International Journal of Pedagogics

The Role of Artificial Intelligence in The Development of Students' Digital Competence on The Basis of a Cluster Approach: On the Example of Integration of Fundamental Sciences

Taylakova Guli Bekmuratovna

PhD, Associate Professor, University of Tashkent for Applied Sciences, Head of the Department of Digital and Fundamental Sciences, Uzbekistan

Abstract: This article explores the integration of the cluster approach and artificial intelligence (AI) technologies in the process of teaching fundamental sciences in higher education. In the context of rapid digital transformation, modern education requires new pedagogical approaches that support the development of students' digital competence alongside their professional knowledge. The study aims to substantiate the effectiveness of AI tools in enhancing digital competence within a cluster-based educational environment. The cluster approach ensures the integration of higher education institutions, research centers, and industry partners, enabling the practical application of theoretical knowledge. Artificial intelligence technologies contribute to modeling complex scientific processes, analyzing large datasets, and supporting adaptive learning. The research applies theoretical analysis, cluster modeling, and pedagogical experimentation to evaluate the proposed approach. The results indicate that the integration of AI technologies into the teaching of fundamental sciences significantly improves students' analytical thinking, digital literacy, and problem-solving skills. The findings also highlight the importance of creating a digital educational environment that supports innovation and practical learning in higher education.

Introduction: Today's globalization and digital transformation processes have brought fundamental changes to the education system, requiring a revision of the content, methods and organizational forms of teaching. In the context of the digital economy, a modern specialist is required not only to have deep professional knowledge, but also to have a high level of digital competence, the ability to analyze and process information, and make effective decisions based on innovative technologies (Redecker, 2017). Therefore, the formation and development of digital competence in the process of training students in higher educational institutions is becoming one of the important pedagogical tasks.

As is known, fundamental sciences such as mathematics, physics, and computer science are the main scientific foundation that forms the theoretical preparation of specialists studying in technical and technological areas. These sciences develop important intellectual competencies in students, such as logical thinking, analytical analysis, modeling, and solving problems based on a systematic approach. However, practice shows that in many educational processes, teaching fundamental sciences is still carried out based on traditional pedagogical approaches (Polat, 2007; Muslimov et al., 2015). As a result, a certain gap is emerging between theoretical knowledge and the requirements of the real digital environment. This leads

to problems such as the low level of practical application of the acquired knowledge by students and the insufficient formation of skills in the effective use of digital tools (Shermanova, 2025).

The cluster approach is considered an important methodological basis for solving this problem. The cluster approach involves taking the education system out of the framework of isolated activities and developing it in an integrally integrated manner with science, technology and production. As a result of such integration, the educational process is aligned with real economic and technological needs, and students have the opportunity to connect theoretical knowledge with practical activities. Within the framework of the cluster model, cooperation mechanisms are formed between higher education institutions, research centers, IT companies and production entities. This creates an important basis not only for updating the content of education, but also for the effective integration of modern technologies into the educational process.

From this point of view, the introduction of artificial intelligence technologies into the educational process can significantly increase the efficiency of the cluster system. Artificial intelligence allows for rapid analysis of large amounts of data, monitoring of learning outcomes, and identifying individual learning characteristics of students. This allows for the development of personalized learning trajectories and the adaptation of educational materials to the student's level of knowledge and interests. Especially in the teaching of fundamental sciences, modeling, visualization, and simulation technologies based on artificial intelligence serve to present complex theoretical processes in an understandable and interactive form.

As a result, the student's activity in the educational process increases, and the opportunity for deep understanding and practical application of knowledge expands. At the same time, artificial intelligence plays a unique "catalyst" role in a cluster educational environment, accelerating the exchange of information between education, scientific research, and production, and stimulating the emergence of innovative ideas.

Thus, the combination of a cluster approach and artificial intelligence technologies in the process of teaching fundamental sciences is an important pedagogical condition for the formation of a modern digital educational environment, the development of students' digital competence, and the effective preparation of them for future professional activities. This approach not only serves to improve the quality and efficiency of education, but also creates a solid foundation for the training of competitive, highly qualified specialists for the innovative economy.

METHODOLOGY

In this study, a number of theoretical and empirical research methods were used in a comprehensive manner to scientifically study the process of developing students' digital competence and determine the effectiveness of the cluster approach and the use of artificial intelligence technologies in teaching fundamental sciences. When choosing research methods, their scientific basis, the ability to deeply illuminate the essence of the problem under study, and their suitability for the real conditions of the educational process were taken into account (Shermanova, 2025).

The theoretical foundations, pedagogical and methodological approaches to the use of digital technologies in teaching fundamental sciences (mathematics, physics, computer science) were studied using the systematic analysis method. Using this method, the essence of the concept of digital competence, its structural components, and its place in the modern education system were analyzed. Also, the current state, problems, and development prospects of the content of fundamental sciences and the integration of digital technologies were systematically considered. As a result, the main principles of a theoretical model serving the effective integration of digital technologies in teaching fundamental sciences were formed.

The cluster modeling method was used as one of the important methodological foundations of the study. With the help of this method, a conceptual model of an innovative educational environment based on cooperation between higher education institutions, research centers and the IT sector was developed. Within the framework of the model, the system of interactions between education, science and production was clarified, and their functional tasks were determined. The educational environment organized on

the basis of the cluster approach was considered an important mechanism that allows integrating students' theoretical knowledge with practical activities, introducing innovative technologies into the educational process, and comprehensively developing digital competence.

The pedagogical experiment method was used at the practical stage of the study and served to determine the effectiveness of the developed methodological approaches. During the experiment, a set of special tasks was developed and put into practice to assess the level of digital competence of students and determine the effectiveness of using artificial intelligence technologies in teaching fundamental sciences. In performing these tasks, Python programming language libraries for scientific calculations (NumPy, Pandas, Matplotlib), as well as adaptive learning platforms, were used. With the help of these tools, students were able to develop skills in modeling complex mathematical and physical processes, analyzing and visualizing data.

During the experiment, students' activities were monitored, their level of knowledge, skills in using digital tools, and analytical approach to solving problems were analyzed. The results obtained were summarized based on statistical analysis, and the effectiveness of the educational model based on the cluster approach and artificial intelligence technologies was assessed.

As a result, the set of methods used made it possible to comprehensively study the research problem, substantiate theoretical conclusions with practical experience, and identify effective pedagogical mechanisms for developing digital competence in teaching fundamental sciences.

RESULTS

As a result of the study, a conceptual model was developed based on a cluster approach to develop students' digital competence. This model involves the formation of modern digital skills in students by integrating artificial intelligence technologies in the process of teaching fundamental sciences. During the study, it was found that the developed model consists of three interrelated components: technological, cognitive and integrative components.

The technological component is aimed at developing students' skills in using digital technologies and artificial

intelligence tools. Within the framework of this component, students learned to use modern software tools and algorithms to perform various calculations in fundamental sciences. In particular, mathematical modeling, data processing and visual analysis of results were carried out using scientific libraries operating in the Python programming environment. In addition, practical tasks were completed on forecasting and modeling certain physical processes using algorithms based on neural networks. This served not only to strengthen students' theoretical knowledge, but also to develop their skills in applying them in a real digital environment.

The cognitive component was aimed at developing students' analytical and algorithmic thinking skills. Within the framework of this component, students acquired the skills of step-by-step analysis of complex issues, critical evaluation of data, and drawing conclusions based on comparing information from various sources of information. In the process of completing educational tasks in fundamental sciences, students gained experience in using an algorithmic approach to solving problem situations, working with data, and systematically analyzing them. This had a positive impact on the development of their scientific thinking and digital thinking culture.

The integrative component involves directing the knowledge and skills acquired in a cluster educational environment to solving real practical tasks. Within the framework of this component, students were offered practical tasks related to production processes or technological problems. In the process of completing these tasks, students had the opportunity to apply the theoretical knowledge acquired in fundamental sciences in combination with digital technologies. As a result, the connection between education, scientific research and practical activities was strengthened.

The results of the conducted pedagogical experiment confirmed that teaching fundamental sciences integrated with artificial intelligence elements has a significant impact on the development of students' digital competence. Analysis of the experimental results showed that the level of digital literacy and use of digital tools demonstrated by students in the experimental group was on average 22 percent higher than in the control group. It was also observed that the level of development of algorithmic thinking, data analysis and

complex problem modeling skills in students in the experimental group also significantly increased (Muslimov, N.A, 2020)

Thus, the results obtained scientifically substantiated the fact that the cluster approach and the use of artificial intelligence technologies in the process of teaching fundamental sciences serve as an effective pedagogical mechanism for developing students' digital competence.

DISCUSSION

The analysis of the research results shows that the cluster approach in the modern educational process is manifested not only as a model of organizational cooperation, but also as a comprehensive digital educational ecosystem. Within such an ecosystem, sustainable cooperation is established among higher education institutions, research centers, and production enterprises. As a result, the exchange of knowledge, technological experience, and innovative ideas occurs in an integrated environment. In particular, the introduction of digital technologies and artificial intelligence (AI) tools into this system not only increases the effectiveness of the educational process but also modernizes the methodology of teaching fundamental sciences.

Fundamental sciences such as mathematics, physics, and informatics play a key role in the formation of analytical thinking, modeling skills, and scientific worldview among students. However, these disciplines are characterized by complex theoretical models, abstract concepts, and multi-stage calculations. In traditional teaching practice, such concepts are often presented mainly through theoretical explanations and mathematical formulas. As a result, students may experience difficulties in understanding the practical significance and real-world application of these scientific concepts.

From this perspective, the use of artificial intelligence technologies creates significant didactic opportunities in teaching fundamental sciences. AI-based tools enable modeling, simulation, and visualization of complex scientific processes, allowing theoretical phenomena to be represented in graphical, dynamic, and interactive formats. Such digital tools enhance students' engagement and support deeper conceptual understanding. For example, in the study of thermodynamic processes in physics, AI-based modeling can be applied using real technological data obtained from industrial enterprises that operate within the cluster environment. In this case, students do not simply learn theoretical formulas or perform isolated calculations. Instead, they gain the opportunity to analyze real production processes using digital tools and predictive algorithms. This approach contributes to the development of essential competencies such as data analysis, modeling, forecasting, and problem solving.

As a result, students gradually reach the highest level of digital competence — the level of creative application, where they are able to independently use digital technologies to solve complex scientific and professional problems. Furthermore, the cluster educational environment creates favorable conditions for linking theoretical knowledge with practical industrial tasks. By applying the acquired knowledge in real or simulated professional contexts, students develop innovative thinking, interdisciplinary analysis skills, and technological problem-solving abilities. Consequently, the educational process evolves from simple knowledge transfer into an integrated system that combines education, scientific research, and practical innovation. (Bekmurodovna, T. G. LBC 94.3 T-2, 46)

Thus, the results of the study confirm that the integration of the cluster approach and artificial intelligence technologies serves as an effective pedagogical mechanism in teaching fundamental sciences. This model not only enhances the development of students' digital competence but also contributes to improving the quality of professional training, strengthening the practical significance of scientific research, and ensuring stronger integration between higher education institutions and industrial sectors.
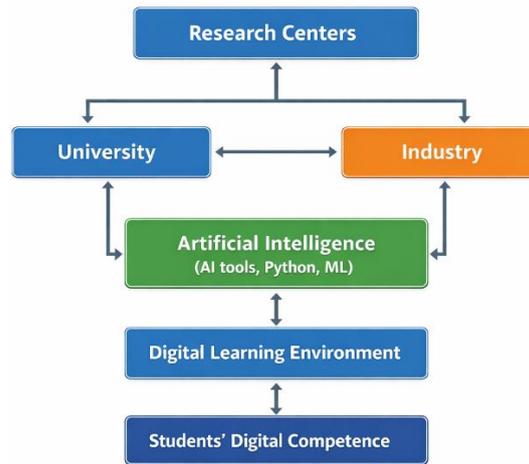
CONCLUSION

The results of the study show that the development of students' digital competence based on a cluster approach is one of the important strategic directions of the modern higher education system. In the current era of increasing digital transformation processes, the need to enrich the educational process with innovative technologies, especially the effective use of modern digital tools in teaching fundamental sciences, is increasing. In this regard, the cluster approach based on the integration of education, science and production is an important pedagogical mechanism for increasing the efficiency of the student training process.

The three-component model (technological, cognitive and integrative) developed during the study was found to allow for the systematic development of students' digital competence. Within the framework of this model, the integration of artificial intelligence technologies with fundamental sciences serves to develop students' analytical thinking, form data analysis and modeling skills, and enable them to function effectively in a digital environment. In particular, modeling and simulation tools based on artificial intelligence create the opportunity to study complex theoretical processes in a more understandable and interactive way. The results of the study also confirmed that teaching fundamental sciences integrated with artificial intelligence elements significantly increases students' digital literacy and technological readiness. The cluster learning environment, on the other hand, provides students with the opportunity to connect theoretical knowledge with real production processes, analyze practical problems using digital tools, and develop innovative solutions.

Thus, the model of integrating artificial intelligence technologies into fundamental sciences education based on a cluster approach takes students' professional training to a new level. Through this model, students will have the opportunity to apply theoretical knowledge to solve real-life and professional tasks using modern digital tools. As a result, the quality of education will increase and a solid scientific and methodological foundation will be created for training competitive specialists who think innovatively and can effectively use digital technologies.

REFERENCES

1. Redecker, C. European Framework for the Digital Competence of Educators: DigCompEdu. Luxembourg: Publications Office of the European Union.

2. Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. Intelligence Unleashed: An Argument for AI in Education. London: Pearson Education.

3. Siemens, G. Connectivism: A Learning Theory for the Digital Age. International Journal of Instructional Technology and Distance Learning, 2(1), 3–10.

4. Baker, R., & Inventado, P. Educational Data Mining and Learning Analytics. In: Learning Analytics: From Research to Practice. New York: Springer.

5. Полат, Е. С. Новые педагогические и информационные технологии в системе образования. Москва: Академия.

6. Muslimov, N.A., Usmonboyeva, M., Sayfurov, D., To'rayev, A. Pedagogik kompetentlik va kreativlik asoslari. Toshkent: Fan va texnologiya.

7. SHERMANOVA, F. (2025). OLIY TA'LIMDA RAQAMLI SAVODXONLIKNI SHAKLLANTIRISHGA TA'SIR ETUVCHI OMILLAR VA ULARNI PEDAGOGIK

BOSHQARISH YO 'LLARI. «ACTA NUUz», 1(1.8), 223-225.

8. Bekmurodovna, T. G. Basic doctoral student, Uzbek Scientific Research Institute of Pedagogical Sciences named after TN Kari Niyazi, Tashkent, Republic of Uzbekistan Brief abstract. The article describes the basic requirements for web resources based on multimedia technologies. LBC 94.3 T-2, 46.