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Education 4.0: Development of the ukrainian educational system in the context of artificial intelligence

Educación 4.0: Desarrollo del sistema educativo ucraniano en el contexto de la inteligencia artificial

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Abstract

This article aims to analyse the concept of Education 4.0 and its key achievements, challenges, and prospects in the context of artificial intelligence development in the Ukrainian educational system. The study explores the transformation and digitalisation of Ukrainian education, including the impact of artificial intelligence on pedagogical methods, the training of qualified professionals, the development of innovative curricula, and ensuring free and continuous access to high-quality education. The research methodology is based on an in-depth analysis of modern literature, examining successful cases of artificial intelligence

integration into Ukrainian education. Particular attention is paid to the modernisation of education through AI-driven solutions, the opportunities and challenges of Education 4.0, and the AI systems that actively support contemporary learning. The findings highlight the potential of Education 4.0 in fostering personalised learning, enhancing the competitiveness of Ukrainian education, and aligning it with European standards. However, multiple challenges hinder its effective implementation, including the Russian invasion, technological disparities across regions, a shortage of retrained specialists, and risks associated with excessive automation, which may diminish the human element in education. This study contributes to the ongoing discussion on adapting Ukraine's education system to the demands of digital transformation.

Keywords: digital competencies, digital pedagogy, interactive learning, learning platforms, personalised learning.

Resumen

Este artículo tiene como objetivo analizar el concepto de Educación 4.0 y sus principales logros, desafíos y perspectivas en el contexto del desarrollo de la inteligencia artificial en el sistema educativo de Ucrania. El estudio examina la transformación y digitalización de la educación ucraniana, incluyendo el impacto de la inteligencia artificial en los métodos pedagógicos, la formación de profesionales cualificados, el desarrollo de planes de estudio innovadores y la garantía de acceso libre y continuo a una educación de alta calidad. La metodología de investigación se basa en un análisis exhaustivo de la literatura moderna, destacando casos exitosos de integración de la inteligencia artificial en la educación ucraniana. Se presta especial atención a la modernización educativa mediante soluciones impulsadas por inteligencia artificial, las oportunidades y desafíos de la Educación 4.0 y los sistemas de inteligencia artificial que apoyan activamente el aprendizaje contemporáneo. Los hallazgos resaltan el potencial de la Educación 4.0 para fomentar el aprendizaje personalizado, mejorar la competitividad de la educación ucraniana y alinearla con los estándares europeos. Sin embargo, múltiples desafíos dificultan su implementación efectiva, incluyendo la invasión rusa, las disparidades tecnológicas entre regiones, la escasez de especialistas capacitados y los riesgos asociados con una automatización excesiva que puede reducir la interacción humana en la educación. Este estudio contribuye al debate sobre la adaptación del sistema educativo de Ucrania a los desafíos de la transformación digital.

Palabras clave: competencias digitales, pedagogía digital, aprendizaje interactivo, plataformas de aprendizaje, aprendizaje personalizado.

Introduction

Ukrainian education is currently undergoing profound transformation processes, both internal and external. First, it is a change in approaches to the learning process aimed at applying the latest technologies while maintaining personalised learning. Secondly, Ukrainian education is heavily affected by the pandemic, the Russian-Ukrainian war, and economic and demographic difficulties. In the face of such influences, it is necessary to find the driving factors that will ensure that education remains effective and ensures its development even in extremely difficult times. In the past, these factors depended on human potential: the qualifications of teachers and the motivation of students. However, the current situation in Ukraine is characterised by the migration of a large number of young people abroad and the loss of skilled workers in the war zone. At the same time, against the backdrop of the rapid development of digital technologies, issues of ethics and pedagogy in the educational process are becoming increasingly relevant. In particular, the use of technologies, including artificial intelligence, causes not only excitement due to new opportunities, but also concern due to potential risks. In particular, in the scientific space, various risks are highlighted, ranging from the loss of authenticity of learning to the reduction of the role of the teacher as a mentor. Therefore, there is a need to carefully consider how AI can harmoniously integrate into the education system without violating its humanistic principles.

Therefore, there is an increasing need to use advanced information and communication technologies that can provide organisational, pedagogical, educational, methodological and cognitive processes

(Boiko et al., 2024). Based on the challenges faced by Ukraine, its experience in implementing rapid change is unique and allows us to analyse the impact of integrating innovative technologies in an unstable economy and civilian security environment. Education in Ukraine is developing quite dynamically: the impact of the COVID-19 pandemic and the full-scale war have led to a shift in education from traditional methods to online learning. Under these conditions, the transition to information and communication technologies and their deeper study has become relevant. At the same time, artificial intelligence technologies are beginning to shape a new era of education (Vasylyuk-Zaitseva et al., 2023). However, even though artificial intelligence is a concern for many researchers, its application in the Ukrainian education system can be a salvation. The use of artificial intelligence in Ukraine has not yet become widespread, but it has already had positive results. Education in Ukraine needs to change dramatically, so it remains important to introduce innovative pedagogy and move to 4.0 programmes that meet the modern challenges of the fourth industrial revolution (Malynovska & Smyrnova, 2023). It will have a powerful impact on the transformation of all humanity, as it involves a symbiosis between humans, machines and artificial intelligence. And education is becoming a key area of transformation. The modernised approach to education influenced by the 4th Industrial Revolution provides a modern understanding of changes in learning modes (Sharma, 2019). Researchers believe that these changes have a global impact, and Ukraine is no exception (Shlenova et al., 2024). For Ukraine, this transition is critically important. The introduction of artificial intelligence can improve the quality of education by personalising learning, automating monotonous work, and developing digital skills. The 4.0 programmes in Ukraine aim to develop key skills of a future specialist: critical thinking, creativity, teamwork, digital literacy, and motivation for continuous development (Honcharuk et al., 2024). This system must adapt to the current difficult realities of war, insufficient financial support from the state, insufficient software, uneven access to modern technologies, and low digital competence of students and teachers. Despite the barriers, the transformation of education in line with the 4.0 concept is a key prerequisite for ensuring the quality of society's development and Ukraine's integration into the global digital space. The purpose of the study is to analyse the impact of artificial intelligence on the Ukrainian educational system in the concept of Education 4.0, to identify opportunities and challenges for the introduction of interactive technologies, and to develop and implement the latest technologies to ensure quality education. The objectives of the article are to analyse the main concepts of Ukrainian Education 4.0, to explore the potential of using artificial intelligence technologies in education and to discuss the main challenges to the implementation of this concept.

The article consists of several sections. The first section - a review of the literature presents the theoretical framework of the study and a critical analysis of recent research. The second section - results and discussion describes the impact of modern technologies on the development of education in Ukraine and identifies the role of AI in the development of education in Ukraine. Also in this part, the obtained data are discussed and compared with other scientists. The third part - a generalization and summary of the obtained results are made and promising directions for the development of Education 4.0 are described.

Theoretical Framework or Literature Review

The transition of Ukrainian Education 4.0 as an important stage in the formation of competitive specialists is determined by the introduction of the technologies of the Fourth Industrial Revolution. The integration of artificial intelligence aims to turn education into a personalised, adaptive and accessible experience for everyone. In recent years, artificial intelligence has increasingly attracted the attention of scientists around the world, as this field is still not sufficiently studied. Yesilevskyi & Kyt (2024) study the development of computer technologies under the influence of artificial intelligence. The authors focus on the rapid transition from traditional teaching methods to the integration of the latest technologies due to COVID-19 and the introduction of martial law in Ukraine, as there is an urgent need for distance education (Tsekhmister et al., 2021). Nowadays, innovative tools are most often used: mobile applications, platforms, and cloud services, which provide continuous access to information (Kuzmenko et al., 2023). AI technologies such as machine learning, intelligent tutoring systems, and automated tools enhance personalized education, streamline data analysis, and improve educational processes (Synorub & Yordan, 2024). Researchers have studied the European experience of introducing innovative technologies. They found that most teachers have a

sufficient level of digital competence, so the European experience is based on the ability to withstand challenges. However, these challenges cannot be identified with those in Ukraine. However, using the example of Ukraine (Bader et al., 2022), the authors demonstrate the positive experience of teachers' information competence and emphasise the importance of supporting the motivational component to overcome obstacles related to the fear of using the latest technologies due to their ignorance. Digital competencies influence curricula, teacher competence, and resources for students (Bobrytska et al., 2024).

The authors emphasise the growing recognition of artificial intelligence technologies. However, in order to ensure its successful integration, it is necessary to address crucial issues related to the quality of content, ethical implications, and the need for comprehensive development. We must approach artificial intelligence holistically. To understand its implementation, it is necessary to analyse the relationship between artificial intelligence tools and the human mind. This answer will provide the necessary information on how artificial intelligence can complement human creativity and help in the educational process. However, researchers call for a balanced use of artificial intelligence, as it should not replace humans but help and complement them. Modern professions are beginning to undergo changes, where a specialist must have knowledge of the latest technologies (Kornytska et al., 2023). Special emphasis is placed on the development of soft skills as a requirement for future employees. In order not to be left on the sidelines of globalisation, Ukrainian education must also be ready for change. This aims to modernise the educational system, which will focus on the development of critical thinking, skills in using the latest technologies and practical competencies of students. The main areas are the introduction of programming, robotics and engineering. However, there are many challenges to its implementation. Introducing artificial intelligence into the Ukrainian education system is still needed to create favourable conditions for inclusive learning (Hudym et al., 2024). This will create the preconditions for meeting the needs of children with special needs. Artificial intelligence can address the need for personalised learning, creating a comfortable learning environment and automatically monitoring students' results. Inclusive education combined with artificial intelligence can reduce stigma, increase the development of social skills, and significantly empower people with special needs while facilitating continuous access to quality education. Interactive whiteboards based on artificial intelligence have contributed to better learning and personalisation of the process for students with different needs. For teachers, this method allows them to expand inclusive methods. The introduction of artificial intelligence facilitates routine work, provides psychological support to participants in the educational process, creates high-quality educational materials, and improves the curriculum (Ivanashko et al., 2024).

Artificial intelligence tools can prepare students for future professional activities and develop important competencies. Studies show that AI tools are already being actively used in training specialists in the sciences and humanities, as well as interdisciplinary specialities such as sociology. Artificial intelligence has unlimited potential for use. These tools help to analyse, interpret and manage large amounts of data, create predictive models in experimental research, solve laboratory problems, and create a safe environment for dangerous experiments. For humanities students, AI can help analyse text, write annotations and conclusions, and compare what they have written with other studies. Researchers are discovering even more possibilities of artificial intelligence (Ahmad et al., 2022). The role of artificial intelligence is important not only for academic applications but also for administrative activities. Such applications help teachers give grades, manage attendance, and determine the level of intelligence. Teachers can easily prepare for classes and, with the help of virtual reality technologies, help students master complex but interesting topics. AI also helps with administrative issues, such as budgeting, resource management, exams, and important documentation. However, some authors believe that using artificial intelligence in education has no connection with education (Chiu et al., 2023). The authors argue that teachers do not understand technology enough to be able to apply it in the classroom. Teachers are often unaware of the capabilities of the latest technologies, so there is uncertainty about the implications of the pedagogical use of innovative technologies. Artificial intelligence often lacks an interdisciplinary approach (Bates et al., 2020).

Thus, technologies developed for a particular discipline may be ineffective for teaching all students. Artificial intelligence technologies are lagging in education. Teachers continue to use traditional methods in the classroom, avoiding integrating anything new. AI technologies can motivate students to learn, but only the

most competent ones get the most out of these technologies. AI can change industries, but not all of them. The main limitation is that data-based learning is only possible (Yuskovych-Zhukovska et al., 2022). This means that any error will be reflected in the learning outcomes. The study of teachers' competence in using artificial intelligence technologies proves the need to improve their qualifications and skills in using the latest technologies (Kyrpa et al., 2024).

The potential of artificial intelligence has been identified as having the ability to revolutionise education by providing personalised learning and instant feedback (Drach et al., 2023). There are many artificial intelligence tools, and the authors believe it is up to the teacher to choose the most convenient ones. At the same time, it is important to understand and adapt artificial intelligence, as it may have a false generation of answers and results. The study's authors value the human mind as unique and creative (Yara et al., 2021). Bashkirova et al. (2024) also addressed similar issues, which allowed them to were able to trace the importance of involving artificial intelligence systems in modern education. Some caveats that these researchers were able to categorize are important, since the use of new platforms also involves certain risks. Babych et al. (2022) analyzed, for example, the importance of medical indicators, for example. The thorough methodology of their study is a relevant addition, as it can complement the study, which can add to the understanding of the possibilities for further improvement of education. Similarly, Polyezhayev et al. (2024) noted the usefulness of digitalization in the field of learning foreign languages and acquiring relevant linguistic skills. In particular scientists noted the possibility of facilitating the creative process of acquiring education, without immersion in formal tasks. And artificial intelligence is just a tool that can facilitate routine work and save invaluable time. When using artificial intelligence technologies in education, it is important to follow the rules of ethics and confidentiality of information. The analyzed works belong to various methodological types. Some studies have thorough empirical data, however, in most of them the sample is not large, which in general complicates the process for analysis. In addition, many studies are more of a review. Accordingly, the scientific space lacks studies that would systematize existing research and describe the role of AI in the Ukrainian Education 4.0 system.

An important drawback of the available publications is their local nature. In addition, many articles do not provide specific data from Ukrainian educational institutions on the practical implementation of technologies and their effectiveness. The analyzed works also do not clearly state what impact AI has on the academic achievements of students with different levels of training. Another notable aspect is the lack of attention to the level of pedagogical training of teachers. However, a particularly important drawback is the lack of coverage of the challenges of using AI in the Ukrainian education system. This study will fill these gaps and describe the main characteristics of the Ukrainian Education 4.0 system and the challenges of implementing AI in current education.

Methodology

The study of the impact of artificial intelligence within the Ukrainian Education 4.0 system concept involves using different approaches. This study focused on using general scientific, pedagogical and synergistic methods. The main focus was on analysing the innovative elements that shape the modern education system under the influence of the challenges that Ukraine is facing. The study offers a detailed review of the literature on the introduction of artificial intelligence in the education of Ukrainian schools and higher education institutions. Scopus, Web of Science, PubMed, Google Scholar, and local sources were used to search for scientific literature. The keywords used in the selection of scientific sources were education 4.0, artificial intelligence, AI, schools, universities, AI technologies, adaptive learning, smart education, education reforms, teacher training, student outcomes, education digitalisation, opportunities, challenges, higher education, machine learning, AI tools.

In more developed countries, the introduction of artificial intelligence has been active in recent years, while in Ukraine, this process is only in the development stage. Therefore, the analysis of scientific literature sources is based on studies of recent years, when there is only a description of the introduction of this system in education, but its consequences have not yet been substantiated, or they exist, but there are

very few studies. The sources of literature were selected according to the following criteria:

1. Research related to AI in education.
2. Overview of Education 4.0 with a focus on personalisation and technology.
3. Articles published since 2015 (when the topic of AI in education began to develop actively).
4. Publications related to the Ukrainian educational system.
5. The language of writing is Ukrainian and English.

The exclusion criteria were:

1. Studies that do not cover the educational context (e.g., general AI technologies).
2. Publications are available only in abstract form.
3. Works that do not correspond to the linguistic or regional context (unrelated to Ukraine).
4. Works written in other languages (except English and Ukrainian)

Using these criteria, 45 scientific literature items were selected, which are dedicated to modern technologies and the use of AI in the Ukrainian Education 4.0 system. The duration of the analysis is from December 2024 to February 2025.

After the initial selection, the sources were analyzed and grouped into thematic categories: (1) implementation of AI in the educational process, (2) inclusion, (3) pedagogical challenges, (4) ethical aspects, (5) administrative use of AI. This made it possible to identify the main trends and contradictions in the scientific discourse. In addition, pedagogical methods such as pedagogical observation and generalisation were used to assess the effectiveness of artificial intelligence. The synergistic approach was based on studying the interaction between the educational system and artificial intelligence technologies. Comparative analysis was used to analyse the differences between the Ukrainian and international experiences of integrating artificial intelligence into education. The application of artificial intelligence technologies and analysis of the experience of its integration into Ukrainian educational institutions allows us to determine the prospects for developing Education 4.0 as the future education.

To ensure the reliability of the results, elements of triangulation were used: comparison of data from different sources, analysis of the views of different authors, and comparison of the international and national context. Some of the sources were previously evaluated by experts (peer review), which reduces the risk of bias. Potential cognitive biases were also considered through a systematic and critical approach to text analysis.

Results and Discussion

The main purpose of this study is to investigate the impact of the fourth industrial revolution on Ukrainian education with a focus on the use of artificial intelligence. In Ukraine, few researchers describe this topic because the latest technologies have not appeared so long ago, and their integration takes a lot of time. In addition, the number of studies on the impact of artificial intelligence is quite small. And not much time has passed since its integration to talk about its impact on Ukrainian society. We are taking small steps to overcome the barriers from education 3.0 to education in more developed countries. For example, the fourth industrial revolution in Germany was first called Industry 4.0. For the first time, the country approved two state programmes focused on developing technology and the Internet (Lokshyna et al., 2021). A key element of Industry 4.0 is global digitalisation, creating "digital twins", cyber-physical systems, merging the real and virtual worlds, augmented reality technologies, and artificial intelligence. These programmes are active in the United States, the United Kingdom, Belgium, France, and Japan. Australia uses the Industry 4.0 programme to conduct research projects and commercialise new developments. In Germany, a similar programme is working to develop research activities in the industrial sector. Japan is implementing the Society 5.0 concept, which is a direct continuation of the Industry 4.0 programme, adding a socio-cultural component to it, i.e. solving society's problems through cyberspace (Kuchai et al., 2017). Ukraine only aims to achieve such goals shortly (Yershov, 2019).

The Fourth Industrial Revolution is a step towards expanding knowledge, where the boundaries between the physical, digital and biological fields are blurred, as Schwab (2016) notes. The revolution is changing life, work and relationships thanks to digitalisation processes. As these processes are happening quite quickly, people need to be able to adapt in time. It is expected that in the future, such technologies will be integrated into one system. They can communicate with each other in real-time, self-adjust and learn new behaviours. This can reduce the number of errors and adapt to users' needs. Cloud technologies, big data processing, biotechnology, 3D-printed medicine, and cryptocurrencies have been the first steps in the world of the new industrial revolution. However, despite economic development, society faces the problems of unemployment, social inequality, climate change, and pandemics (Williams et al., 2023). The gap between rich and poor is widening; millions cannot find work, and wages in some countries continue to decline. Therefore, it is illogical and wrong to continue on this path. The impact of the Fourth Industrial Revolution on higher education means the emergence of a new format of educational institutions that provide new approaches to the learning process. These institutions will be transformed into those that will become independent of state funding and increasingly contribute to developing a competitive society (Miranda et al., 2021).

Education 4.0 in Ukraine is the education of a knowledgeable society that provides training, retraining and advanced training. The purpose of Education 4.0 in Ukraine is to ensure the comprehensive development of students by their needs and the needs of socio-economic systems, to integrate the Ukrainian education system into the European and global educational space, and to increase the competitiveness and development of educational institutions.

Education is one of the key factors in the formation of a coherent society. Ukraine is undergoing significant socio-economic changes and is reforming its education system by introducing modern technologies into the learning process. For Ukraine, Education 4.0 is an urgent need to create an advanced education system that will meet all the challenges of the Fourth Industrial Revolution. To this end, on 10 December 2022, a programme for a major transformation of Ukraine's education - Education 4.0: Ukrainian Dawn - was presented. It is based on rethinking education and ensuring the transition from standardised teaching methods to personalised learning, from a system where learning and skills are improved throughout life. The main principle of Education 4.0 is to invest in one's future and to adopt a human-centred approach that meets the core competencies of modern education (Table 1).

Table 1.
Core competencies of Education 4.0

Competences	Description	Example
Digital literacy	Ability to use digital technologies for learning and content creation.	Work with e-learning platforms, programming, digital resource management.
Critical thinking	Analysis and evaluation of information, search for solutions.	Ability to distinguish facts and analyse sources of information.
Creativity	Ability to create innovative ideas and solve problems out of the box.	Generating new approaches to learning.
Communication	Effective interaction in various formats, including digital environments.	Virtual presentations, collaboration through online tools.
Information literacy	Ability to find, analyse and use information.	Search for relevant information through scientific databases.
Emotional intelligence	Understanding and managing own emotions, effective interaction with people.	Conflict resolution, creating a positive learning environment.
Interdisciplinarity	Integration of knowledge from various fields.	Combining STEM education with humanities, project activities.
Flexibility and adaptability	Ability to adapt to change and learn new things quickly.	Mastering new technologies and adapting to changes.

Source: Authors' own research

Traditional Ukrainian education has begun to give way to the latest teaching methods that can consider an individualised approach to each student. For Ukraine, Education 4.0 is a salvation and a response to the challenges of globalisation and digitalisation. This concept modernises how material is transmitted and presented and puts the individual's needs and capabilities at the centre of the learning process. Many authors emphasise that the successful implementation of this project requires government support, which concerns not only the financial component but also the creation of a regulatory framework (Malieiev et al., 2024). In addition, international cooperation with other countries is important for expanding and gaining new experiences.

Thanks to artificial intelligence technologies, personalised learning is now possible. Barvinok & Pudło (2023) believe that during the Russian-Ukrainian war, the key is to introduce distance or blended learning, as many students cannot study full-time.

The latest technologies make it possible to create such an individual educational trajectory, considering the learner's strengths, interests and the pace of information assimilation. At the same time, a number of serious challenges stand in the way of future education (Skoromnyi et al., 2021). First of all, these are the limitations between the regions of Ukraine. The study by Karpenko et al. (2020) shows that access to the Internet and high-quality and modern equipment is limited in rural areas. Such regions will already be somewhat behind more developed ones, as the conditions created are unequal for teachers and students, creating social and digital inequality at this level. However, the researchers propose solutions to these problems through investments in digital development, the creation of digital literacy programmes, and support for entrepreneurship in technology. Another problem is teachers' insufficient training in using artificial intelligence technologies (Chernenko, 2021).

Education 4.0 requires teachers to be able to work with interactive whiteboards and use data to assess students' progress. This requires retraining of teachers, courses and webinars. It may be especially difficult for older teachers who rarely use the latest technologies due to their lack of knowledge (Dovgyi et al., 2020). Researchers believe that when creating new technologies, such people's needs are often not considered (Chu et al., 2022). In Ukraine, Koka (2023) concludes that separate support should be organised for senior teachers in the form of seminars, webinars and trainings, which arethe administrations of educational institutions are already implementing.

A separate issue remains state funding for the modernisation of education, the purchase of equipment and the development of modern platforms.

Education 4.0 is a challenge and an important step towards modernising the modern education system. This implementation requires the efforts of all participants in transforming education (Table 2).

Table 2.
Key aspects of education transformation in Ukraine in accordance with the Education 4.0 concept

Category	Description	The role of artificial intelligence
Digital platforms	Use of online tools for organising the educational process and distance learning.	Analysis of applicant data, personalisation, and automatic progress monitoring.
Interactive tools	Use of interactive whiteboards, simulators and VR/AR.	Content generation, simulation of learning situations and gamification.
Inclusion in education	Integration of children with special educational needs into the educational process.	Creating individualised curricula, adapting materials and improving the accessibility of educational resources.
A personalised approach	Focusing on the individual characteristics of applicants and their strengths.	Analysis of test results, identification of strengths and weaknesses, recommendations for correcting the learning process.
Development of critical thinking	Developing skills in analysis, argumentation and decision-making.	Modelling situations to develop critical thinking, analysing data and predicting decision outcomes.

Source: Authors' own research.

Today, artificial intelligence is beginning to play a central role in the transformation of Ukrainian education. This allows not only the transformation of the educational process but also the creation of preconditions for the development of creativity, critical thinking, and individualised learning. One of the main advantages of artificial intelligence is task automation when systems make it easier for teachers to analyse students' performance. According to Liubarska (2024), such systems allow teachers to save time on preparation, focusing on the creative and imaginative part of the work. However, Kyrychenko (2020) describes the loss of "human" imagination and creativity, which can easily be replaced by artificial intelligence. At the same time, this will reduce critical thinking and social interaction, and there is a risk of losing cultural identity in the context of globalisation (Wojciech et al., 2021).

Nevertheless, thanks to artificial intelligence, education is becoming more and more accessible to everyone anytime, anywhere, without restrictions.

In the European Union, artificial intelligence is actively used to personalise the learning process. The UK has long been using personalized technologies based on the needs of students. Artificial intelligence analyses their behaviour and mental abilities and generates appropriate tasks (Zhang et al., 2021; Krap et al., 2024). Digital teaching assistants are being actively introduced to provide recommendations and improvements to the curriculum. This allows teachers to correct the programme in time. In Germany, virtual student assistants are used to support the learning process. Such assistants can help answer questions, plan the day, organise studying, and even conduct study sessions.

Ukraine, on the other hand, can only adopt the experience of European countries for the time being. It is only on the verge of transforming the educational process. Nevertheless, there are many initiatives that demonstrate good prospects for this area. For example, artificial intelligence-based platforms are now being actively used in schools and secondary and higher education institutions. The All-Ukrainian Online School, created by the Ministry of Education and Science of Ukraine, has already become an important addition to the development of distance learning. This platform uses artificial intelligence to automate processes, create learning materials and curricula, and analyze student performance. It can offer assignments in various disciplines and quick feedback. At the same time, studies describing cases in specialized inclusive institutions indicate that after the implementation of interactive whiteboards with AI elements, the engagement of students with special needs improved by 35% (Bobro, 2024; Bobrytska et al., 2024). In addition, the study by Vasylyuk-Zaitseva et al. (2023) using indicators such as RRMF (Relative Ranking Mean Factor) and RRP (Relative Ranking Priority) indicates that in the process of modernization of the Ukrainian education industry, artificial intelligence technologies selected from the general rating: −EdTech: 0.0476 (RRMF); 0.083 (RRP) indicates that digital tools and resources are available for effective learning, which stimulates changes in forms of learning; −Virtual and augmented reality (VR/AR): 0.0595 (RRMF); 0.059 (RRP). This technology creates an immersive learning environment that allows students to engage and immerse themselves in real-world scenarios.

The Smart Education platform provides access to interactive lessons that adapt to users' knowledge. The platform's artificial intelligence analyses students' achievements, identifies their strengths and weaknesses, and offers the necessary materials for revision. The Prometheus and EdEra platforms are very popular among Ukrainian teachers. These elements are very useful when searching for materials and lectures in various disciplines. They also offer many webinars and trainings, which are always relevant for teacher training. E-journal platforms allow you to monitor students' progress and attendance. AI tutors and chatbots, such as ChatGPT, have only recently started working in Ukraine but have already become one of the most popular applications (Fiialka et al., 2023). International platforms such as Coursera, Duolingo, and Udemy are also in high demand. Mobile applications, especially, are very convenient to use.

Ukraine has the potential to become a country with a European level of education. Potential areas for the development of artificial intelligence include the creation of a single national adaptive platform, the development of analytics tools, and support for STEM education. The national platform could provide personalised learning to the needs of everyone and create an educational space that would be common to

all educational institutions. The development of analytical tools through the analysis of large amounts of data will allow us to monitor student performance, make predictions and new teaching approaches, and free teachers from routine work. Supporting STEM education in Ukraine plays a key role in training future skilled workers. This includes the creation of virtual laboratories, simulation models and robotic systems. The learning process can be gamified to motivate and create interesting tasks. It is also important to develop digital tutors, which will become an indispensable tool in education. Potential areas of artificial intelligence development in Ukraine should become the basis for creating competitive education. Financial investments in these programmes will yield good results in the future, and the training of specialists will meet the requirements of the modern labour market.

Conclusions

The study of the impact of artificial intelligence on the Ukrainian education system in the context of the Education 4.0 concept shows that there is a huge potential for its implementation and several challenges facing Ukraine. In the example of European countries, the introduction of artificial intelligence into the education system has shown its successful transformation. Applying pedagogical, synergistic and comparative methods allowed us to assess the state of modern Ukrainian and European education. The biggest challenges for Ukraine remain the Russian invasion and the lack of funding to introduce the latest technologies. There are few studies on the results of introducing artificial intelligence into modern Ukrainian education. Analysis of scientific sources has shown that artificial intelligence technologies are being actively introduced into the educational process in developed countries. In Ukraine, however, this process is at an early implementation stage due to lacking the necessary infrastructure and educational programmes for wider adoption. The study only confirmed the importance of introducing the latest technologies into the education system. Ukraine has every opportunity to implement these systems and create its initiatives based on the experience of European countries. In the future, developing guidelines for implementing artificial intelligence, training high-quality personnel, and creating conditions for a continuous safe environment are necessary.

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