Modular Architecture of an Adaptive e-learning System with an Integrated AI Tutor

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***Abstract*—Traditional e-learning systems have limitations in terms of personalization and adaptability, which reduces the efficiency of education. This paper proposes a modular architecture for an adaptive e-learning system based on artificial intelligence with an integrated AI Tutor. The proposed system is a combination of multiple modules that enable continuous data collection and analysis as well as dynamic adaptation of teaching content. The architecture is implemented as layers, namely a client-server structure that provides real-time interaction and personalization. The paper emphasizes the integration of artificial intelligence and learning analytics, which are the foundation for the development of modern adaptive e-learning systems.**

Keywords—e-learning, adaptive architecture, artificial intelligence, learning analytics, personalization

I. Introduction

Modern education is under the influence of digital transformation where e-learning systems play a major role in organizing the teaching process. The widespread use of these systems that have a static structure and limited personalization reduce the effectiveness in terms of students' needs and their characteristics [1],[2].

The development of information technologies such as artificial intelligence and learning analytics enables a new emergence of adaptive systems that enable personalization, analysis and interaction in real time [3],[4]. Such technologies that are part of the systems enable data processing and interpretation in order to make adaptive decisions [5].

Solutions focus on aspects of the learning process without full integration of such intelligent components into an architectural model that will allow continuous feedback and adaptation [6]. This shortcoming limits the possibility of developing systems that are connected, personalized and active. For this reason, this paper proposes a modular architecture of an adaptive e-learning system based on artificial intelligence with an integrated AI Tutor module.

II. Methodology

The research is based on the methodological approach Design Science Research (DSR), applied in the field of information systems and software engineering for the design and development of innovative solutions. Such an approach allows for systematically problem definition, creation of ethics, and analysis.

The first stage is an approach to the identified problem that we define in the introduction that is aimed at scaling off traditional e-learning systems. The problem is the basis for a further design of the proposed system.

The second stage is defining the requirements for the system based on analyzing current research in the areas of adaptive learning, artificial intelligence, and learning analytics. Those studies and their analysis define the need to integrate intelligent components such as learning analytics and AI into a single model with a single architecture.

The third phase is the design of the proposed architecture for the EduAI system, which is modular and layered in structure and allows for the integration of multiple modules. The architecture aims to provide flexibility, scalability, and support for the adaptation of the teaching process.

Within this research, emphasis is placed on the design of architecture as a scientific contribution, while implication and appraisal are not the subject of this research.

III. Related Research

In recent years, the development of e-learning systems that have adaptive and intelligent tutors has accelerated, especially with the development of artificial intelligence and machine learning. Research shows how intelligent e-learning systems using machine learning techniques and natural language processing can provide personalization and adaptability in learning according to the individual level of students [7].

Adaptive learning in modern systems based on the integration of learning analytics, data mining, and knowledge tracking models provide an opportunity to adapt instruction dynamically [8]. Zawacki-Richter et al. show in their study that artificial intelligence is a key part of developing an intelligent system [3]. More recent research has shown that adaptive AI tutors can be scaled for different students, taking into account cognitive and motivational differences that make particular advances in personalized learning [9].

New research shows that the integration of artificial intelligence leads to advanced forms of interaction in which natural communication takes its part, generating additional explanations and feedback [10]. One of those studies is the study by Holmes et al. where tutors move from a system of analysis to a system that provides analysis [4]. Following such research, AI tutors are evolving towards systems that will not only analyze performance but also provide continuous support and guidance in real-time [11].

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Modern architecture research focuses on the development of modular and scalable systems that allow for the integration of other components such as an analytical module, tutor agents, and other mechanisms. Very often, the architecture of intelligent tutoring systems includes a structure that is layered and has a clear separation of functionalities and supports for non-implementation [12]. Troussas et al. show a combination of intelligent components that are the basis for developing advanced systems [6]. Other studies have shown a combination of deep learning and natural language within intelligent tutors and provide content adaptation and enhancement to STEM-related learning [13]. In addition to such research, there is a challenge of integrating components into a single system and providing feedback between analysis and adaptation [14].

Also, new research emphasizes further iteration with natural language learners and thus enables automatic generation of recommendations [15]. Such use and generation increases engagement and improves academic outcomes, and this is combined with learning analytics and personalization mechanisms [16].

Research shows that intelligent systems are moving towards the development of hybrid algorithms that can combine predictive algorithms [17]. It further highlights the importance of data integration and the ability to manage large quantities of educational data [18]. Future trends and research show that e-learning systems are moving and evolving towards being fully autonomous and independently guiding the student through the educational process [19]. However, despite the progress, there are still challenges related to the use of artificial intelligence and are an important direction for further research [20].

The proposed architecture in this paper provides access through the integration of modules into a modular system. Such an approach enables continuous data analysis and adaptation of the teaching process which is a step towards the development of an intelligent e-learning system.

IV. EDUAI SYSTEM ARCHITECTURE

The proposed EduAI system is an intelligent, modular, and scalable e-learning architecture that delivers a dynamic and personalized educational experience. The architecture is designed to overcome the limitations of systems by integrating learning analytics, adaptation mechanisms, and intelligent AI tutoring into a single system model. The architecture is based on the principle of separation of functionalities, in which each module has its own role, but at the same time functions as part of a single system. The architecture is realized as a structure of layers that includes:

- User layer
- Application Layer
- Layer of data.

This approach gives scalability, flexibility, and easy integration of new functionalities.

A. *User layer*

The user layer is the interface that students interact with the EduAI system and plays a key role in the interaction and personalization of learning. The layer provides access to content, activities, quizzes, and progress information, which is designed to be intuitive, accessible, and adaptable to different types of students. The main feature of this layer is the integration of the AI Tutor module, which is available in the interface. This module gives the student the opportunity to ask a question, receive additional explanation and guidance in real time which increases interaction in the learning process. The AI tutor is integrated into it as a communication element and it enables real-time interaction. It improves communication and transforms the system from a passive platform to an intelligent learning environment.

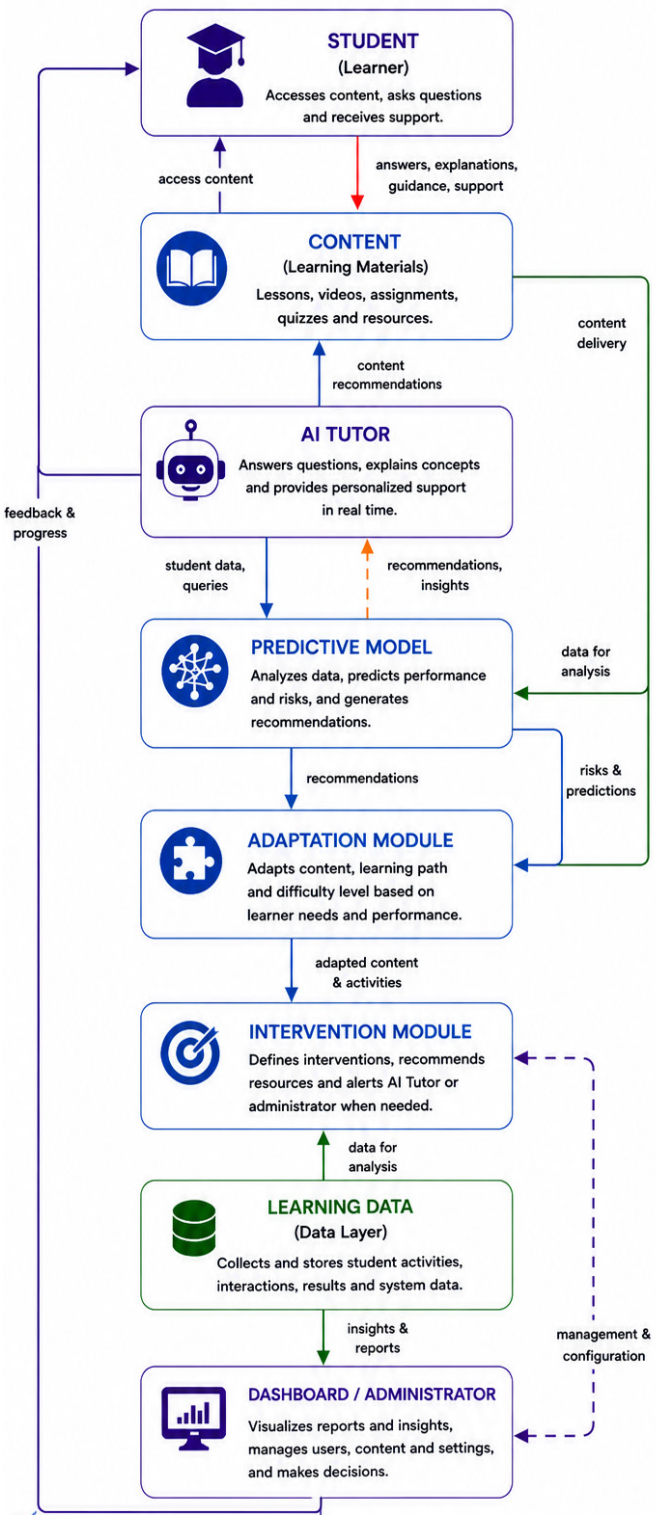

Fig. 1. EDUAI Architecture.

This layer also provides an opportunity to visualize a student's progress through a variety of indicators: mastery level, completion rate, and results. The information obtained from this layer is dynamically updated based on the data obtained from the analytics module, thus allowing for transparency and awareness of its own progress.

The user layer also supports customizable elements, and according to them, content and recommendations are tailored to the needs of the student. In this way, the layer is not just a passive display of information, it is an active part of the intelligence system and contributes to the improvement of learning.

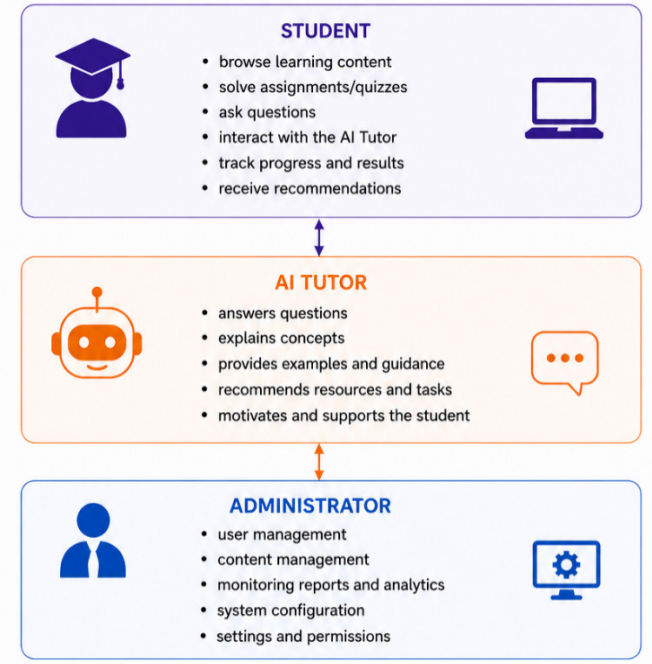

Fig. 2. User layer.

The figure shows the user layer where the three main actors, the student, the AI Tutor, and the administrator interact with the system through this layer. The user layer allows for real-time information exchange through web interfaces, API calls, and technologies, and ensures continuous and interactive communication between all components. Additionally, the image shows the layer's functionalities: an interactive interface, real-time communication, configuration and management, and a security mechanism.

B. Application Layer

A central component of the system architecture is the application layer, which is implemented in basic logic for data processing, analysis, and adaptation of the teaching process. The layer provides integration and coordination of modules that jointly enable intelligent and personalized learning.

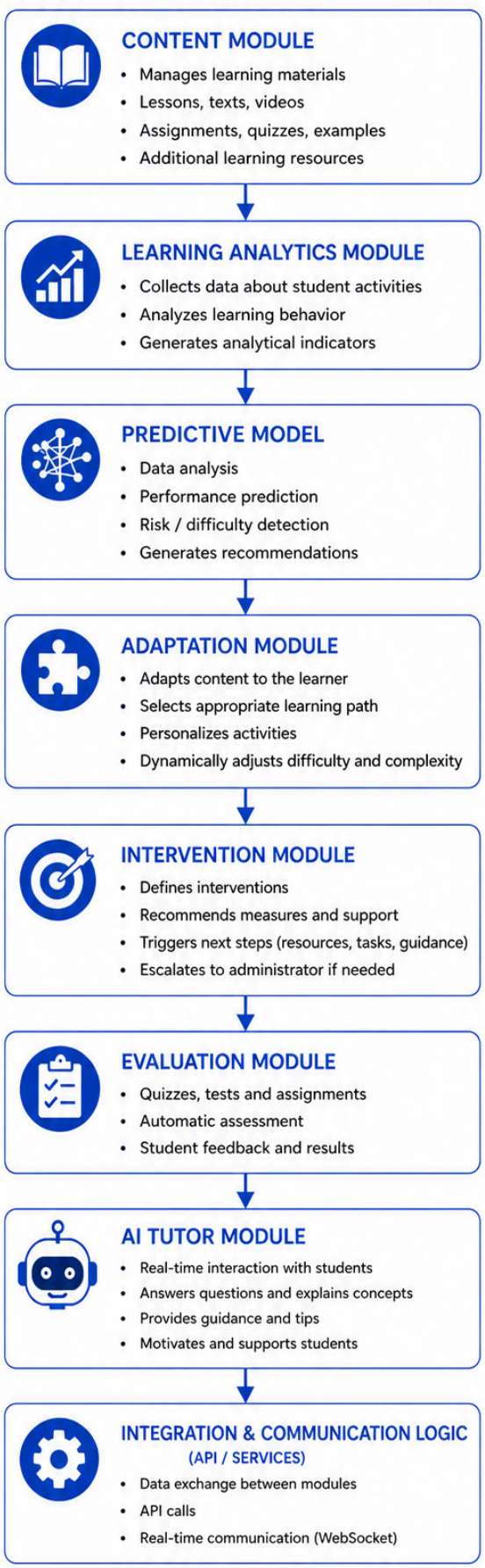

Fig. 3. Application layer.

The application layer includes the following components:

- Content Module: This module manages instructional content that includes lessons, assignments, and other resources. Content is tailored to the student's individual and according to results and analytics.
- Learning Analytics module: collects data on students' activities, time spent learning, number of interactions, outcomes, and behavior. Data is transformed into analytical indicators and serves as the basis for decision-making.
- Predictive model: creates data analysis to predict outcomes, detect risk, and learning difficulties. This is an intelligent component that gives a proactive approach to learning.
- Adaptive mechanism: allows dynamic adjustment of teaching and activities according to analytical results and predictive model. It adjusts the weight and offers a personalized learning path.
- Intervention Module: Defines interventions when detecting difficulties in a student. Interventions may include additional material, references, assignments, or referrals to the AI Tutor.
- AI Tutor: Integrated as an assistant that communicates with the student in real time. In this layer, he uses data from analytics and predictive models to provide guidance and recommendations that contribute to personalized learning.
- Evaluation module: allows assessment of knowledge through a quiz. Its results are used as an input to the analytical and adaptive processes.

C. *Data Layer*

The data layer is a core component of the EduAI system architecture that allows you to store, upload, and retrieve all the necessary data for the system to function. It provides support for analytical and intelligence processes so that it can provide structured and relevant information.

Within this layer, several types of systems are integrated, namely:

- Student Information System: Contains information about students and basics such as profile, demographics, history, and scores. Such data is the starting point for personalizing the learning process.
- Learning Data: includes data generated about the time of the student's interaction with the system, activities, outcomes, interactions with the AI Tutor, time elapsed for learning, and time of activity in the system. The data obtained is the basis for analytical processing.
- Knowledge Base: contains structured resources such as questions asked, examples, interactions. This section uses the AI Tutor to generate responses and recommendations.
- Data management: provides a mechanism for storing, updating, and securing data. It integrates a variety of data sources and provides accessibility to the applicability layer.

The data layer provides a continuous flow of information to the application layer where the data is used for analysis, prediction, and adaptation. This layer is the basis for the functioning of the entire system.

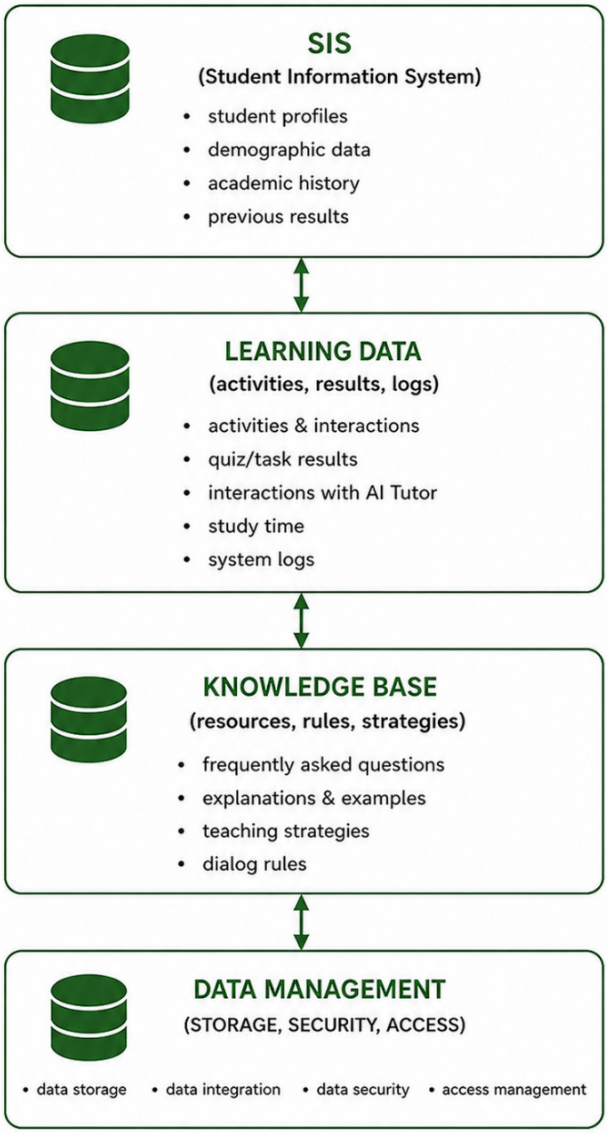

Fig. 4. Data layer.

V. Conclusion

The paper proposes an architecture of an intelligent adaptive e-learning system EduAI based on the integration of artificial intelligence, learning analytics, and adaptive mechanisms into an architectural model. The proposed architecture is modular composed of three layers, creating a clear separation of functionalities, flexibility, and the possibility of integrating new components.

A major contribution to this research is the design of an architecture that provides connectivity between the system and the user and collects data for their analysis and allows for the adaptation of instruction. By integrating analytical mechanisms, the system allows monitoring of students' activities and their progress, which is the basis for decision-making in the learning process.

One of the components that is significant is the integration of the AI Tutor module which allows for real-time interaction, personalization, and interaction with students. Such a module changes the system from a passive platform to an active environment that is intelligent through which the student receives guidance, explanation, and recommendations according to their learning style and need.

The proposed model overcomes shortcomings in traditional e-learning systems and introduces new adaptive mechanisms and intelligent components personalized. This is a major step towards the development of modern intelligent education systems where the center of learning is the student.

In addition, it provides an opportunity to integrate analytical and adaptive components into a single system, which is a very good basis for improving the effects of learning and the teaching process. The implementation of such a system has contributed to improved academic outcomes.

The focus of the paper is on the design of architecture and opens up opportunities for research in Indiana, particularly in prototype development, testing in a real-world educational environment, and analysis of the impact of the system on academic achievement.

Future research may focus on expanding this architecture and applying ethical and safety aspects to the application of the system to education. With this, the proposed model is the basis for indie intelligent, adaptive and sustainable e-learning systems.

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