that minimize errors, support simultaneous testing, and facilitate data reuse.

Focus Groups

A structured focus group session was conducted with stakeholders, including neuropsychologists and system designers, moderated by the Scrum Master. The goal was to define detailed requirements for the APEN system. The discussion covered:

- User roles and access control.
- Security requirements, including authentication and authorization.
- Data storage, structure, and confidentiality.
- Information presentation, emphasizing usability and accessibility.
- Test deployment, including interaction design and feedback mechanisms.
- Design standards to ensure consistency, validity, and clinical appropriateness.

This phase served as the foundation for designing a system tailored to specialists' workflows, ensuring the proposed digital platform would be both usable and clinically effective.

Design

The design phase of APEN was developed in accordance with the second stage of the UX Backlog, where the structure of the system, the definition of user roles, and specification of interactions and requirements were established.

Two primary user types were identified through the contextual inquiry and focus group methods.

- **Evaluator User:** A standard user who is responsible for conducting neuropsychological assessment using APEN. This user can create and manage their own cases and test results but cannot access or modify data from other evaluators.
- **Administrator User**: A privileged role designed for overall system supervision. This user can access all case records and evaluator data, manage user accounts, and perform administrative tasks. However, they cannot generate reports for tests not administered by them.

Functional Requirements

The functional requirements were derived from the user scenarios and redefined through stakeholder meetings and focus groups. Each requirement specifies an action the user must be able to perform and is linked to the authorized roles (Administrator or Evaluator).

- **Authentication and Profile Management:** account creation, login, password reset, profile editing.
- **Subject and Case Management:** create, list, edit, delete subject cases.
- **Test administration:** test configuration, application, real-time feedback, and data storage.
- **Result management**: reviews scores, generate and export reports (PDF, CSV).
- **User and Data Access Control:** for Administrator users.

Non-Functional Requirements

The system must also meet a set of non-functional requirements that ensure robustness, user satisfaction, and legal compliance.

- **Security:** Robust authentication and role-based access control.
- **Usability:** Intuitive interface suitable for non-technical users.
- **Maintainability:** Modular architecture enabling future updates and feature expansions.

- **Cross-Platform Compatibility:** Usable on Windows, macOS, and Linux systems.
- **Data Privacy:** Strict compliance with data privacy standards, aligned with the ethical management of clinical information.

UML Use Case Diagrams

To ensure a structured understanding of how the system meets the needs of its primary user, a UML use case diagram was created to model the interactions of the Evaluator User with the APEN system.

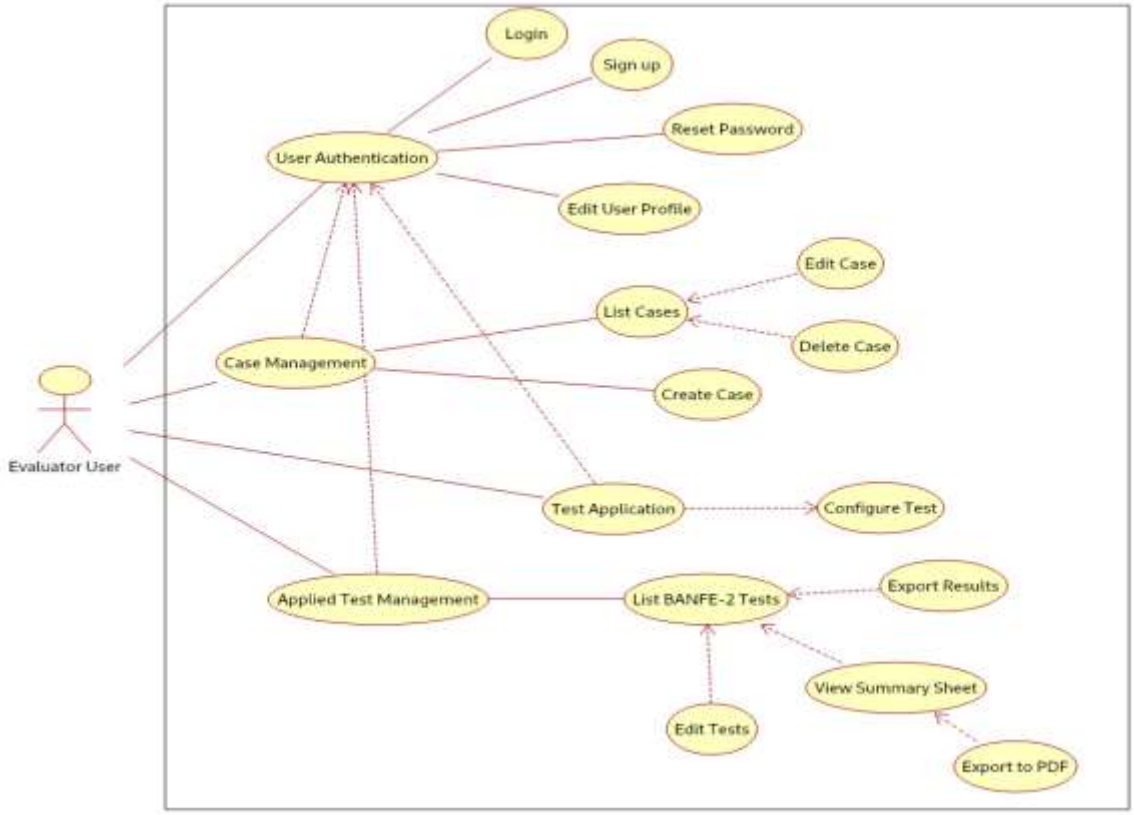

Figure 2. Use Case Diagram.
Source: Own Elaboration.

This user is responsible for managing subject records, administering neuropsychological tests, and consulting and exporting results, all within their authorized scope.

Diagram Elements:

1. Main Actor: Evaluator User: The "Evaluator User" actor represents the system's primary user, responsible for interacting with all functionalities. This user, likely an evaluator or test administrator, has direct access to all system modules, from authentication to results export.
2. Use Cases Grouped by Functionalities:

◦ User Authentication: This module ensures that evaluators can log in securely, register as new users, reset forgotten passwords, and update their user profiles. The associated use cases include: Login, Sign up, Reset Password and Edit User Profile.

◦ Case Management: This set of functionalities is designed to manage cases, understood as specific scenarios or evaluations. It allows users to create, list, edit, and delete cases. The associated use cases are: Create Case, List Cases, Edit Case and Delete Case.

◦ Test Application and Management: This is the system's core functionality, where tests are configured and managed, along with the tools required to process and present results. The use cases include: Configure Test: Initial setup of a test, List BANFE-2 Tests: Viewing and managing specific tests, Edit Tests: Modifying existing tests, Export Results: Generating results in exportable formats, View Summary Sheet: Viewing summary sheets of results and Export to PDF: Exporting reports and summaries to PDF format.

3. Relationships Between Use Cases:

The lines connecting the ovals (use cases) and the actor represent the user's direct interactions with the system. Some hierarchical relationships or dependencies between use cases, indicated by arrows, show how certain functionalities derive from or complement others. For example:

◦ List Cases is connected to Edit Case and Delete Case, indicating that editing or deleting requires listing the available cases first.

◦ View Summary Sheet and Export Results are linked to the applied test management module, demonstrating how the generate data can be viewed and exported.

The main goal of this system is to optimize the evaluation process, from case creation and test configuration to generating exportable reports. Its modular design allows evaluators to manage their activities efficiently and maintain an organized workflow. The presented diagram not only facilitates stakeholders' understanding of the system but also serves as a solid foundation for software development and validation. With this model, it ensures that all key functionalities are considered, which is essential to meet the end user's needs.

Prototyping

As part of the user-centered design methodology, a series of low-fidelity prototypes were developed to define the initial structure, navigation, and functionality of the APEN system. These prototypes allowed the team to explore interface ideas, validate user workflows, and collect feedback before implementing functional modules.

Figure 3 present some of the **initial low-fidelity prototypes** created during the early stages of the project. These mockups were developed using simple tools such as Microsoft Paint and served to visualize core functionalities before actual implementation. **In the figure, some of the prototypes created can be observed**, representing the login and registration screen, the test selection and configuration interface, and the results summary sheet, respectively. These prototypes were used to validate workflows and gather feedback from future users, laying the foundation for the modules built in the final application.

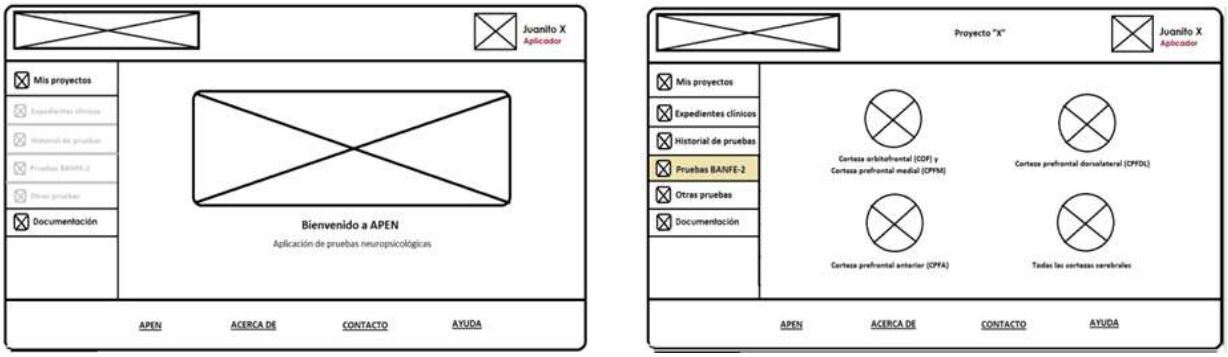

Figure 3. Interface displaying the list of records.
Source: Own Elaboration.

These visual designs were presented during focus group sessions and played a key role in defining system behavior and visual hierarchy. Feedback from users helped refine both the usability and relevance of the features.

Sprint Planning and Deliverables

The APEN development process was divided into six two-week sprints, each focused on delivering functional components aligned with user priorities identified during the UX Backlog phase. Below is a summary of the activities and deliverables for each sprint:

- **Sprint 1: Project Setup and Authentication**
  - Set up Django Backend, PostgreSQL database, and project repository.
  - Implemented user registration, login, and password reset functionality.
  - Defined user roles (Administrator and Evaluator).
- **Sprint 2: Case and Subject Management**
  - Developed modules for creating, editing, listing and deleting clinical records.
  - Integrated frontend forms and validation for subject data.
  - Conducted a sprint review with clinical advisors.
- **Sprint 3: BANFE-2 Test Modules**
  - This phase consisted of approximately 15 sub-sprints, each dedicated to the design and implementation of a specific BANFE-2 subtest.
  - Each sub-sprint included:
    - Interface layout for test.
    - Scoring logic and evaluation criteria.
    - Secure storage and validation of test results.
  - Each module was individually reviewed by clinical experts to ensure technical accuracy and adherence to the original battery structure.
  - Due to the complexity and level of detail required, this extended sprint took approximately five months to complete.
- **Sprint 4: Test Configuration and Application**
  - Created test configuration interface, allowing selection of prefrontal areas.
  - Implemented core logic to administer BANFE-2 tests digitally.
  - Captured test responses and stored them securely.
- **Sprint 5: Results Visualization**
  - Developed result summary screens per subject and test.
  - Enabled export of summary reports in PDF format.
  - Added basic statistical summaries.
- **Sprint 6: Usability Improvements and Heuristic Evaluation**
  - Refactored UI components based on expert feedback.
  - Performed a full heuristic evaluation using Nielsen's principles.
  - Prioritized improvements to accessibility, error messages, and layout.

Heuristic Evaluation

Evaluation is a fundamental component to ensure that the system is usable and accessible, as well as to guarantee acceptance by end users. Following Nielsen's recommendations [16], the heuristic evaluation was conducted by a group of three to five experts in fields such as information systems, software engineering, databases, and programming.

Each evaluator analyzed the system’s interface and functionalities applying the ten classic heuristic principles, aiming to identify usability issues and areas for improvement. Techniques employed included detailed inspection and systematic inquiry to cover as many potential interaction failures as possible.

The findings allowed prioritization of fixes and implementation of improvements aimed at optimizing user experience and meeting required quality and accessibility standards.

Table 1. Heuristic Principles.

Id	Description
PH1	Visibility of the system's status
PH2	Correspondence between software product and the real world
PH3	User control and freedom
PH4	Consistency and adherence to standards
PH5	Recognition rather than recall-based interaction
PH6	Flexibility and efficiency of use
PH7	Help users recognize, diagnose, and recover from errors
PH8	Error Prevention
PH9	Aesthetic and minimalist design
PH10	Help and documentation

5. Results and discusion

The results obtained from the development and implementation of the APEN platform demonstrate the effectiveness of a modular, web-based system for the digital administration of the BANFE-2 neuropsychological battery. The process followed a user-centered methodology (MPIu+a) and was executed through iterative, agile sprints organized under the Scrum framework. This section presents the developed modules, functional validation, heuristic evaluation, and the implications of the system for clinical practice and future research.

Modules Developed in APEN

APEN is composed of several integrated modules designed to guide the neuropsychologist through all stages of the evaluation process, from user authentication to test administration and result reporting. The system interface was iteratively refined to prioritize simplicity, clarity, and accessibility.

Figure 4 illustrates the user interfaces (UIs) designed for managing access to the application. These interfaces allow users to: **Iniciar Sesión:** If the user already has an active account and knows their password, they can authenticate by entering their credentials. **Registrarse**: For users without a prior account, the UI provides a registration flow that guides them through creating an account and setting up a personalized password. The interface is intuitively structured to facilitate both login and registration processes, ensuring a seamless and efficient user experience.

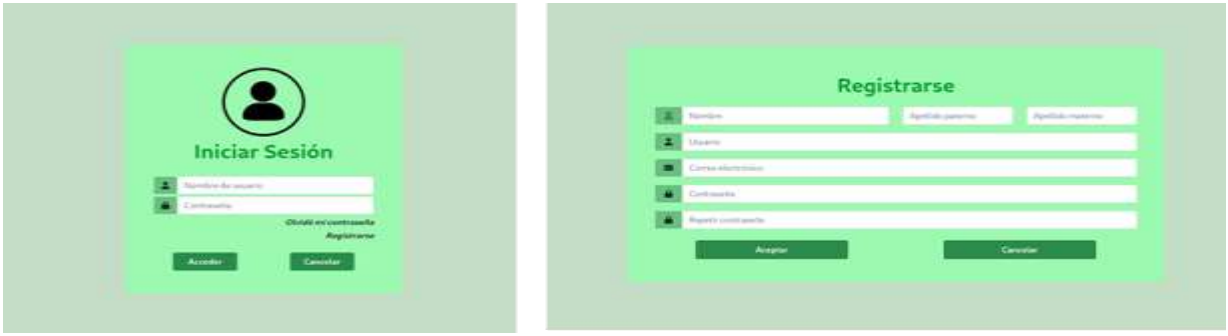

Figure 4. Login and Registration Interface.
Source: Own Elaboration.

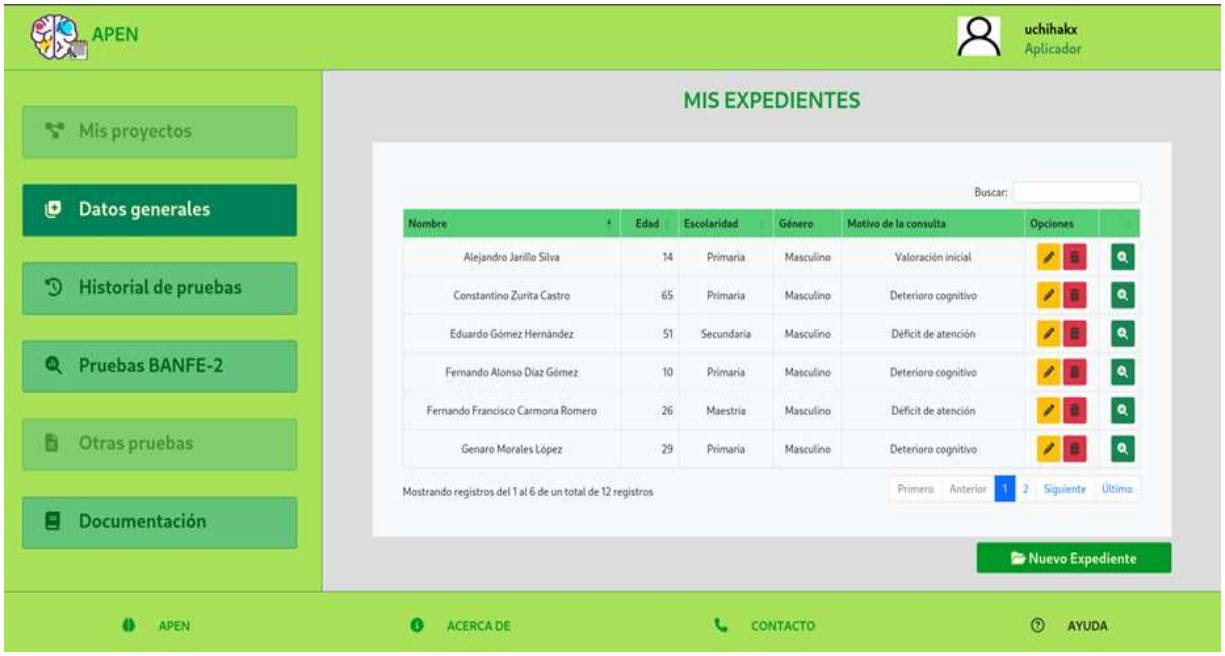

Figure 5. Interface displaying the list of records.
Source: Own Elaboration.

In Figure 5, the user interface (UI) of the "Mis Proyectos" section is presented, designed to facilitate the management of patient-related information. Through this UI, the user has access to various key functionalities: Nuevo expediente: Allows quick registration of a new patient's information. Editar o eliminar expediente: Users can update or remove records as needed, ensuring data accuracy. Detailed information review: It is possible to access the complete record of each patient to review their history. Advanced search and filtering: The interface includes tools to search for specific patients or filter records based on criteria such as education, age, or gender, improving speed and efficiency in data management. This UI combines an intuitive and accessible design with functional tools that optimize the management of clinical records.

In Figure 6, the neuropsychological testing management module is illustrated, designed to streamline and organize the various stages of the evaluation process. This module offers the following features: Test Configuration: Allows the user to select the most suitable neuropsychological tests and customize them according to the specific needs of each evaluation, including setting parameters or application criteria. Test Administration: Facilitates the execution of the selected tests, guiding the user through the process to ensure efficient and consistent administration for the subjects being evaluated. Result Recording: Provides a secure and organized space for storing the results of the tests, allowing for further analysis and comparison.

Figure. 6. Test Application Interface.
Source: Own Elaboration.

This module is designed to offer an intuitive and efficient experience, optimizing the evaluator's workflow and ensuring the structured management of both tests and results. In Figure 7, the interface of the Neuropsychological Test Management module is shown, designed to facilitate efficient management of administered tests for evaluators. Upon entering the module, users are initially presented with an organized list of administered tests, which serves as a starting point for various tasks, such as:

Export selected tests: Allows users to generate downloadable files with test results for use outside the system. Edit individual tests: Provides the option to modify the details of a specific patient's tests. View results: Enables detailed consultation of the results obtained in each test for in-depth analysis. Filter results: Includes filtering tools that assist in searching for specific tests based on established criteria, such as dates, test types, or patient characteristics.

Figure 7. Interface of the Results Visualization Module.
Source: Own Elaboration.

Figure 8. Results Sheet Interface.
Source: Own Elaboration.

In Figure 8, the user interface corresponding to the Results Sheet is displayed, designed to provide a detailed breakdown of the data obtained from the test applied to a particular subject. This interface includes the following features. Detailed result display: Clearly and systematically presents the specific information from the performed test, facilitating analysis. Export options: Allows the user to export the complete results sheet in PDF format, which is useful for saving records, generating reports, or sharing information with third parties in a professional manner.

These modules were developed in 18 sprints, including an extended phase of 15 sub-sprints (Sprint 3) dedicated to the design and

implementation of each BANFE-2 subtest. This modular approach enabled precise testing and validation of each functionality before integration.

Functional Validation

To ensure the system performed as intended, functional testing was conducted across all modules using predefined test cases. These cases were derived from the system's functional requirements and user stories, and they simulated real-world interactions.

Tabla 2. *Approved Functional Requirements*.

Functionality Tested	Requirement	Result
User registration and authentication	RF1 - RF4	Passed
Subject record creation and editing	RF5 - RF8	Passed
BANFE-2 test configuration and application	RF9 - RF11	Passed
Real-time result capture and summary display	RF12, RF14	Passed
PDF and CSV export and visualize results	RF13, RF15 – RF17	Passed

All tested modules performed correctly under expected conditions, confirming that the system meets its operational requirements.

Heuristic Evaluation Results

A heuristic evaluation was conducted by a panel of three experts in areas such as HCI, databases, and web development. Based on Nielsen's 10 usability principles, each evaluator independently reviewed the system and scored each principle based on level of compliance.

Figure 9. Heuristic Evaluation Results.
Source: Own Elaboration.

The overall score was **86.1%**, indicating a high level of usability and adherence to interface design standards. Key findings included:

- **Strengths:** Clear navigation, consistent layouts, intuitive interaction patterns, minimal cognitive load.
- **Areas for improvement:**
  - **PH10 – Help and Documentation:** Insufficient tooltips or contextual guides. User may need help accessing certain modules.
  - **PH11 – Error Prevention:** Error validation in forms could be improved with proactive alerts and inline messages.
  - **PH14 – Diagnosis and Recovery from Errors:** Some error messages lacked clarity or next-step instructions.
  - **PH15 – Accesibility and Flexibility:** Limited support for screen reader and keyboard-only navigation.

Corrective measures for these aspects have been documented for future development cycles to ensure full compliance with usability and accessibility standards.

Discussion

One of the main motivations for developing APEN was to address common problems in the traditional, manual administration of neuropsychological tests. Observations made during contextual inquiry confirmed the

following limitations in paper-based assessments:

- High risk of human error in data collection and scoring.
- Time-consuming processes for organizing and transcribing test data.
- Inability to apply tests concurrently to multiple subjects.
- High consumption of paper and physical resources.
- Limited accessibility for record sharing and collaborative analysis.

The implementation of APEN directly addresses these issues. Automation enables:

- **Time Efficiency**: Reduces total evaluation and reporting time.
- **Error Minimization**: Automated scoring improves reliability.
- **Scalability**: Allows for simultaneous administration of tests.
- **Ecological Benefit**: Replaces large amounts of printed materials.
- **Better Data Management**: Structured storage allows for quick retrieval and analysis.

The platform has the potential to transform how neuropsychological tests are applied in the clinical setting. Its design is especially relevant for public institutions and professionals in Latin America, where access to expensive commercial software is limited. Unlike tools such as **CANTAB** or **PsicoTest**, APEN is:

- Open-source
- Contextualized to Mexican clinical standards.
- Easily customizable.
- Designed with accessibility and usability in mind.

The ability to **generate structured reports** and **store patient records securely** makes it a reliable tool for longitudinal tracking of executive function in various neurological and psychiatric conditions.

The development of the web application was based on a strategic selection of technologies and methodologies that ensure scalability, efficiency, and a high-quality user experience. Django, a Python-based web development framework, is well-known for its emphasis on speed and security. Django facilitated the development of APEN by providing built-in tools such as ORM (Object-Relational Mapping), authentication, and protection against common attacks like CSRF and SQL injection [17]. Bootstrap was used to ensure a responsive and consistent design across devices with different resolutions, significantly reducing development time by avoiding the need to build visual elements from scratch.

By implementing the MVC architecture pattern, the code was organized in a clear manner, separating presentation layers, business logic, and data access. This approach simplifies maintenance and scalability of the application, in line with Fowler's recommendations [19] for modular and reusable software design [18]. Prototyping was used as a crucial technique to ensure the application met user needs. As Nielsen points out, the use of prototypes in interactive system design greatly improves usability by allowing for rapid iterations based on real user feedback [16].

Although the system currently focuses on test administration and reporting, its modular design opens the door to future enhancements such as:

- Integration of **machine learning models** to detect cognitive deterioration patterns.
- Expansion to other neuropsychological batteries beyond BANFE-2.

- Implementation of **assistive technologies** (e.g., voice commands, screen reader compatibility) to improve accessibility.

In summary, the results demonstrate that APEN is a functional, usable, and clinically valuable tool that fulfills its intended objectives. It improves existing workflows in neuropsychological evaluation and offers a strong foundation for future digital innovations in the field.

6. Conclusiones

The development of the APEN web application represents a technically robust and functionally validated solution for the digital automation of neuropsychological assessments, specifically the BANFE-2 battery. The strategic use of technologies such as Django, Bootstrap, and the MVC pattern enabled the construction of a scalable, secure, and modular platform tailored to the needs of mental health professionals.

With a usability score of 86.1%, the system demonstrates strong alignment with user expectations. Iterative prototyping, guided by heuristic evaluation and user feedback, allowed the continuous refinement of both functionality and interface. Identified areas for improvement, particularly in documentation, error handling, and accessibility, provide a clear roadmap for future enhancements.

The hybrid methodology combining MPIu+a with Scrum fostered an agile and user-centered development process, ensuring that clinical relevance and usability were prioritized at every stage. As a result, APEN not only improves the efficiency and accuracy of neuropsychological evaluations but also serves as a replicable model for future digital health tools.

In conclusion, this project contributes a significant step forward in the digital transformation of neuropsychological testing in Latin America. With continued iteration and expansion, APEN holds the potential to become a comprehensive, accessible, and clinically impactful platform in neuropsychological practice and research.

7. Future Research

The development of this work revealed several opportunities for further exploration that could significantly enrich the system and its applicability. Although these proposals were not implemented due to time and technical constraints, they outline important directions for future research and development.

First, the optimization of the examiner’s experience remains a central line of work. Enhancing the user interface and overall usability of the platform would allow for a more agile, intuitive, and efficient administration of tests, while also supporting ongoing professional training through online learning modules.

A second area of focus is the advancement of data management strategies. Building a more robust infrastructure for the collection, storage, and analysis of information would enable faster access to results and support the implementation of longitudinal or comparative analyses, thus strengthening the value of the system as a diagnostic and research tool.

Equally important is the reinforcement of data security and privacy. The integration of advanced encryption mechanisms and compliance with international standards would ensure the ethical and safe management of sensitive health information, an essential requirement in digital health environments.

Another promising direction involves the development of advanced analysis modules. The inclusion of interactive visualizations, dashboards, and statistical summaries could facilitate a clearer interpretation of results and enhance decision-making processes for professionals.

The expansion of neuropsychological assessments also represents a valuable line of inquiry. Incorporating additional batteries and tests within the same platform would not only broaden diagnostic coverage but also reduce the time required for administration and analysis.

Finally, further validation in diverse populations is necessary. Testing the application with individuals across different age groups and with specific clinical conditions would provide insights into its diagnostic accuracy and reveal areas for improvement, ensuring its reliability in real-world clinical contexts.

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