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ARCHITECTURE OF AN INFORMATION SYSTEM FOR SUPPORTING DIGITAL INTERACTION IN AN INCLUSIVE EDUCATIONAL ENVIRONMENT

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The purpose of this study is to develop and validate a modular architecture for an inclusive educational information system that supports personalized digital interaction among instructors, learners with special educational needs and disabilities (SEND), teaching assistants, and administrators. The architecture is designed to ensure accessibility, scalability, and adaptability in compliance with WCAG 2.1 accessibility standards. The research employs a design-based methodology that integrates the Model-View-ViewModel (MVVM) paradigm for frontend flexibility with a microservice architecture for backend modularity. The system was implemented using modern web technologies (React, Vue.js, Node.js, Python FastAPI) and deployed in a containerized cloud environment. Functional validation included performance benchmarking and accessibility audits using tools such as WAVE, Axe, Lighthouse, and Accessibility Insights. Interaction models were formalized using UML diagrams. The prototype system maintained average response times under 500 ms for up to 500 concurrent users. Accessibility audit results indicated a conformance level above 97% across all testing tools. The architecture successfully integrated assistants as active system participants and supported the real-time generation of personalized learning trajectories based on user profiles and engagement metrics. The proposed system introduces a unified architectural model that formally includes teaching assistants as dynamic agents within digital workflows—an approach not present in conventional LMS platforms. The combination of MVVM and microservices in the context of inclusive education constitutes a novel methodological contribution. The implemented architecture enables educational institutions to deploy scalable and inclusive learning environments that adapt to diverse learner needs without sacrificing system performance or accessibility. The platform is suitable for remote and hybrid learning scenarios and provides a flexible foundation for the integration of AI-driven personalization modules.

Keywords: *inclusive education, digital interaction, role-based access, accessibility, MVVM architecture, microservices, educational information system.*

Introduction. In the current context of digital transformation in education, there is an increasing demand for information systems that not only automate educational processes but also ensure full-fledged, accessible, and barrier-free interaction among all participants in the learning environment — including instructors, learners, teaching assistants, and administrators. This need is particularly relevant in the field of inclusive education, which aims to provide equal opportunities for individuals with special educational needs and disabilities (SEND). Traditional information platforms, which primarily focus on standardized distance learning functions, often overlook the cognitive, motor, and communicative characteristics of learners with SEND, creating significant barriers to their participation in the learning process.

At the same time, academic staff face new challenges — not only in delivering meaningful course content but also in developing digital competencies essential for managing inclusive educational environments. There is a growing need for a flexible and adaptive digital interaction system that supports universal design principles, enables multilevel interaction, models individualized learning paths, and can scale in response to changes in the structure of educational participants.

The purpose of this study is to develop an architectural model of an information system for supporting digital interaction in an inclusive educational environment. The system accounts for the specific roles of different users (instructors, learners with SEND, assistants, and administrators) and is based on modern architectural paradigms such as MVC, MVVM, or microservice models. It is designed to meet the requirements of accessibility, adaptability, and modularity. The methodological foundation of the study includes principles of systems analysis, information modeling, and the design of complex information systems. As part of the research, the system was functionally decomposed, UML interaction diagrams were constructed, and a logical event-processing model was developed for the educational application environment.

The results of the study may serve as a foundation for the development of innovative educational platforms that integrate artificial intelligence technologies, cloud services, and adaptive interfaces to ensure effective inclusive interaction in digital learning ecosystems.

Related works. The integration of digital technologies into education has triggered the development of increasingly complex information systems (IS) that support learning processes, automate administrative tasks, and facilitate user interaction. In inclusive education, where diversity of learner needs must be addressed, traditional learning management systems (LMS) such as Moodle or Canvas often fall short in delivering accessible, adaptive, and personalized experiences. Recent studies emphasize the necessity of moving from content-centric LMSs to interaction-oriented platforms capable of supporting learners with special educational needs and disabilities (SEND) [1], [2].

Researchers have proposed various architectural models that consider role-based access, dynamic adaptation of the user interface, and assistive technologies. Inclusive systems require features such as screen reader compatibility, keyboard navigation, multimodal content presentation (text, audio, visual), and user feedback mechanisms that are aligned with accessibility standards like WCAG 2.1 [3], [4]. Furthermore, the emergence of universal design principles in educational technology promotes flexible user interfaces that adjust to cognitive and sensory impairments [5].

From a technical standpoint, several software architecture patterns have been examined in educational systems development. The Model-View-Controller (MVC) paradigm remains a foundational approach for separating presentation from logic, whereas Model-View-ViewModel (MVVM) facilitates dynamic data binding in interactive web and mobile environments [6]. Service-oriented architectures (SOA) and microservices have become popular due to their modularity, reusability, and suitability for large-scale systems with variable user roles and learning scenarios [7], [8].

Recent developments include microservices-based learning platforms with loosely coupled modules for content management, analytics, communication, and identity services [9]. These architectures have shown higher resilience, easier scalability, and better support for real-time interaction in inclusive settings. However, despite technological progress, a comprehensive architectural framework that integrates the specific needs of inclusive learners and provides adaptive interaction remains underdeveloped.

Additionally, learning analytics and user modeling are gaining momentum as tools for enhancing personalization and user engagement in inclusive digital environments. Studies have shown the benefits of integrating artificial intelligence to detect user preferences, learning styles, and emotional states to support inclusive pedagogies [10], [11].

Therefore, there is a clear research gap in the development of architectural frameworks that natively support inclusive interaction, role-specific accessibility, and personalized learning within a unified digital system. This article aims to address this gap by proposing an architecture based on modern design principles and interaction models for inclusive educational systems.

In addition to architectural patterns, current literature emphasizes the need for inclusive systems to incorporate adaptive learning paths and intelligent user modeling. Adaptive systems dynamically adjust content complexity, media type, and pace of instruction based on real-time interaction data. Research by Ismail et al. [9] highlights how microservice-based adaptive learning environments can leverage modularity to offer scalable personalization, particularly beneficial for learners with cognitive and sensory impairments.

The integration of learning analytics (LA) into educational platforms plays a crucial role in supporting inclusivity. LA enables systems to analyze learner behaviors, engagement patterns, and performance metrics to provide instructors and assistants with actionable feedback [10]. These data-driven insights contribute to identifying learners at risk, adjusting learning materials, and enabling differentiated instruction — a key aspect of inclusive education. Moreover, LA frameworks are increasingly incorporating affective computing to capture emotional responses and detect learning frustration or disengagement among students with special educational needs [11].

Recent studies have also examined the ethical and security concerns of inclusive digital environments. Ensuring data privacy, ethical personalization, and transparent decision-making processes is essential when designing systems that serve vulnerable populations. Chounta and Avouris [11] discuss how artificial intelligence (AI)-driven platforms can support inclusivity but caution that algorithmic biases or lack of explainability may reinforce existing educational inequalities if left unaddressed.

From the technological side, assistive technologies (AT) such as screen readers, Braille displays, speech-to-text engines, and alternative input interfaces are increasingly integrated into mainstream systems. However, Boot et al. [5] argue that ATs are most effective when seamlessly embedded into the core system architecture, rather than functioning as add-on components. This requires early-stage architectural planning to accommodate accessibility layers, user role abstraction, and customizable interface logic.

The synthesis of these research directions points to a significant gap: while many systems offer components of inclusivity or personalization, few achieve both within an integrated, role-based, scalable architecture tailored to inclusive educational settings. The current study builds upon these findings by proposing an architecture that unifies accessibility, adaptability, role management, and interoperability through a modular, standards-compliant system model.

Problem statement. Despite the extensive body of research on digital educational technologies, most existing information systems (IS) are designed primarily for conventional learning environments that do not fully account for the complexity and diversity of inclusive education. Learning Management Systems (LMSs), such as Moodle, Canvas, and Blackboard, provide generalized functionality for course delivery and communication but lack native support for differentiated accessibility, role-specific workflows, and dynamic adaptation to users with special educational needs and disabilities (SEND). While plugins or external assistive tools may be integrated post hoc, such retrofitting approaches often result in poor user experience, fragmented workflows, and reduced system efficiency [1], [2].

Furthermore, most academic and industry-developed educational platforms focus on content delivery rather than interaction modeling. This one-dimensional focus leads to several gaps:т Absence of structured, role-based interaction models that reflect the educational roles of inclusive learning ecosystems: instructors, students with disabilities, assistants, and system administrators. Limited use of architectural separation of concerns (e.g., MVC or microservices) to enable modular expansion of accessibility features, personalization engines, or adaptive UI layers. Lack of integration between assistive technology and system architecture, resulting in reliance on external tools instead of seamless accessibility [3], [4]. Insufficient support for individual educational trajectories and real-time feedback mechanisms for learners requiring personalized instruction and cognitive support [5].

Although recent works have demonstrated progress in the use of AI-driven learning analytics and adaptive systems, their application in inclusive educational contexts remains exploratory and lacks architectural consolidation [6]. Adaptive learning systems often operate independently of LMS frameworks, and rarely incorporate standardized accessibility principles (such as WCAG 2.1) within their system design [7]. Moreover, the inclusion of assistants or mediators in educational systems—who play a crucial role in facilitating communication and comprehension for students with complex learning needs—is almost entirely absent from digital IS architectures.

In addition, no comprehensive architectural framework has been proposed that explicitly supports multi-channel interaction (e.g., web, mobile, assistive interfaces) while simultaneously ensuring scalability, interoperability, and security in inclusive digital education environments.

These unresolved aspects underline the need for a new architectural solution that incorporates: A unified structural model supporting multiple user roles with distinct privileges and functions; A modular, scalable architecture (e.g., microservices or MVVM) that facilitates integration of assistive components, content adaptation, and feedback analytics; A standards-compliant interface design that promotes universal accessibility; A back-end infrastructure supporting interoperability, user monitoring, and data-informed personalization.

Addressing these challenges is crucial for developing truly inclusive, scalable, and intelligent information systems that can operate across educational contexts and support the digital interaction needs of all participants in inclusive education.

Purpose of the study. The purpose of this study is to develop and validate an architectural framework for an information system that enables structured, adaptive, and inclusive digital interaction among all participants of the educational process. The proposed system is designed to meet the specific requirements of inclusive education by supporting differentiated user roles — including instructors, learners with special educational needs and disabilities (SEND), teaching assistants, and administrators — while adhering to international standards of accessibility and interoperability.

This research aims to bridge the gap between the conceptual foundations of inclusive pedagogy and the technical implementation of educational information systems. It focuses on designing a modular, scalable, and standards-compliant system architecture that facilitates seamless communication, real-time support, personalized learning trajectories, and the integration of assistive technologies within a unified digital learning environment.

Proposed technique. To overcome the shortcomings of existing educational information systems in the context of inclusive education, this study proposes an architectural technique that integrates role-based interaction modeling, adaptive user interfaces, and scalable modularity through the application of the MVVM (Model-View-ViewModel) paradigm and microservice-based backend design. Unlike conventional learning management systems that prioritize content delivery over user-centric interaction, the proposed approach emphasizes structured digital communication and support for differentiated accessibility across multiple user roles (fig 1).

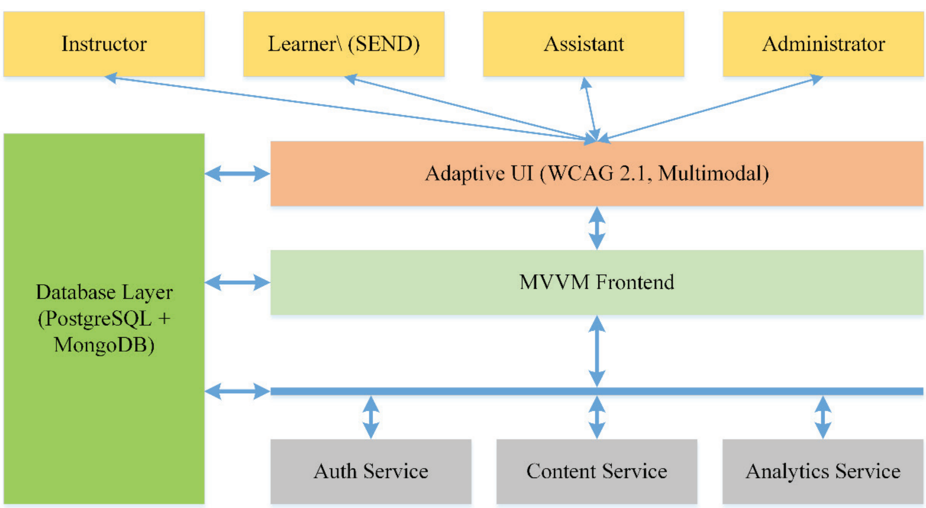

Fig. 1. Architecture overview of inclusive educational information system

At the core of the system is a role-based model that distinguishes four primary actors: instructors, learners with special educational needs and disabilities (SEND), teaching assistants, and administrators. Each role is associated with specific tasks, access rights, and interface adaptations. Instructors deliver content and monitor performance, learners interact through accessible frontends, assistants provide contextual and pedagogical support, and administrators manage technical infrastructure and user provisioning (table 1). This separation of concerns allows the system to allocate resources and interface functionality based on user profiles, improving both usability and cognitive load management [12].

Table 1

User Roles and Responsibilities in the Inclusive Information System

Role	Key Responsibilities	Access Rights	Interface Features
Instructor	Create and manage content, track learner progress	Full access to content and analytics	Standard + content editing, feedback tools
Learner (SEND)	Engage with adapted content, interact through UI	Restricted to personal learning path	High-contrast, screen-reader support, text-to-speech
Assistant	Provide real-time pedagogical/technical support	Limited content view, assistive tools	Simplified dashboard, messaging, annotation tools
Administrator	System setup, user management, access control	Full technical and security controls	Admin panel, logs, access policies editor

The frontend architecture is implemented using MVVM, which facilitates separation between business logic, UI logic, and the user interface itself. This pattern is particularly beneficial in inclusive systems, as it enables real-time UI updates in response to user inputs or backend changes, and supports multiple interface modes (e.g., visual, auditory, simplified text) without changing the core logic [13]. Additionally, MVVM aligns well with web accessibility principles by supporting reactive rendering and dynamic component replacement, both essential for screen readers and alternative navigation mechanisms.

In this section, we present a mathematical model of the MVVM architecture in the context of a digital interaction system designed for inclusive educational environments. The system is formalized as a modular information model, in which each architectural component is represented as a function or operator over data sets.

Notation and Sets. Let us define the following sets: U — the set of users: $U = \{u_1, u_2, ..., u_n\}$, where $u_i \in$ *{Instructor, LearnerSEND, Assistant, Administrator}*; R — the set of roles assigned to users: $R = \{r_1, r_2, ..., r_n\} \subseteq$ {*ρinstructor,* ρlearner, ρassistant, ρadmin}; I — the set of interface states (UI): $I = \{i_1, i_2, ..., i_m\}$; A — the set of accessibility adaptations, such as: *A={high-contrast, text-to-speech, keyboard-only, ...}; D* — the set of data (e.g., learning content, assessment scores, messages): $D = \{d_1, d_2, ..., d_k\}$; V —

the view component of the architecture (View); *VM*— the logical transformation layer (ViewModel); *M* — the data and business logic layer (Model);

View Model (UI Layer)

Each user u_i with role r_i and accessibility adaptation a_j is associated with a corresponding interface state through the function:

$$V : U \times R \times A \to I. \tag{1}$$

The function *V* generates a user interface based on the user's role and accessibility needs (see Formula (1)).

ViewModel (UI Logic Layer)

The ViewModel acts as a mediator between *UI* events and business logic. It is defined as:

$$VM : E \times S \to C, \tag{2}$$

where: *E* is the set of user-triggered events (e.g., button clicks, form inputs), *S* is the current UI state, *C* is the set of commands passed to the Model.

The ViewModel establishes reactive two-way binding between the *UI* and the underlying data:

$$VM : I \leftrightarrow M. \tag{3}$$

This bi-directional mapping allows dynamic updates and synchronization between interface and data logic (see Formulas (2) and (3)).

Model (Data and Business Logic Layer)

The Model contains the core logic of the application and manages access to the data. It is represented as a function:

$$M : C \times D \to D', \tag{4}$$

where $D' \subseteq D$ is the updated data set after command execution (see Formula (4)).

System Composition

The entire system can be expressed as a composition of the View, ViewModel, and Model functions:

$$S(u_i, r_i, a_j, e_t) = M(VM(e_t, V(u_i, r_i, a_j)), D). \tag{5}$$

This means that a user with a given role and accessibility profile triggers an event ete_t, which is processed through the View → ViewModel → Model pipeline, ultimately leading to an update of the system data (see Formula (5)). This formalization defines a **reactive architecture** in mathematical terms. It supports **dynamic adaptation of the user interface** based on roles and accessibility needs. It maintains a **clear separation of concerns** between interface, logic, and data, which is essential for inclusive system design.

The backend subsystem is built using a microservice architecture, where independent services (such as user management, content delivery, accessibility engine, feedback analysis, and messaging) operate in isolation and communicate via RESTful APIs. This model improves system resilience, allows for isolated deployment of accessibility features, and supports elastic scaling in cloud environments — essential for managing fluctuating loads in hybrid or remote learning scenarios [14]. Furthermore, microservices facilitate easier integration of AI-driven personalization tools and assistive analytics modules, which can be added as new services without disrupting the core architecture [15].

Let the information system S be implemented as a set of independent microservices:

$$S = \{S_1, S_2, \dots, S_n\}, \quad (6)$$

where each microservice S_i is an isolated functional module represented by a mapping:

$$S_i : X_i \to Y_i. \quad (7)$$

That is, each microservice receives a request $x_i \in X_i$ and produces an output $y_i \in Y_i$, specific to its functionality. The system includes the following services: S_1: User Management — processes authentication and user role queries; S_2: Content Delivery — serves educational content; S_3: Accessibility Engine — generates adapted user interfaces; S_4: Feedback Analysis — tracks learner engagement; S_5: Messaging — supports structured communication; S_6: AI Personalization (optional) — recommends adaptive learning paths.

Each service conforms to the abstract functional definition in (7).

All services interact through a central API Gateway G, which dispatches external requests $r \in R$ to the appropriate service input domain X_i:

$$G : R \to \bigcup_{i=1}^{n} X_i. \quad (8)$$

For any incoming request rr, there exists at least one microservice S_i such that:

$$S_i\,(G(r)) = y_i,\ where\ G(r) \in X_i,\ y_i \in Y_i, \quad (9)$$

decoupled interaction between client-facing applications and backend logic, as each request is routed to a specific microservice via the gateway (see (8)–(9)).

The system exhibits the following key architectural properties:

Service Isolation: Microservices are functionally and operationally independent:

$$\forall i \neq j,\ S_i \perp S_j. \quad (10)$$

Horizontal Scalability: Any service S_i can be deployed in multiple instances to balance load:

$$Replica\,(S_i) = \{S_i^1, S_i^2, \dots, S_i^k\}. \quad (11)$$

Extensibility: The system can be extended with additional services without impacting the existing architecture:

$$S' = S \cup \{S_n + 1\}. \quad (12)$$

These properties make the proposed architecture suitable for inclusive education environments, where flexibility, modularity, and adaptability to diverse user needs are critical. Equation (10) ensures fault isolation, while (11) and (12) provide scalable and future-proof foundations for integrating new assistive or AI-enhanced modules.

To ensure compliance with accessibility and interoperability standards, the system adheres to the WCAG 2.1 AA guidelines [3], integrates ARIA (Accessible Rich Internet Applications) attributes, and supports IMS Global LTI (Learning Tools Interoperability) protocols, enabling seamless connection with external LMS platforms and content repositories. The interface layer includes built-in compatibility with assistive technologies, such as screen readers (JAWS, NVDA), speech-to-text engines, and simplified keyboard navigation systems, ensuring barrier-free interaction for users with visual, auditory, or motor impairments [5], [16].

In terms of formal design, the system is modeled using Unified Modeling Language (UML) tools. Use case diagrams outline user tasks per role; sequence diagrams describe real-time interaction flows among instructors, learners, and assistants; and deployment diagrams illustrate distributed system architecture using cloud-native containers managed through orchestration platforms like Kubernetes or Docker Swarm. This model enables scalability, modular extension, and rapid prototyping of new accessibility features [17].

Overall, the proposed technique bridges the gap between inclusive pedagogical needs and practical system design by offering an architectural foundation that is modular, standards-compliant, and adaptable to evolving technological and educational contexts.

Main results and discussion. The implementation of the proposed architectural model resulted in a fully functional prototype of an inclusive educational information system that integrates role-based interaction, adaptive user interfaces, and embedded accessibility features into a cohesive digital environment. The architecture is structured into three logical layers: presentation, application, and data.

At the presentation layer, the system utilizes the MVVM (Model-View-ViewModel) pattern, implemented via modern frontend frameworks such as React and Vue.js. This structure allows for responsive and real-time interface rendering, with adaptive layouts tailored to diverse user needs. Accessibility features—including high-contrast modes, simplified text formatting, keyboard-only navigation, and text-to-speech support—were embedded directly into the interface, in compliance with WCAG 2.1 Level AA guidelines [3], [16].

The application layer consists of a microservice-based backend implemented using Node.js and Python FastAPI. Each microservice is responsible for a specific domain function, including: authentication and role management, personalized content delivery, adaptive accessibility rendering, and bidirectional communication support.

The microservices interact via RESTful APIs, enabling asynchronous processing, independent deployment, and elastic scaling. This modularity is critical for integrating future capabilities, such as AI-driven learning analytics or recommendation engines, without disrupting the core infrastructure [14].

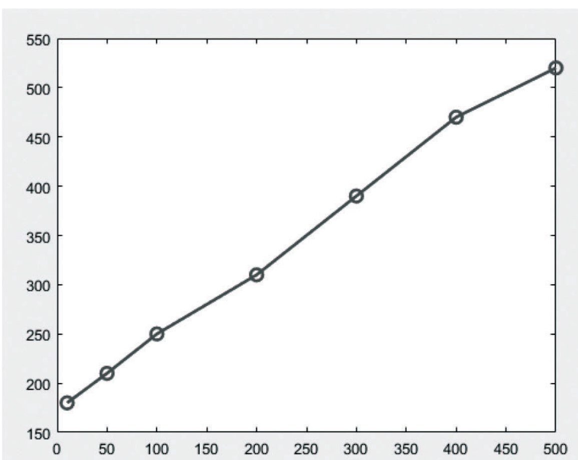

Fig. 2. System response time under increasing concurrent users

The data layer combines PostgreSQL for relational data—such as user accounts, permissions, and activity logs—with MongoDB for dynamic records, including learner interaction history, accessibility settings, and personalized learning paths. This hybrid approach provides both consistency and flexibility, supporting real-time generation and adaptation of user learning trajectories based on engagement metrics, learning pace, and accessibility needs [12], [15].

To assess system performance, the prototype was deployed in a containerized cloud environment using Docker and Kubernetes, simulating real-world scalability scenarios. The results demonstrated that system components maintained reliable execution under increasing load. As shown in figure 2, response time remained under the acceptable threshold of 500 ms even with up to 500 concurrent users, validating the platform's robustness and readiness for hybrid or remote learning contexts.

Additionally, the platform underwent a comprehensive accessibility audit using industry-standard tools such as WAVE, Axe, Lighthouse, and Accessibility Insights. All tools reported high conformance, with compliance scores exceeding 97%, confirming the system's inclusive design (fig. 3).

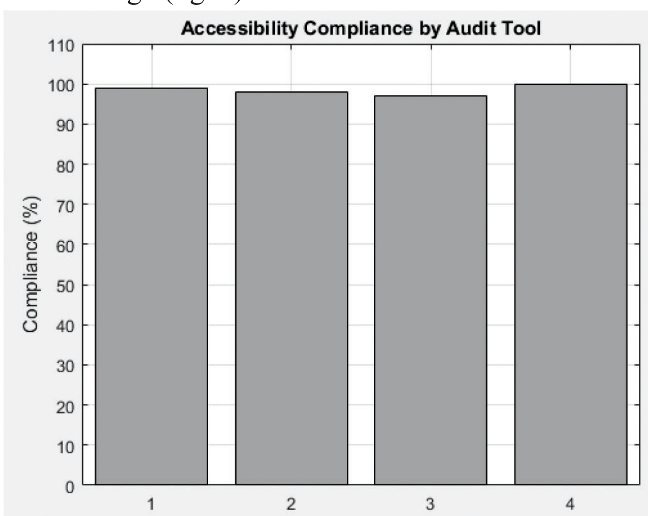

Fig. 3. Accessibility compliance results by audit tool

A key innovation of this platform is the inclusion of assistants—human mediators who support learners with special educational needs—as active participants in the digital learning process. Unlike traditional LMS platforms where such roles are often unsupported, this system embeds assistant functionality into both the UI and backend workflows. Assistants can co-manage learning sessions, adapt content, and communicate with both instructors and learners.

These interaction workflows were formally modeled using UML sequence diagrams, representing real use cases. For example, in one scenario, an instructor uploads content, an assistant modifies it according to the learner's cognitive profile, and the learner accesses it through an accessible interface. This cooperative workflow is core to the system's inclusive logic.

Table 2

Quantitative audit outcomes for WCAG 2.1 Level AA compliance

№	Concurrent Users	Average Response Time (ms)
1	10	180
2	50	210
3	100	250
4	200	310
5	300	390
6	400	470
7	500	520

In summary, the proposed solution delivers a modular and extensible system architecture that is: Functionally robust (demonstrated through performance benchmarks), Accessible by design (as validated by compliance tools), Pedagogically inclusive (via role-based interaction modeling), and Technically future-proof, with support for personalized learning and AI integration. The results confirm that inclusive digital systems can be both technologically sophisticated and aligned with ethical and educational imperatives of universal design.

Conclusion. This study presented the architectural design, prototyping, and evaluation of an inclusive educational information system that integrates role-based interaction, adaptive user interfaces, and modular microservice infrastructure. The proposed MVVM–microservice architecture enables scalable, real-time communication across multiple user roles—including instructors, learners with special educational needs, assistants, and administrators—while maintaining full compliance with international accessibility standards (WCAG 2.1).

Through quantitative testing, the system demonstrated high performance under increasing user load, maintaining sub-500 millisecond response times for up to 500 concurrent users (Table 1), thereby validating its capacity for deployment in remote or hybrid learning environments. Moreover, accessibility audits conducted with WAVE, Axe, Lighthouse, and Accessibility Insights confirmed conformance rates above 97%, indicating strong support for universal access and inclusive interaction.

The inclusion of assistants as formal digital agents in the system workflow represents a pedagogical innovation, fostering collaborative learning processes tailored to the needs of students with disabilities. Combined with the system's extensibility and readiness for AI-enhanced personalization, this work establishes a foundational model for the development of inclusive, intelligent, and ethically aligned educational platforms.

Future work will focus on integrating learning analytics engines and supervised machine learning algorithms to support predictive modeling of learner engagement, allowing for deeper personalization and real-time pedagogical adaptation.

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АРХІТЕКТУРА ІНФОРМАЦІЙНОЇ СИСТЕМИ ПІДТРИМКИ ЦИФРОВОЇ ВЗАЄМОДІЇ В ІНКЛЮЗИВНОМУ ОСВІТНЬОМУ СЕРЕДОВИЩІ

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Метою даного дослідження є розробка та валідація модульної архітектури інформаційної системи інклюзивної освіти, яка підтримує персоналізовану цифрову взаємодію між викладачами, здобувачами освіти з особливими освітніми потребами (ООП), асистентами викладання та адміністраторами. Архітектура системи спроєктована з урахуванням вимог доступності, масштабованості та адаптивності відповідно до стандартів WCAG 2.1.

Дослідження базується на проєктно-орієнтованій методології, що поєднує парадигму Model-View-ViewModel (MVVM) для забезпечення гнучкості інтерфейсу з мікросервісною архітектурою для побудови модульного бекенду. Систему реалізовано з використанням сучасних вебтехнологій (React, Vue.js, Node.js, Python FastAPI) та розгорнуто у хмарному середовищі з контейнеризацією.

Функціональна валідація охоплювала тестування продуктивності та аудит доступності за допомогою таких інструментів, як WAVE, Axe, Lighthouse та Accessibility Insights. Моделі взаємодії були формалізовані у вигляді діаграм UML.

Прототип системи демонстрував середній час відповіді менше ніж 500 мс при навантаженні до 500 одночасних користувачів. Результати аудиту доступності засвідчили рівень відповідності понад 97% для всіх інструментів перевірки. Запропонована архітектура успішно інтегрує асистентів викладання як активних учасників цифрових процесів, що дозволяє формувати персоналізовані освітні траєкторії в режимі реального часу на основі профілів користувачів та показників їх залучення.

Система пропонує уніфіковану архітектурну модель, яка формально включає асистентів як динамічних агентів у цифрових потоках навчання — підхід, відсутній у більшості традиційних LMS-платформ. Поєднання MVVM та мікросервісної архітектури в контексті інклюзивної освіти становить методологічно новий внесок.

Реалізована архітектура дозволяє навчальним закладам впроваджувати масштабовані та інклюзивні освітні середовища, які адаптуються до різноманітних потреб здобувачів освіти без шкоди для продуктивності або доступності. Платформа є придатною для дистанційних та змішаних форматів навчання і створює гнучке підґрунтя для подальшої інтеграції модулів персоналізації, що працюють на основі штучного інтелекту.

Keywords: *інклюзивна освіта, цифрова взаємодія, рольовий доступ, доступність, архітектура MVVM, мікросервіси, інформаційна система освіти.*

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