ANNOTATION
dissertation for the degree of «Doctor of Philosophy» (PhD)
on speciality 6D060200 - «Informatics»

NAURYZBAYEV BAUYRZHAN AMANGAZYULY

DEVELOPMENT OF AN INTELLIGENT SELF-LEARNING SYSTEM FOR ANALYZING THE PROCESS OF LEARNING to SOLVE MATHEMATICAL PROBLEMS

General characteristics of the work. The dissertation work considers the issues of studying the effectiveness of using intelligent technologies in the development of computational thinking of students using artificial intelligence methods to personalize the educational process.

With the rapid development of technology and digitalization, mathematics is becoming one of the key disciplines that foster critical thinking and analytical skills needed in professional and personal life. However, current approaches to teaching mathematics often fail to meet the challenges of the time, which is reflected in the decline of students' performance. Data from international studies, such as PISA and TIMSS, show insufficient levels of mathematical literacy, especially in the aspects of solving problems of high complexity.

In the era of digitalization, one of the urgent tasks is the digital transformation of the education system using artificial intelligence technologies. Traditional teaching methods are not always effectively adapted to the needs of learners, which underlines the importance of using intelligent systems that can personalize the educational process.

The use of artificial intelligence in education is gaining popularity due to its ability to improve the learning process, increase learner engagement and provide personalized learning. Current research confirms that artificial intelligence is capable of automating routine tasks such as assessment, knowledge diagnosis and creating adaptive educational programs.

The number of students is increasing every year and the shortage of teachers, especially in rural areas, is becoming more pronounced. Intelligent systems can serve as an additional tool to facilitate the work of teachers and provide quality assistance to learners. In this context, this research is important not only at the national level but also at the international level, as learning and skills development processes require a unified approach to educational management. Thus, **the relevance of the thesis work** is related to solving the problem of developing intelligent systems capable of personalizing the educational process, allowing improving the quality and efficiency of the educational process.

The object of the study is the process of learning to solve mathematical problems using intelligent systems.

The subject of the study is the models and algorithms used to create an intelligent self-learning system designed to analyze and improve the effectiveness of the mathematics learning process.

The purpose of the study is to develop an intelligent self-learning system for analyzing the learning process of mathematical problem solving, which integrates graph neural networks to diagnose learners' knowledge and generate personalized

recommendations.

Objectives of the study.

- To analyze existing approaches and technologies for adaptive learning of mathematics;
- To develop a model of graph neural networks for diagnostics of students' knowledge;
- To create algorithms for error analysis and formation of personalized learning trajectories;
- Implement and test an intelligent system for teaching mathematics based on machine learning methods.

Research Methods. The research methodology is based on the integration of theoretical and empirical methods aimed at developing an intelligent self-learning system for analyzing the process of learning to solve mathematical problems. Particular attention is paid to the use of graph neural networks (GNN) as a tool for diagnosing gaps in students' knowledge and forming personalized learning trajectories. This approach allows for the effective modelling of complex relationships between topics of educational material and students' actions, which contributes to the accurate prediction of their educational achievements.

The theoretical framework of the study includes analyses of existing approaches to adaptive learning and intelligent educational systems. Modern developments including graph-based knowledge models, big data processing methods and artificial intelligence technologies have been studied. The literature analysis identified key research gaps such as the limitations of personalization in traditional learning systems and the low adaptability of existing technologies to the changing needs of learners.

The methodological approach is based on the development of a mathematical model of the knowledge graph. The knowledge graph is a structure in which the nodes of the graph represent topics, tasks and skills, and the edges of the graph express the relationships between them. To create this model, curriculum data as well as students' performance on assignments were used to ensure that the knowledge graph was adapted to specific educational contexts.

The main tool for analysis is a graph neural network that updates the representations of the nodes and edges of the graph based on student performance data. This system allows not only to identify problem areas in knowledge, but also to adapt learning trajectories in real time.

The experimental part of the research was aimed at testing the developed system in the real educational process. The experiment used quasi-experimental research methods, including comparison of the control and experimental groups of students. The control group was taught using traditional methods, whereas the developed intelligent system was used in the experimental group. The data collected during the experiment were processed using statistical analysis methods, which made it possible to evaluate the impact of the system on students' performance, activity and accuracy of knowledge diagnostics.

Quantitative and qualitative analysis methods were used as an objective assessment of the effectiveness of the system. Quantitative methods included calculation of accuracy indicators, speed of task completion and performance level. Qualitative methods were based on student and teacher questionnaires and analyses of their perceptions of the system.

The key stage was the application of the Item Response Theory (IRT) model to

analyze individual student performance and predict their educational outcomes. Thus, the proposed research methodology integrated modern graph neural network technologies, mathematical models and experimental analysis methods, which provided a comprehensive evaluation of the developed system and its potential for integration into the educational process.

The methodology used was aimed at solving key tasks of adaptive learning, including diagnosing gaps in knowledge, forming personalized trajectories and improving the efficiency of the educational process.

Scientific novelty. The scientific novelty of the thesis research consists in the development of a unique intelligent self-learning system based on graph neural networks, which allows adaptively analyzing and correcting the process of teaching mathematics.

The main scientific provisions put forward for defense and possessing signs of scientific novelty:

1. A model of graph neural networks for diagnostics of students' knowledge level;
2. An algorithm for the analysis and formation of personalized learning trajectories;
3. An intelligent self-learning system for adaptive learning of mathematics.

Practical value of the research results. The practical significance of the study lies in the development of a system that can be applied in schools and universities in Kazakhstan to improve the quality of mathematics education.

The developed intelligent system has the potential for scalability and adaptation in various educational institutions. The main area of scalability is integration with cloud platforms such as Google Cloud or Microsoft Azure, which will allow efficient processing of large volumes of data and ensure smooth functioning of the system in the conditions of increasing number of users.

In addition, the system can be easily integrated with popular learning management platforms such as Moodle and Blackboard, which simplifies its implementation into the existing educational infrastructure.

Additionally, the developed system can be adapted for use in other educational disciplines such as physics, chemistry or language sciences due to the versatility of the graph neural network architecture.

A promising direction is the integration of the system with national educational programs, which will allow scaling its application at the level of the whole country.

Testing of work. The main results of the dissertation work were reported and discussed at the following events:

– II International Conference on «Economic and Social Trends for the Sustainability of Modern Society» (ICEST-II) (Krasnoyarsk, Russian Federation, 2021);

– Scientific seminar of the Faculty of «Information Technologies» of L.N.Gumilev Eurasian National University (Astana, Kazakhstan, 2024);

– Meeting on information and technical sciences at «Alikhan Bokeikhanov University» (Semey, Kazakhstan, 2024).

– Scientific seminar of the school «Digital Technologies and Artificial Intelligence» of D.Serikbayev East Kazakhstan Technical University (Ust-Kamenogorsk, Kazakhstan, 2024).

Publications. 8 scientific papers have been published on the topic of the dissertation, including: 1 article in a journal indexed in the Scopus database (CiteScore percentile of 63%), 3 articles in articles in publications recommended by the authorized body of the Ministry of Higher Education of the Republic of Kazakhstan, 1 article in in the proceedings of international conference (Russia), 3 articles in journals indexed in the Russian Science Citation Index (RSCI).

Structure and volume of the dissertation: The thesis consists of an introduction, three chapters, conclusion, list of references and appendices.

In the introduction the relevance and current state of the problem are considered, the aim and objectives of the research are formulated, the scientific novelty and practical significance of the work are determined.

The first chapter is devoted to the theoretical foundations of adaptive learning and application of graph neural networks in educational analytics. A review of existing intelligent tutoring systems is presented and the concept of knowledge graphs for analyzing educational data is developed.

The second chapter contains the development of a mathematical model of the knowledge graph and algorithms for analyzing student data. It also presents the structure of the intelligent self-learning system, including its main components and methods of learning adaptation.

The third chapter describes the approbation of the developed system, analyses its effectiveness and prospects of implementation in the educational process of Kazakhstan. The results of experimental testing and their interpretation are presented.

The conclusion summarizes the results of the study, outlines the main conclusions and proposals, and formulates the theoretical and practical results of the work. Scientific novelty, practical significance and prospects of introduction of the developed intellectual self-learning system for analyzing the process of learning to solve mathematical problems in the educational process are substantiated.