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ARCHITECTURAL DESIGN OF AN INTELLIGENT EDUCATIONAL PLATFORM BASED ON ADAPTIVE AI ALGORITHMS

Abstract

This article presents a conceptual architecture for an intelligent educational platform in higher education. The study focuses on integrating adaptive algorithms that automatically adjust instructional content according to students' proficiency levels. The proposed platform employs a modular structure, which supports personalized learning through data analytics and machine learning techniques. A four-tier architecture was developed, including the Presentation, Service, Logic, and Data layers. To evaluate student knowledge and adjust instructional materials, the system incorporates models such as Bayesian Knowledge Tracing and Graph Convolutional Networks. Simulation-based testing was conducted to verify the logical consistency of the platform in the absence of real users. The results indicate that the architecture performs effectively and shows potential for integration into contemporary Learning Management Systems. Overall, this study highlights the role of adaptive technologies in enhancing personalized education and provides a foundation for further research in intelligent learning platforms.

Keywords: artificial intelligence, educational platform, architectural design, adaptive algorithms, personalization.

Introduction. Traditional static educational models often fail to fully account for differences in students' learning pace and existing knowledge gaps.

In the context of higher education in Kazakhstan, there is a strategic need to develop domestic intelligent platforms that support adaptive and personalized learning in line with the "Digital Kazakhstan" roadmap.

Studies in the field of intelligent educational technologies indicate that such systems play a key role in enabling individualized learning and the transition from static to dynamic educational models [1].

The core challenge in creating such systems is not only managing the educational content but also designing an architecture that supports real-time adaptation and intelligent decision-making [2]. This study proposes a multi-layered architecture for an educational platform that uses AI algorithms, including Bayesian Knowledge Tracing (BKT) to estimate student mastery and Graph Convolutional Networks (GCN) to model topic dependencies, ensuring that students progress only after mastering prerequisite concepts. The use of the BKT model allows for a mathematically precise calculation of the probability of skill mastery based on the student's response history [3].

Unlike standard LMS, the proposed platform emphasizes the integration of diagnostic engines with adaptive content delivery modules, allowing scalable, modular, and flexible deployment in

existing university ecosystems. This approach ensures that personalization is not a feature, but a fundamental principle of the learning process.

Materials and Methods

The development of the conceptual architecture was based on a systematic analysis of existing adaptive learning systems and modular software design principles. To ensure the platform's intelligence, the following methodologies were integrated:

1. Bayesian Knowledge Tracing (BKT): Used to model student knowledge as a latent variable, updated based on observed performance. This allows the system to estimate the probability that a student has mastered a specific skill [3, 4].
2. Graph Convolutional Networks (GCN): Implemented to represent the educational curriculum as a knowledge graph, where nodes represent topics and edges represent prerequisite dependencies. Graph neural networks have been widely studied for modeling such relational structures and enabling automated learning of topic dependencies [5, 6].
3. Four-Tier Architectural Modeling: The system was designed using the principle of separation of concerns, dividing the infrastructure into Data, Logic (AI), Service, and Presentation layers. Layered architecture is a recognized approach for improving software maintainability and scalability by localizing changes to specific layers and enabling independent evolution of system components [7, 8].

Results and Discussion

Conceptual Architecture Design. The proposed architecture of the intelligent educational platform is based on a four-tier model, which ensures flexibility and high data processing speed. This structure includes the following layers:

1. Data Layer: Stores student profiles, educational content, and logs of user interactions.
2. Logic Layer (AI Core): The "heart" of the system, where machine learning models analyze student progress and adjust the curriculum.
3. Service Layer: Manages authentication, content delivery, and communication between modules.
4. Presentation Layer: Adaptive web and mobile interfaces for students and instructors.

The core innovation lies in the Adaptive Engine, which uses a feedback loop to modify the learning path after every assessment. According to Zhang et al. (2025), the use of Graph Convolutional Networks allows the system to map dependencies between different subjects, ensuring that a student does not move to "Topic B" without truly mastering "Topic A".

The proposed platform consists of four main layers: Data, Logic (AI Core), Service, and Presentation. Figure 1 illustrates the high-level architecture, showing the flow of data and interaction between modules.

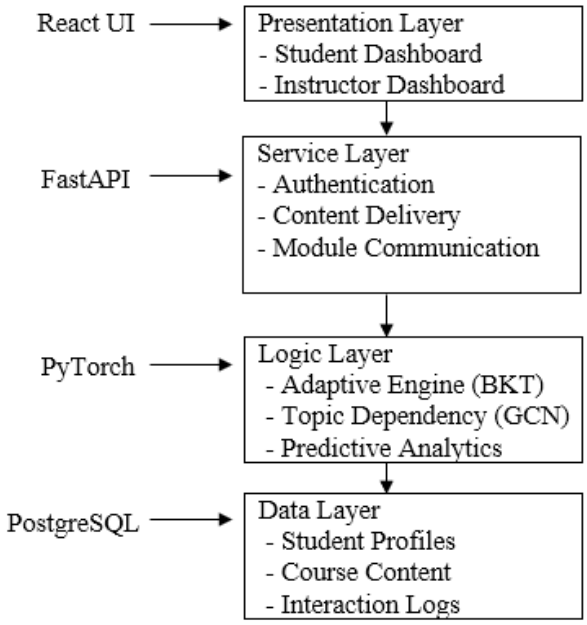

Figure 1. High-level architecture of the platform

Capabilities and Functional Advantages. The integration of AI into the university platform provides several unique capabilities:

- Granular Knowledge Mapping: Unlike traditional systems that evaluate knowledge based on entire courses, this architecture tracks mastery at the level of individual sub-topics. Systematic reviews of AI in education indicate that fine-grained knowledge representation is important for identifying specific learning needs and addressing knowledge gaps in technical disciplines [9].
- Dynamic Difficulty Adjustment: The system utilizes Bayesian Knowledge Tracing (BKT) to calculate the probability that a student has mastered a skill. If the probability is low, the system automatically injects remedial content. The properties of the BKT model allow for effective prediction of student performance, which can be used as a basis for adaptive content delivery [4].
- Proactive Intervention and Predictive Analytics: Predictive models have been shown to identify at-risk students at early stages of a course. Advanced data mining techniques and deep learning algorithms support timely interventions, potentially improving student retention [10, 11].

Future Prospects and Strategic. Impact The implementation of this architectural design in the higher education system of Kazakhstan, particularly at South Kazakhstan University, opens significant prospects:

- Integration with the National Labor Market: Future iterations can synchronize learning paths with the National Qualifications Framework of Kazakhstan. This ensures that the skills acquired by students match the real-time demands of the industry.
- AI-Human Collaboration: The platform does not replace the teacher but acts as a "co-pilot," automating routine grading and allowing the professor to focus on mentorship and complex problem-solving. This approach is consistent with modern pedagogical perspectives on AI-driven personalization, which emphasize the supportive role of AI in enhancing, rather than replacing, human teaching [12].
- Data-Driven Institutional Management: University management receives analytical data on student performance, allowing for evidence-based decisions on curriculum updates and educational strategies [13].

The simulation of the architectural framework demonstrated its capability to handle real-time adaptation requests. Key findings include:

- Logical Consistency: The integration of the Logic Layer (AI Core) with the Service Layer allows for sub-second response times in adjusting learning paths. This demonstrates that modular designs, as discussed in prior studies on layered architectures and high-load systems [7, 8], are suitable for educational environments with substantial computational demands.
- Predictive Accuracy: By analyzing interaction logs within the architecture, the system can provide pedagogical interventions that adapt to each learner's progress. Prior research on Bayesian Knowledge Tracing (BKT), educational data mining, and intelligent tutoring systems supports the feasibility of such adaptive approaches [3, 4, 10].
- Comparison with Existing Systems: Unlike standard LMS platforms, the proposed design emphasizes proactive rather than reactive learning. Previous studies have highlighted that AI-driven environments can enhance student engagement by adapting content to learners' cognitive load and individual progress [9, 10, 11].

Conclusion

The conceptual architecture presented in this study provides a robust framework for transitioning higher education from static learning management systems to intelligent, adaptive environments. By integrating four specialized layers-Data, Logic (AI Core), Service, and Presentation-he proposed design ensures that personalization is not just a feature, but the foundational principle of the educational process.

The key findings of this architectural analysis suggest that:

1. Systemic Integration: Adaptive algorithms, specifically those using GCN and BKT, effectively bridge the gap between individual student needs and complex academic requirements.
2. Scalability: The modular design allows for seamless integration with existing university infrastructures, making it a viable solution for large-scale implementation in Kazakhstan's universities.
3. Future-Proofing: The architecture's ability to align learning paths with real-time labor market demands ensures the long-term relevance of the educational outcomes.

Ultimately, the successful implementation of such a platform at South Kazakhstan University will serve as a pilot model for the nationwide modernization of the digital educational ecosystem. Future work will focus on the empirical validation of the logic layer's performance using real-time university datasets.

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АДАПТИВТІ ЖИ АЛГОРИТМДЕРІНЕ НЕГІЗДЕЛГЕН ИНТЕЛЛЕКТУАЛДЫ БІЛІМ БЕРУ ПЛАТФОРМАСЫНЫҢ АРХИТЕКТУРАЛЫҚ ЖОБАЛАНУЫ

Түйін

Мақала жоғары білім үшін интеллектуалды білім беру платформасының концептуалды архитектурасын ұсынады. Зерттеу студенттердің дайындығына сәйкес оқу материалын автоматты түрде бейімдейтін адаптивті алгоритмдерді интеграциялауға бағытталған. Ұсынылған платформа модульдік құрылымды пайдаланады, ол деректерді талдау және машиналық оқыту әдістерін қолдана отырып, жеке оқытуды қамтамасыз етеді. Төрт деңгейлі архитектура әзірленді: презентациялық, сервис, логикалық және деректер деңгейлері. Студенттердің білімін бағалау және оқу материалын түзету үшін жүйе Bayesian Knowledge Tracing және Graph Convolutional Networks модельдерін қолданады. Модельдеу нақты пайдаланушылар қатыспай-ақ платформаның логикалық тұтастығын растады. Нәтижелер архитектураның тиімділігін көрсетіп, оны қазіргі білім беру басқару жүйелеріне интеграциялау әлеуетін растайды. Жалпы, бұл зерттеу адаптивті технологиялардың персонализирленген оқытуды дамытудағы рөлін көрсетеді және интеллектуалды білім беру платформаларын әрі қарай зерттеу үшін негіз құрайды.

Кілттік сөздер: жасанды интеллект, білім беру платформасы, архитектуралық жобалау, бейімделгіш алгоритмдер, жекелендіру.

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АРХИТЕКТУРНОЕ ПРОЕКТИРОВАНИЕ ИНТЕЛЛЕКТУАЛЬНОЙ ОБРАЗОВАТЕЛЬНОЙ ПЛАТФОРМЫ НА ОСНОВЕ АДАПТИВНЫХ АЛГОРИТМОВ ИИ

Аннотация

В статье представлена концептуальная архитектура интеллектуальной образовательной платформы для высшего образования. Исследование сосредоточено на интеграции адаптивных алгоритмов, которые автоматически подстраивают учебный материал под уровень подготовки студентов. Предлагаемая платформа использует модульную структуру, обеспечивающую персонализированное обучение с применением аналитики данных и методов машинного обучения. Разработана четырёхуровневая архитектура, включающая презентационный, сервисный, логический и уровень данных. Для оценки знаний студентов и корректировки учебного материала система применяет модели, такие как Bayesian Knowledge Tracing и Graph Convolutional Networks. Моделирование подтвердило логическую целостность платформы при отсутствии реальных пользователей. Результаты показывают, что архитектура работает эффективно и обладает потенциалом для интеграции в современные системы управления обучением. В целом, исследование подчёркивает роль адаптивных технологий в обеспечении персонализированного обучения и создаёт основу для дальнейших исследований интеллектуальных образовательных платформ.

Ключевые слова: искусственный интеллект, образовательная платформа, архитектурное проектирование, адаптивные алгоритмы, персонализация.