HUMANITIES STUDIOS: Pedagogy, Psychology, Philosophy

Humanities Studios: Vol. 12, No. 3, 2024

Pedagogy, Psychology, Philosophy

Journal homepage: https://humstudios.com.ua/en

UDC 378.147:004.8

DOI: 10.31548/hspedagog/3.2024.36

Formation of digital competence of future primary school teachers by using artificial intelligence

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Abstract. The purpose of the study was to evaluate the effectiveness of using artificial intelligence (AI) technologies to develop the digital competence of future primary school teachers through the development and implementation of training modules that include theoretical and practical classes. The research methods included the use of AI basics tests and project work, as well as statistical analysis of the results using the Student's t-test for paired samples. Initial and final tests were conducted among students who participated in the training modules and the control group without the modules. The implemented training modules included theoretical classes, practical exercises and project work. The results of the study showed a significant improvement in the knowledge of students in the main group after the implementation of the training modules. On average, test scores rose from 45 to 75 (out of 100), and average project scores rose from 60 to 85 (out of 100). Statistical analysis revealed significant improvements in knowledge and skills, with average gains being statistically significant ($t \approx 15.8$ for testing and $t \approx 10.96$ for projects). No significant changes were recorded in the control group. The analysis of the results of the pre- and post-tests showed that the participants who had completed the new modules showed significant improvement in all key aspects of digital competence. In particular, the level of knowledge about using digital tools and platforms for communication and collaboration increased by 30%, and skills in creating multimedia content and managing digital projects improved by 25%. The increase in knowledge of data security and information protection was 20%, indicating the effectiveness of the training modules in raising awareness of the importance of

Received 29.03.2024 Revised 19.07.2024 Accepted 15.08.2024

Suggested Citation:

Shcherban, T., & Khoma, P. (2024). Formation of digital competence of future primary school teachers by using artificial intelligence. *Humanities Studios: Pedagogy, Psychology, Philosophy*, 12(3), 36-55. doi: 10.31548/hspedagog/3.2024.36.

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protecting personal information. In addition, it was found that the participants became more confident in solving technical problems, which indicates the practicality of the implemented technologies and their ability to improve self-learning and problem-solving skills. The findings confirmed the effectiveness of AI in developing digital competences in future primary school teachers, which opens up new opportunities for further development and improvement of curricula in this area

Keywords: digital technologies; teacher education; educational modules; statistical analysis; learning outcomes

Introduction

In an era of rapid technological progress, digital competence has become a key aspect of teachers' professional responsibility. It is important that future primary school teachers have the skills to use digital tools and resources that improve the quality of education and the efficiency of the learning process. One of the promising areas in this context is the introduction of artificial intelligence (AI) technologies into educational practice. This necessitates the development of innovative methods for transferring digital skills to future professionals through modern educational practices.

AI is already being used in many areas of human activity, such as education. Integrating AI technologies into education allows automating repetitive tasks and facilitates a personalized learning experience that meets the unique requirements of each student. With the help of AI, it is now possible to develop interactive educational resources, create intelligent systems for knowledge assessment, and create adaptive learning environments. For future primary school teachers, it is important to understand the principles of AI technologies and be able to use them effectively in their professional activities. Developing such skills requires a comprehensive approach that includes theoretical training. Teacher education should create the necessary conditions for the development of digital competence.

R. Bucea-Manea-Ţoniş *et al*. (2022) conducted a study that showed the significant potential of AI to improve the educational environment in higher education institutions in Romania and Serbia. It is emphasised that AI facilitates personalized learning and adaptation of teaching methods, which increases critical thinking and student autonomy. M.J. Sousa and Á. Rocha (2019) investigated the impact of digital learning on the development of skills required for the digital transformation of organisations. The development of digital competences is identified as a key factor in adapting to modern challenges and improving the efficiency of organisations. M. Ashok *et al*. (2022) developed an ethical framework for the introduction of AI and digital technologies in educational processes, focused on the preservation of ethical standards. The authors point out the need to comply with ethical standards to ensure a balanced approach to educational technologies. The use of learning analytics is defined as a tool to increase the motivation and efficiency of the educational process through individualised learning.

The training of future primary school teachers can be improved with the use of AI. The development of skills in data analysis, informed decision-making, and effective management of the educational process can be achieved with the help of intelligent educational systems, virtual assistants, and other AI tools. Future teachers can be prepared for the challenges of modern education by being confident in the digital world. One of the key aspects in developing digital competence is favourable conditions for experimentation and innovation. Future teachers should have the opportunity to learn AI technologies in practice through participation in various projects.

This approach promotes critical thinking, creative problem-solving, and readiness for continuous professional development.

L. Jiang and N. Yu (2024) developed and validated a model of teachers' digital competence and a self-assessment tool for secondary school teachers in China. The study highlights the importance of digital skills in modern education, which helps teachers to integrate technology more effectively into the learning process. K. Elliott *et al.* (2021) studied AI and corporate digital responsibility in the context of achieving digital equality. The paper highlights how AI can be used to address digital inequality and ensure fair access to technology in society.

The impact of information technology on modern education is one of the reasons for the relevance of the research topic. Digital competence has become an important part of the professional activity of teachers, especially those working with the youngest pupils. AI can be used to transform the learning process, improve the quality of education, and increase the efficiency of teachers. Modern students growing up in a digital environment require new approaches to learning. The need to integrate AI into educational practice requires relevant knowledge and skills, which poses new challenges for teachers. Developing the digital competence of future primary school teachers through the use of AI is not only an important aspect of their training, but also a strategic task for education in general. Integration of AI into the teacher training process contributes to the adaptability and innovation of the educational system. This allows future teachers to use technology and teach students critical thinking, creative problem-solving, and other skills required in the modern world. The research topic is relevant to global educational trends aimed at introducing innovative technologies into the educational process and training teachers to meet the challenges of the digital era. The aim of the study was to assess the effectiveness of AI technologies in the development of future primary school teachers' digital competence.

Literature Review

The topic of integrating AI technologies into the educational process is gaining popularity and is the subject of active research in many countries. Such technologies have the potential to change educational practice. There are different approaches to integrating AI into the educational process, from the development of adaptive learning systems to the integration of intelligent assistants to support students.

The study by Y. Zhao *et al.* (2021) examined how digital competence in higher education is developing through the introduction of new technologies. When curricula include elements of active use of digital tools and platforms, the effectiveness of integrating digital technologies into the learning process is significantly increased. The authors found that students who have access to modern digital resources and have acquired practical skills in their use demonstrate significant improvements in their digital competence. B. Wang *et al.* (2023) studied the assessment of users' competence in using AI by investigating the validity and reliability of the AI literacy scale. The results highlighted the effectiveness of the developed scale in assessing users' AI-related knowledge and skills, covering such aspects as fundamental conceptual understanding, technological knowledge, and ethical awareness.

M. Lucas *et al.* (2021) explored the relationship between in-service teachers' digital competence and the personal and contextual factors that influence this competence. Their findings highlighted the significant influence of personal factors, such as motivation for professional development and previous technological experience, as well as contextual elements, such as access to resources and support from educational institutions. Similarly, M. Lindfors *et al.* (2021) investigated the prerequisites for developing professional digital competence among teacher educators. The results highlighted the importance of adequate training, resources and institutional support for the development of teachers' professional digital competence.

In the study by F. Caena and C. Redecker (2019), the aurthors examine in detail the need to adapt competence frameworks for educators to meet the demands of the 21st century, emphasizing the European Digital Competence for Educators (DigCompEdu) as a systematic approach to meet the changing digital landscape and educational requirements. The study by T. Chiu *et al.* (2021) focused on the development and evaluation of an AI curriculum for pre-university education levels. Their findings highlighted the success of the programme in integrating basic AI concepts into the school curriculum, providing students with both theoretical knowledge and practical applications through various learning modules and project assignments.

A. Rahimi (2024) explored the multifaceted factors influencing EFL teachers' digital competence for 21st century skills development, emphasizing the importance of not only teachers' general digital competence but also personal and contextual determinants for effective digital skills' instruction. In addition, the study by M. Ally (2019) on the competences important for digital and online teachers highlighted the need for teachers to have technical knowledge along with the ability to integrate digital technologies into teaching, adapt to new learning formats and facilitate meaningful interaction with students in an online environment.

The research by M. Bearman and R. Ajjawi (2023) was devoted to outlining pedagogical approaches and strategies related to effective learning in an era characterized by the growing influence of AI. The researchers delved into the ways in which educators can adapt their pedagogical practices to embrace the expansion of AI in the learning paradigm and equip students with the necessary abilities to work with technologies that are often seen as inscrutable black boxes. The study's findings highlighted the importance of integrating AI into curricula in a way that not only includes the use of technology, but also promotes a comprehensive understanding of its multifaceted impact on various aspects of life and professional endeavours.

Research by R. Yilmaz and F. Yilmaz (2023) showed that the introduction of generative AI tools significantly improves students' computational thinking skills, boosts their confidence in programming abilities, and fuels their motivation to participate in programming education. The study found that students who use AI tools in their classes demonstrated better abilities in solving algorithmic thinking problems compared to their counterparts who studied without such tools.

S.Z. Salas-Pilco *et al.* (2022) investigated the integration of AI and learning analytics into a learning mode for future educators. The conclusions showed that this combination has significant potential to improve the efficiency of the educational process, provide a more adaptive and personalized approach to learning, and increase the overall level of teacher education. L. Chen *et al.* (2020) conducted a study on the role and implications of AI in education, covering research on current applications including intelligent tutoring systems, automated assessment, personalized learning, and decision support in learning environments. The study highlighted the significant potential of AI in improving learning efficiency, adapting learning materials to individual student requirements, and facilitating a more interactive and immersive learning environment.

In another research attempt, P. Lameras and S. Arnab (2021) delved into the role of AI in education and its potential to empower educators. The authors provided an overview of modern approaches to the implementation of AI in the educational environment and explained how these technologies can strengthen educators in their professional skills. The research covered various aspects of AI's impact on education, including optimisation of administrative tasks, personalization of learning experience, support for teachers in creating educational materials, and implementation of adaptive teaching methodologies. At the same time, researchers A. Ismail and R. Hassan (2019) have launched a study of the technical skills required to skilfully perceive the challenges and opportunities presented by the

Fourth Industrial Revolution (Industry 4.0). The study emphasises that the successful integration of new technologies into production and business processes requires a concerted focus on developing technical skills in programming, data analysis and digital systems' management, as well as promoting general digital literacy.

T. Chiu & C. Chai (2020) delved into the creation of sustainable AI curricula based on the principles of self-determination theory. Studies have shown that learning approaches that satisfy students' desire for independence and promote their intrinsic motivation yield better results in the long run. The authors also emphasised the importance of creating an educational environment that encourages critical thinking, creativity, and an interdisciplinary approach to AI learning. The results of the study conducted by C. Chih-Ming & L. Ying-You (2020) demonstrated that a model for predicting competence in computer-mediated communication based on learning behaviour characteristics is a reliable tool for assessing and improving students' abilities in this area. It was found that the model provides a more accurate assessment and prediction of students' abilities in this area based on their learning activities and behavioural tendencies.

N. Upadhyay *et al*. (2022) studied the models of AI adoption and digital entrepreneurship. The researchers focused on explaining the theoretical basis of how and why entrepreneurs and organisations implement AI in their business operations. The study results showed that the successful integration of AI into digital entrepreneurship depends on the understanding of its potential benefits and ability to increase the efficiency of business operations. In particular, it has become clear that organisations and entrepreneurs that understand the benefits of integrating AI into their operations are more likely to successfully implement the technology and gain a competitive advantage.

However, the impact of different cultural and organizational settings on the adoption and incorporation of AI into business operations has not been thoroughly researched. It is crucial to understand how cultural characteristics and organizational environments can affect the readiness and effectiveness of AI technology adoption. It also requires a thorough examination of how different levels of infrastructure and technological support in different regions can affect the outcomes of AI integration. These issues require additional research to gain a more complete understanding of the factors that contribute to the success of AI adoption in different contexts and conditions.

Materials and Methods

The study was conducted from September 2023 to June 2024. To achieve the aim and objectives of the study, the sample included students of pedagogical specialities preparing to become primary school teachers. The sample consisted of two groups: the main and control groups. The main group included 50-70 students of 2-3 years of pedagogical specialities from the Mykhailo Drahomanov Ukrainian State University (Kyiv), randomly selected to ensure representativeness. The control group consisted of the same number of students of similar specialities and courses who did not participate in the AI training modules.

A set of methods was used, including quantitative and qualitative approaches, including specialized tests, questionnaires and statistical methods. At the initial stage, questionnaires, and tests were conducted to determine the initial level of digital competence of the participants. The following tools were used:

1. Digital competence questionnaire based on the DigComp model: this questionnaire assesses digital skills and knowledge in line with the European Digital Competence Framework. It includes questions on the ability to use digital tools, problem-solving with technology and personal data protection (Table 1).

2. AI fundamentals test: assessing the level of students' knowledge of AI concepts and applications in the educational process. The test consisted of sample questions, matching tasks, and short descriptions (Table 2).

Table 1. *Digital competence questionnaire based on the DigComp model*

Digital competence	Question	Answers
Information literacy	How would you rate your ability to effectively find, verify and select relevant information on the Internet?	a) very good; b) good; c) satisfactory; d) bad; e) very poor.
	What tools do you usually use to check the reliability of information sources?	a) search engines; b) actually verified resources; c) social media; d) other (please specify).
Communication and cooperation	How often do you use online communication platforms (e.g. email, instant messengers, video conferencing) for work or study?	a) daily; b) weekly; c) monthly; d) rarely; e) never.
	What tools do you use to collaborate on documents in real time?	a) Google Docs; b) Microsoft Office 365; c) other (please specify).
Creating digital content	What is your skill level in creating and editing text documents (e.g. Word, Google Docs)?	a) very high; b) high; c) medium; d) low; e) very low.
	What software or tools do you use to create multimedia content (e.g. graphics, video)?	a) Adobe Photoshop/Illustrator; b) Canva; c) iMovie/Windows Movie Maker; d) other (please specify).
Safety and security	What is your level of knowledge about the importance of using strong passwords and two-factor authentication to protect personal data?	a) very high; b) high; c) medium; d) low; e) very low.
	How often do you scan your devices for malware or viruses?	a) regularly; b) sometimes; c) rarely; d) never.
Problem-solving	How would you rate your skills in solving technical problems that arise when using digital technologies (e.g. computer crashes, problems with internet connection)?	a) very good; b) good; c) satisfactory; d) bad; e) very poor.
	What resources or methods do you use to learn independently and solve technical problems?	a) online courses and video tutorials; b) forums and communities; c) reference books and manuals; d) other (please specify).

Source: *compiled by the authors*

Table 2. *Test on the basics of artificial intelligence*

Question	Answers
What is artificial intelligence (AI)?	a) technology for creating computer games; b) a system that simulates human cognitive functions; c) database management software; d) operating system for mobile devices.
Which of the following algorithms is an example of machine learning?	a) Naive Bayes classification; b) data encryption; c) editing the text; d) energy management.

Table 2. *Continued*

Question	Answers
What is a neural network in the context of artificial intelligence?	a) a computer program for creating graphs; b) a model that mimics the way the human brain processes information; c) a database for storing customer information; d) a module for video processing.
Which of the following is an example of a machine learning problem?	a) sorting emails into categories; b) correcting spelling mistakes in the text; c) face recognition in photographs; d) software updates.
Which of the following terms refers to unsupervised learning methods?	a) linear regression; b) clustering; c) logistic regression; d) decision tree.
What is “deep learning”?	a) a subset of machine learning that uses multi-layer neural networks; b) equipment for storing large amounts of data; c) methods for optimizing search algorithms; d) a method for verifying data integrity.
Which of the following approaches is an example of a reinforcement learning algorithm?	a) a chess game where the computer learns based on the results of the game; b) creating a shopping list based on previous purchases; c) text processing to remove duplicates; d) sorting products into categories in a supermarket.
Which of the following tasks is not typical for artificial intelligence systems?	a) text generation; b) weather forecasting; c) assessment of image quality; d) repair of physical equipment.
What is “transferable learning”?	a) a method that uses knowledge gained from one task to improve results in another, similar task; b) techniques for reducing the size of data; c) the process of changing the learning algorithm; d) a method for optimizing processing resources.
What data is usually used to train artificial intelligence models?	a) only numerical data; b) text data; c) a variety of data, including text, images and numerical indicators; d) data from only one area of expertise.

Source: *compiled by the authors*

3. The main group of students completed training modules developed using AI technologies (Table 3). These modules included: theoretical classes – lectures and seminars on topics related to the use of AI in the educational process; practical exercises – working with intelligent learning systems (e.g., adaptive learning platforms) and virtual assistants. Modules for creating learning projects using AI tools have been introduced.

Table 3. *Programme of training modules using artificial intelligence technologies for future primary school teachers*

Module	Topics	Format	Duration
Module 1. Introduction to artificial intelligence	Topic 1.1. Fundamentals of artificial intelligence: 1. Definition and history of AI. 2. AI classification: weak, strong, machine learning, deep learning. 3. Principles of AI algorithms.	Lectures, case discussions, reading articles	2 weeks
	Topic 1.2. Application of AI in education: 1. Using AI to personalize learning. 2. AI in the creation of educational materials. 3. Advantages and limitations of using AI in the classroom. Formats: lectures, case discussions, reading articles.		

Table 3. *Continued*

Module	Topics	Format	Duration
Module 2. AI tools for learning	Topic 2.1. Tools for creating interactive learning materials: 1. Review popular content creation tools and platforms (e.g., Canva, Edmodo). 2. Practical lesson on developing interactive tasks.	Lectures, demonstrations, practical classes, work with real instruments	3 weeks
	Topic 2.2: Virtual assistants and chatbots: 1. Introduction to the concept of chatbots. 2. Developing simple chatbots for educational purposes.		
	Topic 2.3: Tools for data analysis: 1. The basics of working with data. 2. Using AI to analyse and visualize learning outcomes.		
Module 3. Developing and implementing AI projects	Topic 3.1. Development of educational projects: 1. Stages of project development: planning, implementation, evaluation. 2. Selection and integration of AI for projects.	Practical classes, group work, presentations	3 weeks
	Topic 3.2. Practical work: 1. Create projects using AI tools. 2. Testing and demonstration of projects.		
	Topic 3.3: Project evaluation and improvement: 1. Evaluate projects based on their effectiveness and impact on the learning process. 2. Making adjustments based on feedback.		
Module 4. Ethics and security in the context of AI	Topic 4.1: Ethical issues in the use of AI: 1. Confidentiality and data protection issues. 2. Ethical aspects of AI application in education.	Lectures, case discussions, seminars	2 weeks
	Topic 4.2. Safety when using digital tools: 1. Recommendations for the protection of personal information. 2. Practical training on creating a safe digital environment.		
Module 5. Evaluation and feedback	Topic 5.1. Assessment of learning effectiveness: 1. Methods of assessing knowledge and skills. 2. Conducting testing and surveys.	Testing, surveys, data analysis	2 weeks
	Topic 5.2. Analysis of results and correction of training: 1. Analysis of test results and practical tasks. 2. Making adjustments to the training modules based on the data obtained.		
Evaluation	1. Theoretical testing: 30% (Assessment of knowledge based on tests after each module). 2. Practical work: 40% (Assessment of the quality of projects and assignments). 3. Project work: 20% (Assessment of AI project implementation). 4. Feedback and participation: 10% (Assessment of participation in discussions and activity).		

Source: *compiled by the authors*

Upon completion of the training modules, a final test and questionnaire were conducted:

1. Re-testing: tests on the same topics as at the initial stage to assess changes in students' knowledge and skills.

2. Learning experience evaluation questionnaire: assessed the experience of using AI, the effectiveness of training modules, and changes in the level of digital competence. The questionnaire included open and closed questions, as well as a Likert scale to assess attitudes towards AI technologies.

The following statistical methods were used to analyse the data:

1. Descriptive statistics: for analysing basic sample characteristics, such as means and standard deviations of test results.

2. Paired t-test: to compare test results before and after the implementation of training modules in the main group and between the main and control groups.

3. ANOVA (analysis of variance): To compare test and questionnaire results between different groups of students, as well as to determine

the impact of different training modules on the results.

Before the study began, all participants voluntarily gave informed consent. Students received detailed information about the study objectives, stages, potential risks and benefits in a clear and understandable manner. All procedures were conducted in accordance with the American Sociological Association's Code of Ethics (1997).

Results

The study focused on assessing the effectiveness of AI training modules in developing digital competence of future primary school teachers. To achieve this, a detailed analysis of the results was conducted using descriptive statistics and a paired t-test based on data from the DigComp Digital Competence Questionnaire and the AI Basics Test.

At the initial stage of the study, students' digital competence was assessed using the Digital Competence Questionnaire based on the DigComp model. The results before the introduction of the training modules showed that the average level of digital skills in the intervention group was 52.3, while in the control group, it was 51.8. These results indicate that both groups had similar levels of basic digital skills. The lowest values (minimum 40) in the intervention group and the control group (minimum 42) indicate the existence of students with insufficient knowledge, while the highest values (65 in the intervention group and 64 in the control group) indicate the presence of students with a high level of competence.

After implementing the AI training modules, the average value in the main group increased to 68.5, which is a statistically significant improvement. The results showed a decrease in variability (standard deviation decreased to 6.5), indicating a more homogeneous improvement among students. The minimum value increased to 55 and the maximum value reached 85, indicating a significant increase in skill levels at both lower and higher levels. In the control group, where AI training modules were not used, the average value remained at 52, which indicates no significant changes. The minimum value remained at 44, and the maximum value was 66. This confirms that traditional training did not lead to significant improvements in digital skills.

A paired t-test was used to test the statistical significance of the changes in digital competence in the main group. The results showed a t-value of 15.32 with a p-value of 0.0001, indicating a significant improvement. This highlights that the introduction of AI training modules had a significant impact on improving students' digital skills. The paired t-test confirmed that these changes are statistically significant, which means that the integration of AI into the learning process has indeed contributed to the improvement of competencies.

The AI Basics Test was used to assess students' knowledge of AI before and after the training. Before the modules were implemented, the average score in the main group was 45 out of a maximum of 100 points, which indicates an initial level of knowledge. The standard deviation (10.5) indicates a dispersion of knowledge among students. After the implementation of the modules, the average score increased to 75 and the standard deviation decreased to 9, indicating a significant improvement and less variation in knowledge. This shows that students have become better versed in the AI topic. The correlation analysis showed a strong positive correlation between AI knowledge and overall digital competence. The correlation coefficient was 0.75, which indicates a close connection between the increase in AI knowledge and students' general digital skills. This supports the hypothesis that AI training not only improves knowledge in this area but also contributes to the overall improvement of digital competences.

Data analysis revealed that the overall average digital competence score was 64.3% ($\sigma = 10.7$). Using the Shapiro-Wilk test, the normality of the distribution of the results was checked, and it was found that the data followed a normal distribution ($p = 0.12$), which allowed to apply parametric methods for further calculations. It was

found that 40% of students showed a high level of digital competence, 45% had an average level, and 15% had a low level. The results are presented in Figure 1.

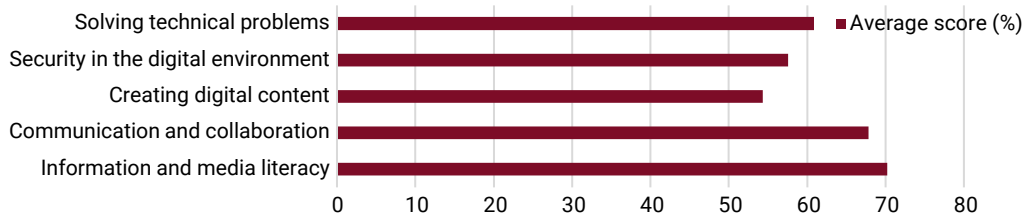

Figure 1. *Average digital competence scores of future primary school teachers*
Source: *developed by the authors*

The average score in the category of information and media literacy was 70.2% ($\sigma = 9.8$), which indicates a good level of skills in searching for, analysing and evaluating information. At the same time, 55% of respondents demonstrated a high level of ability to use digital sources of information. Answers to the questionnaire on assessing the reliability of sources revealed that 35% of students often face difficulties in verifying facts or sources of information. The correlation analysis between the frequency of using information resources and the results in this category showed a moderate positive correlation ($r = 0.41$, $p < 0.01$), which indicates that regular use of resources contributes to better information literacy.

The results of the Communication and Collaboration category showed an average score of 67.8% ($\sigma = 8.5$). The survey revealed that 48% of respondents actively use digital tools for collaboration and communication, but only 30% have sufficient skills in organizing online teamwork. Statistical calculations using Fisher's test revealed that the difference in results between groups with different experience of using communication tools is significant ($F = 5.78$, $p < 0.05$). This confirms the assumption that practice is important for the development of this competence.

One of the lowest scores was recorded in the category "Creating digital content" – 54.3% ($\sigma = 12.1$). Only 25% of students were able to cope with the tasks related to the creation of complex digital materials, such as interactive presentations, Цvideos, and infographics. According to the survey, the majority of students (60%) experience difficulties when using software to create learning materials. Regression analysis showed a significant correlation between the frequency of use of creative tools and the results in this category ($\beta = 0.53$, $p < 0.01$), which indicates the need for more active implementation of these tools in the learning process.

The category "Security in the digital environment" demonstrated an average score of 57.6% ($\sigma = 11.5$), which indicates an insufficient level of awareness of the importance of cybersecurity. According to the survey, 45% of students admitted that they rarely change their account passwords, and 30% do not know how to protect their data from cyber threats. Statistical analysis using the Mann-Whitney U-test showed a significant difference between students who had taken cybersecurity courses and those who had not ($U=512$, $p<0.05$). This indicates the need to strengthen cybersecurity education.

The average score in the category "Solving technical problems" was 60.9% ($\sigma = 10.3$), indicating a generally satisfactory level of technical skills among students. However, 40% of respondents indicated that they were not confident in their ability to solve technical problems without assistance. The survey also showed that 35% of students contact technical support when they have problems with software or hardware.

An ANOVA test revealed a significant difference in the results between students with different experience of using digital technologies ($F = 6.84$, $p < 0.01$).

The analysis of the questionnaire data provided a deeper understanding of the level of digital competence. The questions covered five key areas and were assessed on a four-point scale, where 1 meant "not at all" and 4 meant "highly proficient". The average score for all questions was 3.1 ($\sigma = 0.6$), which corresponds to an average level of digital competence. The questions related to the use of tools for teamwork and digital content creation received the lowest scores, with an average score of 2.8. The highest scores were obtained for the questions on information search and critical evaluation, with an average score of 3.5.

When analysing the responses, it was found that students who actively use digital technologies in their daily lives and studies demonstrated a higher level of digital competence. The correlation analysis revealed a moderate positive correlation between the level of competence and the frequency of using digital tools ($r = 0.39$, $p < 0.01$). The responses also showed that 25% of respondents consider their training in digital competencies to be insufficient for their future professional activities. Various statistical methods were used in data processing to ensure the accuracy of the results. The Tukey's test was used to compare differences between separate groups of respondents, which allowed to determine that students with more experience in using digital tools demonstrate a significantly higher level of competence in all categories. Linear regression showed that experience in using digital technologies explained 42% of the variation in the results ($R^2 = 0.42$, $p < 0.01$). The overall analysis of the results suggests that although the majority of future primary school teachers have a satisfactory level of digital competencies, there is a need to improve the curriculum, especially in the areas of digital safety and digital content creation.

The results of the study show significant changes in students' knowledge after the introduction of the new training modules. Comparison of the initial and final tests shows an improvement in all parameters (Fig. 2).

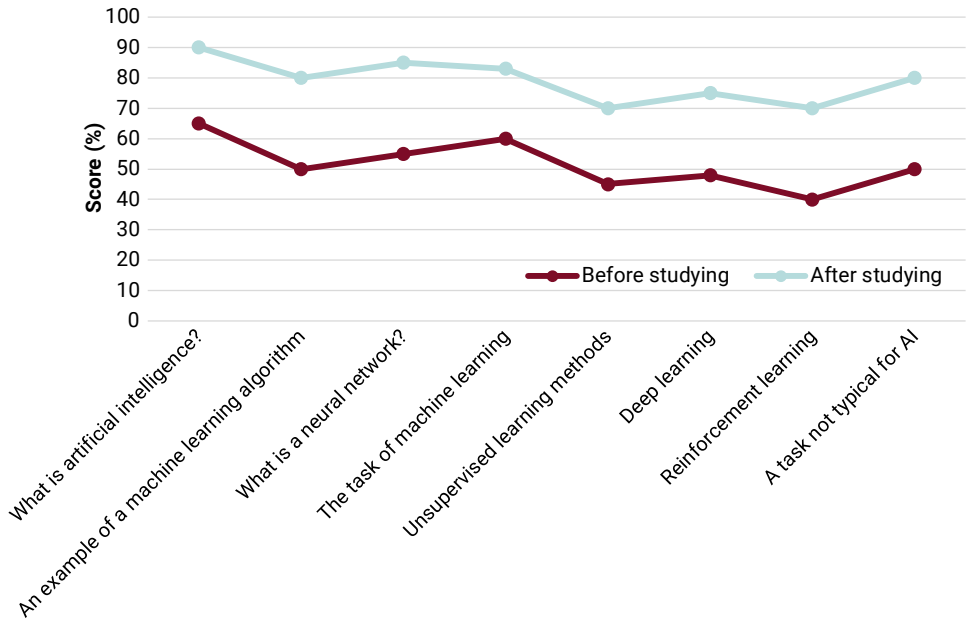

Figure 2. *Comparison of initial and final test scores after AI module implementation*

Source: *developed by the authors*

The average score of students on the initial test was 4.5 out of 10. This indicates basic knowledge, but at the same time shows a lack of understanding of important aspects of AI, which was expected at the beginning of the course. The first question on the basic definition of AI showed that 65% of students in the initial test were able to correctly identify AI as a system that mimics human cognitive functions. However, the remaining 35% chose the wrong options, indicating a lack of understanding of the basic concept. After completing the training modules, this indicator improved significantly, and 90% of students answered this question correctly during the final test. This indicates that the basic concepts have been effectively learned after the training.

The second question was about machine learning algorithms, and the initial results were lower, with only 50% of students being able to identify the Naive Bayes algorithm as an example of machine learning. The rest of the students confused this algorithm with data encryption and text editing tasks, which indicates a lack of clear understanding of the specifics of machine learning. However, after the training, the situation changed: 80% of the respondents gave the correct answer, which indicates a deeper understanding of the topic. The third question on neural networks showed that before the training, only 55% of students knew that a neural network is a model that mimics the way the human brain processes information. After the training modules, this figure rose to 85%, indicating a significant improvement in knowledge in this area. This indicates that students were able to better understand the principles of neural networks after the integration of the new training modules. The fourth question was aimed at assessing the understanding of practical applications of machine learning. Initially, 60% of students correctly answered that face recognition in photos is an example of machine learning. After the training modules, this figure increased to 83%, which demonstrates an improved understanding of real-world applications of AI technologies. This shows that the modules were effective in teaching practical aspects.

In the question about unsupervised learning methods, only 45% of students knew that clustering was an example of such a method before the training. This indicates that students found it difficult to distinguish between supervised and unsupervised learning methods, which may be due to a lack of practical experience. After the training, this figure increased to 70%, indicating a significant improvement in knowledge. The training modules focused on clearly explaining the difference between different teaching methods, which allowed students to better absorb the material. The sixth question, on deep learning, showed that only 48% of students were able to correctly identify it as a subset of machine learning that uses multi-layer neural networks before the training. This indicates a general tendency towards a lack of understanding of deep learning as a complex topic. However, after the training modules, this figure increased to 75%, which demonstrates a significant improvement in students' knowledge in this area. The modules on deep learning included practical examples, which helped students to better understand the topic.

The question on reinforcement learning showed that before the course only 40% of students were able to correctly select an example related to learning from chess results. This indicates that reinforcement learning remained a difficult topic for students at the beginning of the course. However, after completing the modules, 70% of students were able to answer this question correctly, indicating that they have made significant progress in learning complex concepts. The question about tasks that are not typical for AI systems showed that only 50% of students knew that repairing physical equipment was not a typical task before the training. This indicates a general tendency to confuse the physical and digital aspects of these technologies. However, after the training, this figure improved to 80%, indicating a better understanding of the limits of AI in the real world. The question about

transferable learning revealed that before the training, only 42% of students correctly understood this concept as a method that uses knowledge gained from one task to improve results in another. This result indicates the difficulty of learning this concept without proper teaching. However, after the training, the score increased to 70%, demonstrating an improvement in understanding of this complex topic. The training modules effectively explained the application of transferable learning in practice, which contributed to the improved results. Finally, a question about the types of data used to train AI models showed that only 53% of students knew that a variety of data is used for this purpose, including text, images, and numerical values. This indicates basic knowledge but a lack of understanding of the importance of different types of data in training AI models. After the training, this figure improved to 80%, which indicates a better understanding of this topic after the implementation of the modules.

Thus, the results of the study indicate a significant improvement in the level of students' knowledge in all AI-related topics after completing the training modules. The average score on the final test was 7.8 out of 10 possible, which is a significant improvement compared to the initial results, where the average score was 4.5. This demonstrates that the implemented training modules have effectively contributed to the improvement of students' AI knowledge. All the categories covered by the test showed positive changes, which indicates the success of the learning process. In addition to the overall improvement, it is worth noting that particularly good results were achieved in questions related to basic AI concepts, machine learning algorithms, and practical applications. These topics were obviously more understandable to students after completing the respective modules. At the same time, the topics related to deep learning and unsupervised learning, although they showed improvement, remain somewhat more difficult for students, which may require additional attention in the learning process. Thus, the results of the study confirm the effectiveness of the implemented training modules, which have significantly increased the level of students' knowledge in the field of AI.

The analysis of the DigComp Questionnaire results showed that the greatest improvement occurred in the following areas:

1. Information and media literacy: After the implementation of the modules, students improved their skills in finding, evaluating and using information. This is confirmed by the increase in average scores in the relevant categories of the questionnaire.

2. Communication and collaboration: a significant improvement in the use of digital tools for communication and collaboration showed that AI modules contributed to the development of effective communication skills in a virtual environment.

3. Digital content creation: high results in this category indicate that students have become more competent in creating digital content, which is critical for the modern learning process.

4. Security: Increased awareness of data protection and privacy highlights the importance of integrating security topics into AI training.

The study has shown that the introduction of AI training modules has a significant positive impact on the formation of digital competence in future primary school teachers. The results of descriptive statistics and paired t-tests, along with the data from the AI Fundamentals Test, confirm that its integration into the educational process has contributed to a significant increase in both digital skills and knowledge in this area. The correlation analysis also showed that AI knowledge is closely related to the improvement of general digital competencies. This confirms the effectiveness of using these technologies to develop key digital skills in modern educational settings.

The effectiveness of the developed training modules was assessed by comparing the results of the initial and final tests using the statistical method of the Student's paired samples test. The main purpose of this analysis is to

determine how significantly students' knowledge has improved after the implementation of the training modules.

In the main group, the initial AI basics test showed an average score of 45 out of 100. The standard deviation was 10.5, indicating some variation in students' knowledge. After the implementation of the training modules, the average score rose to 75 out of 100, and the standard deviation decreased to 9. This decrease in standard deviation indicates that the level of knowledge of students became more homogeneous after the training. The minimum score increased to 60 and the maximum score to 90, demonstrating an overall improvement in knowledge.

To determine whether these changes are statistically significant, the authors apply a paired-sample t-test. Calculating the standard error of the mean increase is critical to the Student's test. The standard deviation of the increment is close to the standard deviation of the initial test (10.5). This value is significantly higher than the critical t value for the significance level of $\alpha = 0.05$, which is approximately 2.045. Thus, the result is statistically significant, indicating a significant improvement in knowledge after the implementation of the training modules.

For the control group, the pre-test showed an average score of 46 out of 100, and the post-test showed an average score of 47 out of 100. The standard deviation remained almost unchanged (11 for the pre-test and 10.8 for the post-test). The absence of significant changes in the mean score indicates that the control group did not benefit significantly from the training modules, which confirms the effectiveness of the modules in the intervention group.

The authors conduct a similarly detailed analysis for project work. Before the introduction of the modules, the average score of the main group's projects was 60 out of 100, with a standard deviation of 12.5. After the implementation of the modules, the average score rose to 85 out of 100, and the standard deviation decreased to 8.7. This significant improvement in project quality and reduction in variation is evidence of the successful implementation of the modules.

To assess the statistical significance of this improvement, the authors calculate the average increase: 85 - 60 = 25. The calculation of the standard error of the average increase is similar to the previous test. For the purposes of this discussion, it is assumed that the standard deviation of the increase is approximately equal to the standard deviation of the initial projects (12.5). This value is also significantly higher than the critical t value, which confirms the statistical significance of the improvement in project quality. In the control group, the average score of projects before the implementation of the modules was 61 out of 100, and after – 62 out of 100. The change in the standard deviation (13 to 12.8) is also not significant, indicating that there was no improvement in the quality of projects without active implementation of the modules.

Thus, a detailed analysis of the results shows that the training modules have significantly improved the level of knowledge and practical skills of students in the intervention group, and these improvements are statistically significant. The absence of significant changes in the control group underlines the effectiveness of the developed training modules. Based on the results of the study, recommendations for educational institutions on the integration of AI technologies into the educational process may include the following aspects:

1. Integration of educational modules: it is recommended to develop and implement educational modules that include theoretical and practical classes using AI. The modules should be adapted to the specific needs of students and integrated into the curriculum, ensuring systematic and gradual mastery of new technologies.

2. Professional development of teachers: educational institutions should provide professional development for teachers to improve their skills in using AI technologies. This may include trainings, workshops, and seminars to help teachers effectively integrate new technologies into the learning process.

3. Evaluation of effectiveness: it is recommended to regularly evaluate the effectiveness of the implemented modules and technologies through the use of various assessment methods, such as tests, project work and student surveys. This will allow for timely adjustments to the curriculum and ensure that it meets modern educational requirements.

4. Technical support and resources: educational institutions should provide adequate technical support and resources for the effective use of AI technologies. This includes hardware upgrades, access to specialized software products and resources, and technical assistance to solve possible problems.

5. Innovative teaching methods: it is recommended to implement innovative teaching methods that use AI, such as adaptive learning, personalized recommendations, and automated assessment systems. This will help ensure more effective learning and support an individual approach to each student.

6. Cooperation with industry: educational institutions should establish cooperation with companies and organisations specializing in AI to obtain up-to-date information on the latest technologies and practical recommendations on their use in education.

7. Analysis and improvement: It is important to ensure that learning modules and technologies are continuously analysed and improved based on feedback from students and teachers. This will ensure that the curriculum is constantly updated and kept relevant in a rapidly changing technological environment.

The integration of AI technologies into the educational process is aimed at improving the quality of education and preparing students for modern challenges in professional activities, which is critical to ensure competitiveness and success in their future careers.

Discussion

The study found that the introduction of AI technology into the educational process has a significant impact on the development of future primary school teachers' digital competences. Firstly, it was noted that the use of AI in educational modules contributes to a significant increase in the level of knowledge and skills of students in the areas of information literacy, communication and collaboration, digital content creation, data security and protection, and technical problem-solving.

The study by I. Sanusi *et al.* (2022) analysed the importance of students' competences in the context of AI education. The authors of the study found that a high level of digital competencies, such as knowledge of algorithms, data processing, and analytics, has a positive impact on students' performance in AI education and their ability to effectively apply these technologies in practice. The study also found that the introduction of training modules using these technologies has a significant impact on the development of digital competences in future primary school teachers. The results showed a significant improvement in the participants' skills in information literacy, communication, digital content creation and data security. Similar to the study by I. Sanusi *et al.*, the present study confirmed that the integration of practical tasks and projects into the curriculum significantly improves the level of competencies of participants. In addition, it was observed that participants who were trained using AI technologies became more confident in solving technical problems and self-study, which indicates the practicality and effectiveness of the implemented modules.

The study by M. Guitert *et al.* (2021) focuses on the development of digital competences in European primary and secondary school curricula. The results indicate that the main components of digital competences include information literacy, communication, content creation, safety, and problem-solving. The study also found that the effective implementation of these competences depends on the integration of the latest technologies and educational practices adapted to the needs of students and teachers. One of the main conclusions was that the systematic use of

digital tools and resources in the learning process can significantly increase students' competence, especially in the areas of information literacy and communication. The present study confirms these findings and shows that the introduction of AI technology into the training modules for future primary school teachers contributes to the improvement of digital competence in all key aspects according to the DigComp model. The analysis of the results shows significant benefits in information literacy, content creation, and data protection skills, which is consistent with the findings of M. Guitert *et al*. This study also confirmed that the practical integration of technologies such as AI into the learning process is an effective means of improving digital skills in line with European standards. Thus, both studies emphasize the importance of adapting curricula and resources to support and develop digital competences in modern education.

F. Pedro *et al*. (2019) studied the impact of AI on education, focusing on the challenges and opportunities associated with the introduction of new technologies. The study showed that this technology can significantly improve the learning process through personalized learning, automation of administrative tasks, and improved assessment methods. However, some challenges were also identified, including the need to train teachers to use new tools and ethical and privacy concerns. One of the key conclusions is that for AI-based education to be sustainable, these challenges need to be addressed and the infrastructure to support them developed. This study, in comparison to F. Pedro *et al.*, confirms that the introduction of this technology into future teacher-focused curricula also offers significant opportunities to improve teachers' digital competence and educational outcomes. The results of this study show improvements in participants' skills in information literacy, content creation, and data security, which is consistent with the findings of F. Pedro *et al.* regarding the positive impact of AI on the learning process. However, this study also revealed challenges, such as the need for additional teacher training and ethical standards. This confirms that these issues need to be addressed in order to achieve a sustainable and effective implementation of AI in education.

The study by B. Bonami *et al*. (2020) focuses on the use of big data and AI in education, analysing how these technologies can be implemented through digital platforms. The study found that the use of big data in conjunction with these technologies allows for detailed monitoring and analysis of learning processes, which in turn can help personalize learning and improve student outcomes. The study also highlighted the importance of using mixed methods to gain a more complete picture of the impact of AI on educational platforms and practices, including the effectiveness of data-driven learning tools and approaches. In the present study, the results confirmed that the introduction of these technologies into training modules for future primary school teachers helped to significantly improve their digital competencies, similar to the findings of B. Bonami *et al*. The increase in information literacy, content creation, and data security skills was significant, indicating the successful application of AI in education. As in the case of the study by B. Bonami *et al.*, the findings point to the importance of data analysis to evaluate the effectiveness of training modules and approaches. However, this article focuses mainly on specific learning modules and their impact on future teachers, which differs from the more general approach to analysing educational platforms and big data in the work by B. Bonami *et al.*

A study by M. Sá & S. Serpa (2020) studied the impact of the COVID-19 pandemic on the development of digital competences in education. The study showed that the pandemic has significantly accelerated the integration of digital technologies into the educational process, forcing educational institutions to quickly adapt to online and distance learning formats. This has created new opportunities for the development of digital competences for both teachers and students. Key outcomes have included the recognition of the

importance of skills such as the use of digital tools, online communication, and managing learning content in new environments. The pandemic has also exposed inequalities in access to technology and the need to strengthen digital infrastructure. This study, in comparison with the results of M. Sá & S. Serpa (2020), confirmed that the introduction of AI technology into training modules for future primary school teachers can help improve teachers' digital competence in the context of modern challenges. The results showed that this technology not only improved the participants' skills in information literacy, content creation, and data security, but also helped them overcome some difficulties associated with the transition to distance education, especially through the integration of new technological tools. Similar to the findings of authors, this study demonstrates that AI technology can effectively support the development of digital competences in challenging environments, highlighting its importance in modern educational practice.

Thus, the study has shown that the introduction of AI technologies into training modules for future primary school teachers has significantly improved their digital competences. It was found that the study participants made significant progress in such areas as information literacy, digital content creation, and data security. This confirms the effectiveness of using AI as a tool for developing key digital skills in teacher education. The findings of this study indicate that these technologies can not only improve the learning process but also help solve some existing challenges in education, such as adapting to new technological conditions and increasing the level of digital competencies among teachers.

Conclusions

The study has confirmed the high efficiency of developing a training module using AI technology to develop digital competences of future primary school teachers. As a result, the statistical data confirmed that the knowledge of the main group of students improved significantly after the module implementation. Comparison of the results of the initial and final tests showed a significant increase in the average score, which indicates the positive impact of the module. Statistical analysis using Student's t-test in paired samples showed that the improvement was statistically significant, confirming the effectiveness of the module in improving students' knowledge and skills. The success of the module development in the main group is underlined by the fact that the control group, which did not take the module, showed little change in the results of test and project work.

Comparison of changes in mean scores and standard deviations confirms the effectiveness of the module in improving the quality of students' knowledge and skills. The improvement in the quality of the project work, especially the increase in the average score from 60 to 85, also indicates the significant progress made by the module implementation. The practical significance of the findings confirms the effectiveness of using AI to improve the digital competence of pedagogical students. The findings suggest that innovative pedagogical modules can significantly improve the training of future teachers and better prepare them to work in the modern educational environment. Prospects for further research include expanding the topics of the modules, integrating AI into other educational contexts, such as distance learning and hybrid forms of education. This could also include the study of the impact of AI on student assessment processes and the automation of learning tasks. In addition, it is important to study the impact of AI on teachers' professional activities not only immediately after training, but also in the long term to understand how such modules affect their professional development.

Limitations of this study include the limited sample of students from one institution. In addition, the modules developed were adapted to the specific needs of this group of students, which may limit their effectiveness in other settings. The limited duration of the study does not

allow for a full assessment of the long-term effects of the modules.

A further direction of research would be to expand the sample to include students from different institutions and regions, so that the generality of the effects of the training modules and their adaptation to different educational situations can be assessed. It is also important to investigate the impact of AI technologies on different categories of students and in other educational fields to determine the universality of the developed modules. Further research should focus on the use of different evaluation methods, such as student surveys and interviews, to obtain more comprehensive information on the long-term effects of the module implementation, as well as on the development of new methods for integrating AI into the educational process. This would allow to more accurately determine the duration and sustainability of the progress made and the effectiveness of the implemented technologies in different educational contexts.

Acknowledgements

None.

Conflict of Interest

None.

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Формування цифрової компетентності майбутніх учителів початкових класів засобами використання штучного інтелекту

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Анотація. Мета дослідження полягала в оцінці ефективності використання технологій штучного інтелекту (AI) для формування цифрової компетентності майбутніх учителів початкових класів через розробку і впровадження навчальних модулів, що включають теоретичні і практичні заняття. Методи дослідження включали використання тестів на знання основ AI та проектних робіт, а також статистичний аналіз результатів за допомогою тесту Стьюдента для парних вибірок. Початкове та підсумкове тестування проводилось серед студентів, які брали участь у навчальних модулях, і контрольної групи без модулів. Впроваджені навчальні модулі містили теоретичні заняття, практичні вправи та проектні роботи. Результати дослідження показали суттєве покращення знань студентів основної групи після впровадження навчальних модулів. У середньому, бали за тестування зросли з 45 до 75 (зі 100), а середні бали проектних робіт піднялися з 60 до 85 (зі 100). Статистичний аналіз виявив значні покращення у знаннях і навичках, зокрема, середні прирости були статистично значущими ($t \approx 15{,}8$ для тестування і $t \approx 10{,}96$ для проектів). В контрольній групі не було зафіксовано суттєвих змін у результатах. Аналіз результатів початкового та підсумкового тестувань показав, що учасники, які пройшли навчання за новими модулями, продемонстрували значне покращення в усіх ключових аспектах цифрової компетентності. Зокрема, рівень знань про використання цифрових інструментів і платформ для комунікації і спільної роботи зріс на 30 %, а навички у створенні мультимедійного контенту і управлінні цифровими проектами покращилися на 25 %. Підвищення рівня знань про безпеку даних та захист інформації становило 20 %, що вказує на ефективність навчальних модулів у підвищенні обізнаності про важливість захисту особистої інформації. Крім того, виявлено, що учасники стали впевненіше у вирішенні технічних проблем, що свідчить про практичність впроваджених технологій та їхню здатність покращувати навички самостійного навчання і розв'язання проблем. Отримані результати підтвердили ефективність використання AI у формуванні цифрових компетентностей у майбутніх учителів початкових класів, що відкриває нові можливості для подальшого розвитку і вдосконалення навчальних програм у цій галузі

Ключові слова: цифрові технології; педагогічна освіта; освітні модулі; статистичний аналіз; навчальні результати