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Professional training of computer science teachers through the system of staged continuing education

Formación profesional del profesorado de informática mediante el sistema de formación continua escalonada

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Abstract

The aim of the study is to assess the effectiveness of staged continuing education in the formation of professional competencies of computer science teachers and its impact on adaptation to digital technologies. The research methods included questionnaire surveys of teachers with different work experience, a pedagogical experiment with division into control and experimental groups, analysis of learning outcomes, and statistical assessment of the impact of digital technologies on teaching. The results of the study showed that the staged education system significantly increases digital literacy (+38%), the integration of STEM methodologies (+34%), and the effectiveness of adaptive curricula (+29%). The best indicators were demonstrated by teachers with 5–8 years of experience, who were able to combine technological training with practical experience. The findings prove the effectiveness of the implementation of staged education for the development of technical and pedagogical

competencies. The academic novelty is the developed integrated training model that combines adaptive programmes, digital platforms, and interactive methods. Further research prospects include a long-term analysis of the effectiveness of this model in training teachers of other subjects and expanding its capabilities by integrating artificial intelligence and virtual reality.

Keywords: Continuing education, teacher training, computer science, educational technology, pedagogical competence, digital platforms, technical literacy.

Resumen

El objetivo del estudio es evaluar la eficacia de la formación continua por etapas en la formación de competencias profesionales de los profesores de informática y su impacto en la adaptación a las tecnologías digitales. Los métodos de investigación incluyeron encuestas por cuestionario a profesores con distinta experiencia laboral, un experimento pedagógico con división en grupos de control y experimental, el análisis de los resultados del aprendizaje y la evaluación estadística del impacto de las tecnologías digitales en la enseñanza. Los resultados del estudio mostraron que el sistema de enseñanza por etapas aumenta significativamente la alfabetización digital (+38%), la integración de metodologías STEM (+34%) y la eficacia de los planes de estudios adaptativos (+29%). Los mejores indicadores los demostraron los profesores con 5-8 años de experiencia, que fueron capaces de combinar la formación tecnológica con la experiencia práctica. Los resultados demuestran la eficacia de la implantación de la formación por etapas para el desarrollo de competencias técnicas y pedagógicas. La novedad académica es el modelo de formación integrada desarrollado, que combina programas adaptativos, plataformas digitales y métodos interactivos. Otras perspectivas de investigación incluyen un análisis a largo plazo de la eficacia de este modelo en la formación de profesores de otras materias y la ampliación de sus capacidades mediante la integración de la inteligencia artificial y la realidad virtual.

Palabras clave: Formación continua, formación del profesorado, informática, tecnología educativa, competencia pedagógica, plataformas digitales, alfabetización técnica.

Introduction

Modern computer science teacher training requires the integration of digital technologies into the educational process. Technical literacy and the ability to use ICT are key conditions for the professional activity of teachers, but traditional approaches do not always take into account the rapid development of technologies, which complicates teacher adaptation.

The staged system of continuing education promotes the gradual development of professional competencies through interactive platforms and adaptive learning, which increases the level of teachers' technical and pedagogical training. However, there are still some problems of insufficient integration of digital tools, low level of technical training, and unequal access to technologies.

The research is intended to improve the training of computer science teachers in accordance with the requirements of the digital society. The integration of technical innovations into the pedagogical process will contribute to the teachers' professional development and ensure that education meets modern standards.

The aim of the study is to assess the effectiveness of staged continuing education in building of professional competencies of computer science teachers and determine its impact on the teachers' adaptation to modern digital technologies.

Empirical objectives of the study:

1. Study the impact of staged continuing education on the development of technical and pedagogical competencies of computer science teachers.

2. Assess the effectiveness of the use of digital learning platforms and adaptive educational programmes in increasing the level of teachers' digital literacy.
3. Compare the results of the control group (CG) and the experimental group (EG) to determine changes in teacher training after the implementation of the staged education system.

The results of the study will contribute to the improvement of professional training of computer science teachers, the development of effective models for integrating technical innovations into the educational process, and the creation of conditions for the long-term development of pedagogical education.

This article is structured into the following sections: a theoretical framework that outlines the conceptual basis of the study, a methodology section detailing the research design, results of the empirical investigation, a discussion that compares findings with existing literature, and final conclusions summarizing the key insights.

Literature Review

An analysis of current research on the professional training of computer science teachers demonstrates different approaches to the effective integration of technical innovations into the educational process. Martin et al. (2024) emphasize the role of facilitators in ensuring inclusivity and equity, while Kazimova (2024) focuses on a systemic approach to learning, including theoretical, practical and technical training. The author emphasizes that long-term training programmes enable teachers to gradually build their professional competencies and adapt them to technological changes.

Pavlova (2023) emphasizes the importance of a practice-oriented approach through the integration of real-world tasks into the educational process, which contributes to the development of professional skills. In turn, Vlasii (2021) emphasizes the modernization of practical training through interactive technologies, such as simulators and virtual laboratories, without which the effectiveness of learning decreases.

Li et al. (2021) emphasize the use of computerized educational systems that personalize learning and improve the academic skills of technical students. However, as Cao & Dong (2020) note, the effectiveness of these systems depends on their integration into comprehensive programmes based on professional certification, which ensures compliance with modern labour market requirements.

Goode et al. (2020) emphasize the role of professional communities in the development of computer science teachers, although they do not take into account the level of their previous digital training. Ayanwale et al. (2024) analyse the teachers' readiness for digital transformation within the framework of the Education 4.0 concept, but do not detail the mechanisms for overcoming barriers to the introduction of technologies into traditional educational structures.

Shen et al. (2022) study multi-level learning of transformative language models, emphasizing its effectiveness for learning complex topics, but do not offer practical recommendations for its adaptation for teacher training. Akhsutova et al. (2024) support this idea, emphasizing the need to combine multi-level learning with a competency-based approach, although they do not take into account the difficulties of integrating it into curricula for teachers with extensive experience.

Forné et al. (2022) emphasize the interdisciplinary approach in implementing digital technologies in open educational platforms, but do not analyse the possible challenges of such an approach in different educational contexts.

Shi and He (2021) point out the need to integrate artificial intelligence (AI) into curricula, emphasizing that the modern labour market requires specialists who have not only basic knowledge, but also an understanding of complex algorithms and technologies, such as machine learning (ML) and big data

analysis. They prove that traditional teaching methods, which mostly focus on theoretical aspects, are insufficient for the formation of competencies necessary in modern computer science.

The study by Kulikov et al. (2022) emphasizes the importance of digitalization of educational processes in the post-war economy of Ukraine, which is consistent with the need for effective models of training teachers for the challenges of the digital environment. However, the work does not sufficiently consider practical mechanisms for introducing digital technologies into the pedagogical education system, which limits its application in the context of the development of the teachers' continuing education.

Alazzam et al. (2023) analyse digital platforms in the economy, but their conclusions are also relevant for the educational sphere, as they prove the importance of digital solutions for optimizing the educational process and implementing continuous education for teachers. However, the study does not take into account the specifics of pedagogical activity, which may affect the effectiveness of integrating digital tools into teaching.

Cherniavska et al. (2023) explore the AI use in educational management, which correlates with our analysis of the impact of AI tools on improving the competencies of computer science teachers and personalizing teaching. However, the authors focus more on administrative aspects, not paying enough attention to the pedagogical component, which is key in our study.

Bachiieva et al. (2024) emphasize the importance of integrating digital technologies into curricula and the development of pedagogical tasks, which confirms the need to adapt teacher training to modern technological conditions. However, the study lacks an analysis of the long-term impact of such approaches on teachers' professional development, which remains an important aspect for further research.

Materials and Methods

The study was conducted in three stages to assess the effectiveness of staged continuing education in building of professional competencies of computer science teachers, with an emphasis on technical training, educational technologies, and digital tools. This research applied a quasi-experimental design with pre-test and post-test measurements for both control (CG) and experimental (EG) groups.

At the first stage, a theoretical analysis of academic literature on the training of computer science teachers and the implementation of digital technologies was carried out.

The second stage included an empirical study with the participation of 180 teachers, divided into the CG and the EG depending on their teaching experience. The CG studied using traditional methods, while the EG underwent a staged training programme using digital technologies. The study was conducted over a period of six months, from March to August 2024, according to a structured training schedule. Each module lasted approximately three weeks and included practical activities, digital tool training, and reflection sessions.

The third stage was data analysis to assess the impact of the programme on the development of professional competencies. The collected data were processed using SPSS software. Statistical tests included paired sample t-tests for within-group comparisons and independent sample t-tests for between-group comparisons. In cases where parametric assumptions were not met, non-parametric Wilcoxon and Mann-Whitney U tests were applied. Statistical methods were used to assess the reliability of changes and compare the effectiveness of traditional and modern approaches.

Research methods

The following methods were used to achieve the aim:

1. Survey. A questionnaire was developed to collect data on the level of technical training, teachers' readiness to introduce digital technologies into the educational process, and to assess the effectiveness of the staged education programme. The questionnaire contained both closed and open questions, allowing the collection of both quantitative and qualitative data. It included five main dimensions: digital skills, pedagogical flexibility, platform usage, perceived challenges, and readiness for integration of technologies. Each dimension consisted of 3–5 items evaluated on a 5-point Likert scale.
2. Pedagogical experiment. It was implemented by comparing teaching results in the CGs and EGs. The CGs used traditional teaching methods, and the EGs used the staged continuing education programme. The study used a quasi-experimental design without random assignment, with pre- and post-intervention testing. The study lasted 6 months, after which a comparative analysis of the results was conducted.
3. Statistical analysis**.** The data obtained during the study were processed using SPSS. Descriptive statistics were used to calculate means and standard deviations. Inferential statistics included the paired samples t-test, Mann–Whitney U-test, and Wilcoxon signed-rank test to assess the reliability of changes in the level of professional competencies of the research participants.
4. Content analysis. It was used to analyse questionnaire responses, literature sources, and assess changes in teachers' professional activities after the programme was implemented.

Sample

The study involved 180 computer science teachers from different regions of Ukraine. The sample was formed taking into account teaching experience and divided into three categories:

1. Young teachers (1-3 years of experience) – 60 people

   - 30 people – CG
   - 30 people – EG
   - The inclusion of this group made it possible to assess the impact of the programme on the development of basic pedagogical and technical competencies.

2. Teachers with experience from 5 to 8 years – 60 people

   - 30 people – CG
   - 30 people – EG
   - In this group, the improvement of professional competencies and adaptation to new technologies were studied.

3. Experienced teachers (over 10 years of experience) – 60 people

   - 30 people – CG
   - 30 people – EG
   - The adaptation of experienced teachers to digital technologies was assessed.

The division into groups made it possible to assess the effectiveness of staged education in different categories of teachers and identify the features of the integration of digital technologies into the professional activities of teachers.

The staged training programme implemented for the experimental groups lasted 6 months and consisted of four consecutive modules: (1) digital literacy and cybersecurity, (2) basics of programming (Python, Scratch), (3) implementation of STEM approaches through project-based learning, and (4) application of artificial intelligence tools in education. Each module included interactive online sessions, individual

practical tasks, and group project activities aimed at gradually building both technical and pedagogical competencies.

Research tools

The following tools were used to implement the study: the staged continuous education programme, Google Forms for collecting responses from study participants, Microsoft Excel for data systematization, SPSS for statistical processing of the obtained data, as well as educational platforms: Moodle, Microsoft Teams, Blackboard — for testing digital methods of teacher training; Kahoot, Edmodo — for evaluating interactive approaches in teaching; Articulate 360, Desmos — for creating interactive educational materials (Table 1). The study was conducted over a six-month period with a clearly defined schedule of activities for each module, ensuring the consistency and gradual accumulation of professional competencies.

Table 1.
The programme for assessing the level of digital literacy and pedagogical competencies of computer science teachers

Assessment area	Verification methods	Assessment criteria	Task Format
Digital literacy	Online testing, practical assignments	Accuracy, speed, and completeness of tasks involving digital tools	Using word processors, spreadsheets, cloud tools, and cybersecurity practices
Programming	Practical tasks, code analysis	Correctness of code, logic of algorithms	Writing basic code in Python/Scratch
STEM approaches	Evaluation of developed projects	Integration of subjects, application of technologies	Developing an interdisciplinary lesson using STEM
AI use	Analysis of the use of AI tools	Practicability of use in education	Using ChatGPT, Dialogflow to create learning content
Pedagogical competencies	Expert evaluation, peer and self-assessment	Adaptability, clarity of instruction, integration of technology	Developing an interactive lesson with digital technologies

Source: developed by the authors based on their own research.

The use of these methods and tools ensured the comprehensiveness of the research and the reliability of the obtained results. Additionally, the questionnaire included specific items aligned with each assessed area, allowing for multidimensional data collection and triangulation.

Results

The results of the study confirmed that the staged continuing education significantly influenced the development of digital literacy of computer science teachers. The implementation of a special in-service training programme allowed the EG participants to improve their technical skills and confidence in using digital platforms.

Initial analysis showed differences in the level of digital competencies among the participants: young teachers (1–3 years of experience) had basic digital skills, but lacked experience in applying them in teaching; teachers with 5–8 years of experience were better at integrating technology, but had a medium level of mastery of modern digital platforms; teachers with more than 10 years of experience had the lowest initial training.

After six months of the experiment, the level of digital literacy in the CGs increased slightly (+5–7%), while in the EGs the increase was on average 35%, and among young teachers – 41%. The best results were demonstrated by teachers with 5–8 years of experience, who effectively applied new skills in the teaching process.

The use of interactive educational platforms contributed to the increase in technical competence. Google Classroom improved the organization of distance learning, Kahoot – quick knowledge testing, and Microsoft Teams and Blackboard helped teachers to master complex digital environments. Moreover, training in cybersecurity and cloud technologies increased teachers' awareness of personal data protection and the safe use of electronic resources. To assess the statistical significance of the observed differences between CG and EG, the independent samples t-test and the Mann–Whitney U test were used, depending on the distribution of the variables. The differences were considered statistically significant at the level of $p < 0.05$.

Figure 1 presents the average value of the level of teachers' digital literacy in the CGs and EGs before and after the programme implementation.

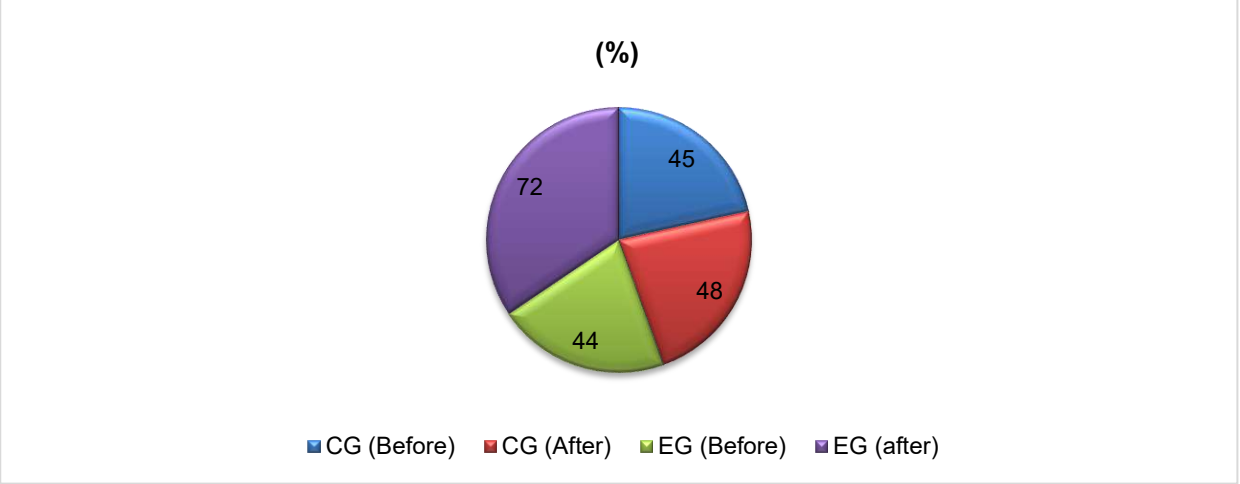

Figure 1. Comparison of the level of teachers' digital literacy in the CGs and EGs before and after the programme implementation.
Source: developed by the authors based on their own research.

The analysis of the research results revealed significant differences in the adaptive capacity between young (up to 3 years of experience) and experienced teachers (5–8 years and over 10 years of experience). Young teachers quickly mastered digital technologies, working effectively with the Microsoft Teams, Blackboard and Articulate 360 platforms. They demonstrated the fastest mastery of new tools, which allowed them to actively create interactive educational materials.

In contrast, experienced teachers (5–8 years of experience) and teachers with over 10 years of experience demonstrated higher efficiency in using digital technologies to improve teaching methods. They adapted curricula by integrating AI, VR/AR, and adaptive educational resources. Thanks to a deeper understanding of students' educational needs, they created more structured educational materials, improving the quality of the educational process through digital technologies.

Table 2 presents a comparison of the speed of adaptation to digital tools among different groups of teachers.

Table 2.
Comparison of the speed of adaptation to digital tools in different groups of teachers

Teacher group	Average adaptation time (weeks)	Usage comfort level (%)	Integration of technology into the learning process (%)
Young teachers (up to 3 years)	2	85	60
Experienced teachers (5-8 years)	4	78	85
Senior teachers (10+ years)	6	65	90

Source: developed by the authors based on their own research.

The analysis of the use of digital platforms showed that the EG teachers were more successful in integrating technology into the learning process compared to the CGs. Moodle was most effective for teachers with more than 10 years of experience, as it helped to systematize the teaching material. Young teachers preferred Google Classroom because of its integration with other digital tools. Using Kahoot helped to enhance motivation, especially among teachers with 5–8 years of experience.

Among the additional platforms, Microsoft Teams was the most convenient for interactive interaction, Blackboard was used for developing complex training courses, and Edmodo was used for communication and sharing materials. Overall, participants in the experimental groups who actively used these platforms significantly improved their level of digital competence, while the CGs demonstrated a lower level of technology integration into the learning process. The statistical significance of differences between teacher groups regarding adaptation speed and technology integration was confirmed using one-way ANOVA and the Kruskal–Wallis H test. Significant differences were observed at $p < 0.05$.

Table 3 contains data on the effectiveness of various digital platforms in training computer science teachers.

Table 3.
Evaluation of the effectiveness of various digital platforms in training computer science teachers

Digital platform	Description	Ease of use (1-5)	Teaching effectiveness (1-5)	Popularity among teachers (%)	Increase in digital competence (%)
Moodle	A platform for managing distance learning that enables creating online courses, assignments, and tests.	4,2	4,3	75	22
Google Classroom	A tool for organizing the learning process that simplifies communication between teachers and students, enabling to create assignments and tests.	4,5	4,6	80	25
Kahoot	An interactive platform for creating quizzes that increases student engagement in the learning process through gamification.	4,7	4,8	85	27
Microsoft Teams	A platform for organizing video conferences, group discussions, and collaborative work with educational materials.	4	4,1	60	18
Blackboard	A learning management system with advanced capabilities for creating interactive content, assessing and tracking student progress.	3,8	4	50	15
Edmodo	An educational social network that enables teachers to interact with students, provide materials and evaluate work.	3,9	4,2	55	17

Source: developed by the authors based on their own research.

The results of the study showed the high effectiveness of STEM approaches and adaptive programmes in developing methodological competencies of computer science teachers. The highest indicators were demonstrated by teachers with 5–8 years of experience, with the level of mastery of interdisciplinary projects increased by 34% compared to the CGs. Young teachers quickly mastered the basics of STEM methodologies, but the level of their integration of these approaches into the educational process remained lower (+27%) because of the lack of practical experience.

Teachers with more than 10 years of experience adapted to STEM methods more slowly because of the lack of previous experience working with similar technologies. In the CGs, the level of mastery of STEM methodologies increased by only 8–12%, which indicates the insufficient effectiveness of traditional methods of advanced training. The main barriers for the CGs were limited access to adaptive learning resources and lack of practice in using interdisciplinary tools, which emphasizes the importance of a comprehensive approach to training computer science teachers. To assess the statistical significance of differences between the CG and EG, the Kruskal–Wallis test and the Mann–Whitney U test were used, depending on the variable type and distribution. The improvements observed in the EG were statistically significant at $p < 0.05$.

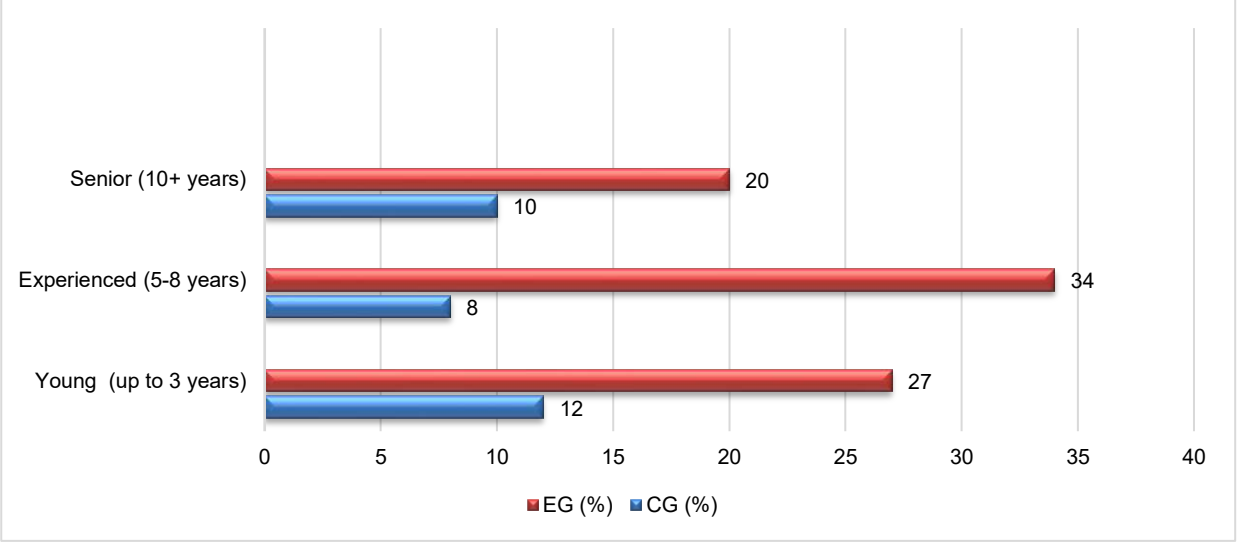

Figure 2. Percentage of mastery of STEM methods in the CGs and EGs before and after the programme implementation.
Source: developed by the authors based on their own research.

The results of studying the effectiveness of the modular programme of staged continuing education showed that teachers achieved the highest level of success in the module Digital Literacy Fundamentals, where the average increase in competencies was 42% among the EGs. This confirms the importance of developing basic technical skills to increase the effectiveness of the educational process. The module Programming for Teachers showed the greatest difference between young specialists and teachers with more experience: in the group of 1–3 years, the level of mastery increased by 38%, while in the group of over 10 years — only by 19%, which indicates the difficulty of mastering programming languages without prior experience.

The greatest difficulties were caused by the introduction of AI into the educational process - success rates among the EGs increased by an average of 25%, however, a significant part of teachers with experience over 10 years needed additional time to adapt to these technologies. STEM approaches showed moderate growth across all categories, especially among teachers with 5–8 years of experience (+34%), confirming the effectiveness of integrating interdisciplinary methods into the educational process.

The CGs did not demonstrate significant changes in any of the modules, confirming the need for systematic teachers' professional development through staged continuing education. Statistical comparison of CG and EG results was performed using the independent samples t-test for normally distributed data and the Mann–Whitney U test for non-normal data. Statistically significant differences ($p < 0.05$) were observed across all modules, supporting the effectiveness of the programme.

Table 4 presents comparative results of teacher performance across different modules of the staged continuing education programme.

Table 4.
Learning outcomes across modules of the staged continuing education programme

Programme module	Competency gains in young teachers (1-3 years), EG (%)	Competency gains in experienced teachers (5-8 years), EG (%)	Competency gains in experienced teachers (10+ years), EG (%)	Competency gains in control groups (CG, %)
Digital Literacy Fundamentals	42	40	35	5
Programming for Teachers	38	30	19	4
STEM Approach to Learning	27	34	22	8
AI use	22	25	18	6

Source: developed by the authors based on their own research

The results of the study showed a significant improvement in the pedagogical competencies of the EG teachers. The greatest increase was recorded in methodological competence, which was manifested in the active use of adaptive methods and interactive tools. Professional competence increased due to the more effective use of practical examples, and communicative competence — due to improved interaction with students. Innovative activity was significantly activated due to the introduction of digital technologies and the creation of interactive materials. The use of ICT increased, which had a positive effect on the organization of distance learning. Reflective competence improved due to the greater teachers' interest in professional development and self-improvement.

The statistical significance of the observed changes was confirmed using Student's t-test ($p < 0.05$) for normally distributed data and the Mann–Whitney U test for non-parametric comparisons between groups. These tests validated that the gains observed in the experimental groups across all modules were not due to chance and demonstrated the effectiveness of the staged programme.

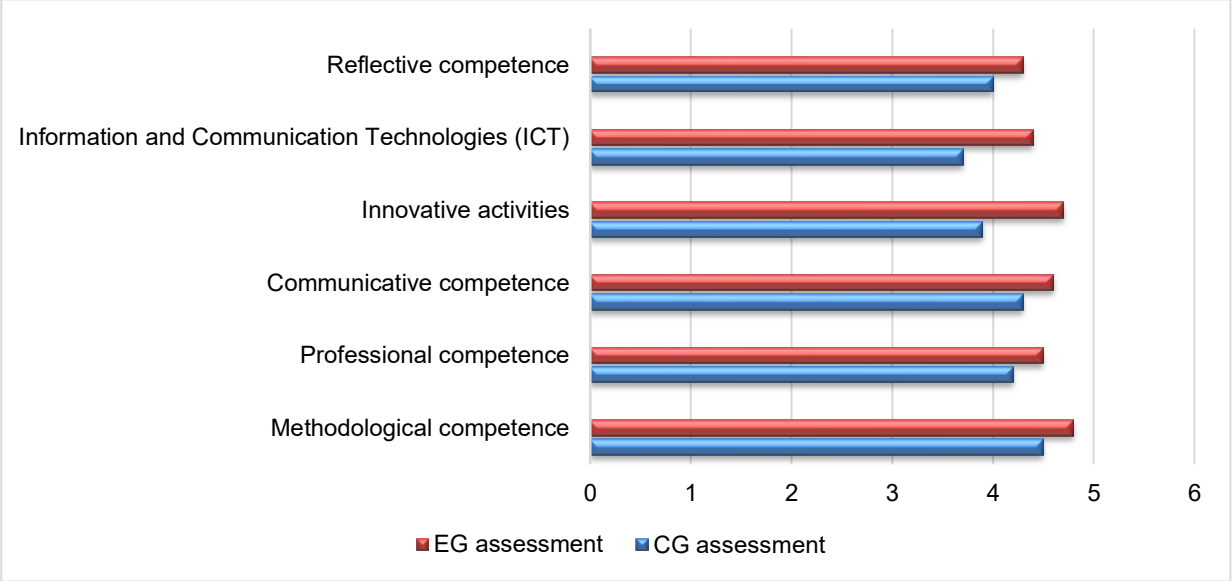

Figure 3. Assessment of pedagogical competencies of teachers of the CGs and EGs after the experiment
Source: developed by the authors based on their own research.

The results of the study showed a significant increase in the level of teachers' readiness to implement modern digital technologies after completing the staged continuing education. The highest indicators were demonstrated by teachers with 5–8 years of experience, among whom 81% of the EG participants noted an increase in confidence in using digital tools. Young specialists (1–3 years of experience) quickly adapted to new platforms, however, 27% of respondents noted that they lacked practical experience to effectively apply technologies in the educational process.

In the group of teachers with more than 10 years of experience, the level of adoption of digital technologies also increased, although the adaptation was slower. A total of 62% of the EG participants expressed full readiness to use digital tools, while this figure was only 41% in the CG. In general, among the CGs of all categories, the level of technology implementation increased by only 10%, which indicates the low effectiveness of traditional methods of professional development.

Among the EG participants, the overall level of readiness for the implementation of digital technologies increased by 30–40% depending on work experience, which confirms the effectiveness of the staged education system in preparing teachers for digital transformation. To validate these changes, the Chi-square test for independence was applied to assess differences in categorical readiness levels between groups. All reported improvements were statistically significant ($p < 0.05$), supporting the reliability of the observed effect.

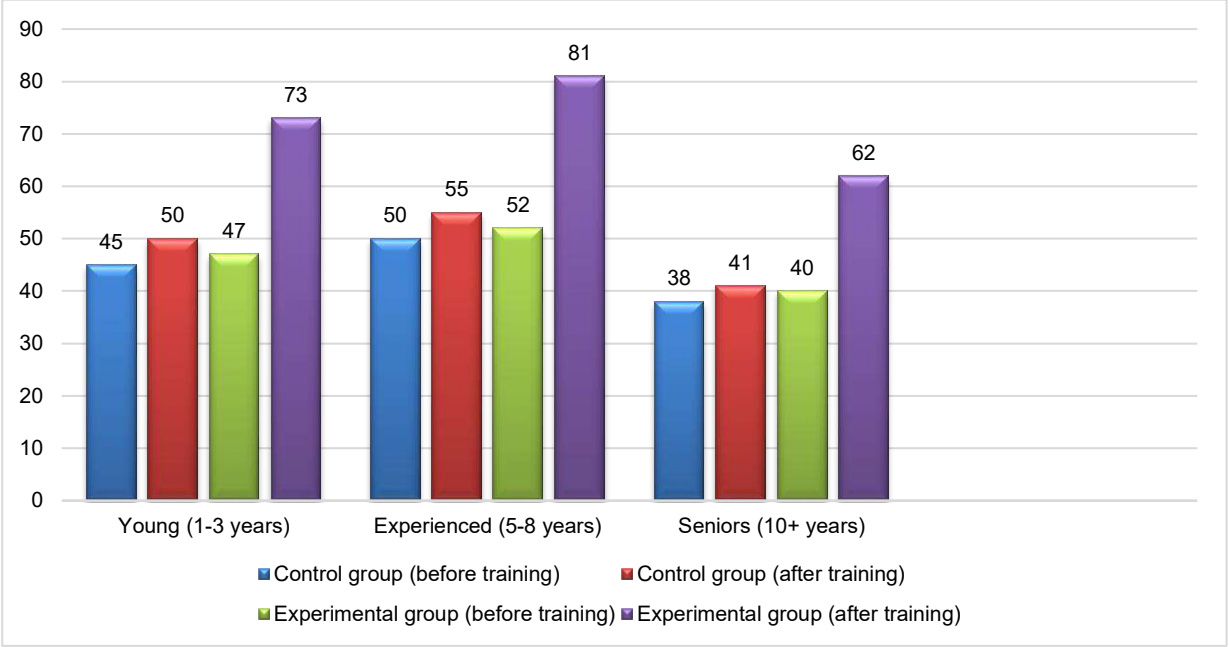

Figure 4. Level of teachers' readiness to implement digital technologies in the educational process (before and after training)
Source: developed by the authors based on their own research.

The results of the study confirmed significant differences between the CGs and EGs in key indicators of professional training of computer science teachers. The greatest increase in competencies was observed in the EGs in digital literacy (+38%), integration of STEM methods (+34%), and the use of adaptive programmes (+29%). Young specialists (1–3 years) showed rapid mastery of digital platforms, but were inferior to teachers with 5–8 years of experience in the practical application of technologies in teaching.

Experienced teachers (5–8 years of experience) achieved the highest results in the application of interactive methods and the AI use to personalize the educational process (+36%). At the same time, the group with more than 10 years of experience demonstrated slower mastery of new technologies, although the level of confidence in digital skills increased by 27% among the EG. Statistical analysis was conducted using the Student's t-test and Mann-Whitney U test to compare means between CGs and EGs. The observed differences were statistically significant at the level of $p < 0.05$.

Table 5 presents a comparative analysis of the CG and EGs by key parameters.

Table 5.
Comparison of the CG and EGs for all key parameters

Parameters	CG, %	EG, %	Growth in EG, %
Digital literacy	10	38	28
Integration of STEM approaches	12	34	22
Use of adaptive programmes	9	29	20
Practical use of technology	11	36	25
AI use	8	27	19
Level of confidence in digital skills	10	30	20

Source: developed by the authors based on their own research

In the CGs, the indicators remained almost unchanged or increased insignificantly (no more than 10–12%), which indicates the insufficient effectiveness of the traditional approach to advanced training without the use of staged continuing education. In general, the EG outperformed the CG in all key aspects, proving the effectiveness of the proposed methodology. All improvements observed in the EGs were statistically significant at the level of $p < 0.05$ according to the Student's t-test and the Mann–Whitney U test, depending on data distribution.

Discussion

The results of the study confirmed the effectiveness of the staged system of continuing education in the training of computer science teachers, especially regarding the implementation of digital platforms and adaptive educational programmes.

Liang (2022) analyses the concept of Outcome-Based Education (OBE) in the training of specialists in electronic information science, emphasizing the importance of adaptive educational programs and big data analysis. This is consistent with the results demonstrating the effectiveness of adaptive methods in the formation of pedagogical competencies. However, unlike Liang (2022) who considers the training of technical specialists, this study focuses on the teachers' adaptation to digital tools, which adds a pedagogical aspect to the overall concept of learning.

The study by Yuan et al. (2020) confirms the effectiveness of adaptive curricula in training computer science specialists. Similarly, the obtained results demonstrate the positive impact of adaptive learning on the professional training of computer science teachers. However, the main focus in the study by Yuan et al. (2020) is on technical skills only, while our research combines technical and pedagogical components, making the approach more comprehensive.

Castro & Oliveira (2022) emphasize the importance of the Kahoot and Google Classroom platforms for increasing student engagement in the learning process. The obtained data confirm that these platforms also contribute to the development of teachers' pedagogical competencies. However, unlike the study by Castro & Oliveira (2022) which focuses on programming education, this work considers a wider range of pedagogical skills.

Sherman et al. (2021) emphasize the importance of information systems in the digital educational environment, focusing on the need to integrate digital tools into professional training. The obtained results confirm the importance of this approach, but the difference with our study is that adaptive learning is additionally implemented, which ensures individualization and a more effective combination of technical and pedagogical competencies.

Yang et al. (2022) explore aspects of teacher professional development in the digital environment: the former focus on the connection between education and industry through professional certification, and the latter on the teachers' readiness to implement digital technologies in the educational process. Both approaches are partially consistent with the use of Moodle and Google Classroom platforms in professional development, but their focus on the labour market or general qualification requirements leaves out the specifics of pedagogical training, which is key in this work.

Maxkamova (2024) complements these results with an analysis of the adaptation of computer-based curricula to modern requirements, emphasizing their role in improving the educational process. However, her research mainly focuses on the technical aspects of digital tools, while this work focuses on the integration of pedagogical competencies with technological skills, which makes the proposed model more comprehensive.

Pahl (2020) and Kilbury et al. (2023) explore methods for improving pedagogical skills through active learning: the former analyses the "learning by teaching" approach, while the latter focuses on the use of

educational videos to develop teachers' practical skills. Both approaches have something in common with the findings on the integration of interactive platforms such as Kahoot and Google Classroom, however, Pahl (2020) emphasizes student interaction, without taking into account the adaptation of curricula, while Kilbury et al. (2023) only consider the narrow aspect of classroom management, while the use of digital platforms provides a comprehensive improvement of pedagogical competencies.

Serik et al. (2023) analyse a neural network-based proctoring system that demonstrates the effectiveness of technical control. However, their approach differs significantly from adaptive curricula, as it focuses on ensuring academic integrity, rather than on the development of pedagogical competencies and personalization of the educational process.

Gajdzik and Wolniak (2023) investigate the role of creativity and innovative thinking in professional training in the context of smart manufacturing, confirming the importance of developing open innovation skills in today's digital transformation. However, their research focuses mainly on aspects of employee adaptation to automated technologies, without paying attention to specific methods of training computer science teachers through the system of continuing education.

In contrast, Abar et al. (2021) analyse the implementation of computational thinking in primary education in the AI age, focusing on the teacher's role in building of digital competencies. The authors emphasize the need to update teaching approaches taking into account modern technological challenges, which is relevant in the context of studying the professional training of computer science teachers. However, although their work covers the issue of integrating AI into the educational process, it does not reveal the issue of continuous education and the formation of pedagogical skills through a system of staged training.

Sârb (2023) supports the concept of continuous improvement of teachers' knowledge, but his research focuses on artistic disciplines. In contrast, the staged education system considered in this work combines technical and pedagogical training, which allows for a more effective integration of digital technologies into the educational process.

Shan et al. (2020) and Zhou (2021) confirm the effectiveness of the phased approach in education, demonstrating its benefits in the field of health care and adapting curricula to digital realities. Although their research has different areas of application, the structured learning model remains universal for the development of both technical and methodological competencies of teachers.

Yuan et al. (2020) explore the integration of theoretical and practical skills in the training of computer science specialists, which has something in common with the concept of STEM methods and the use of digital technologies. However, their approach is focused mainly on technical training, while the focus of the considered model is also on the development of pedagogical competencies, which is critically important for computer science teachers.

The analysis of the mentioned studies demonstrates that the staged system of continuing education, taking into account digital platforms such as Moodle and Kahoot, provides the necessary integration of technical and pedagogical approaches. This increases the effectiveness of training computer science teachers to teach in a modern educational environment.

Limitations

The study is limited by the difference in the levels of technical support of schools, which influenced the implementation of the staged system of continuing education, and the insufficient adaptation of digital platforms to the specifics of pedagogical activity. Besides, the short period of the study (2 months) does not allow to fully assess the long-term impact of the programme on the teachers' professional development.

Recommendations

It is recommended to expand access to modern digital platforms and technical equipment in all educational institutions, as well as to introduce advanced training programmes for teachers focused on the integration of digital technologies into the educational process. Further studies should cover a wider sample of schools and a longer period to assess the long-term impact of the staged education system.

Conclusions

The results of the study confirmed the effectiveness of the phased system of continuous education for the training of computer science teachers, based on the integration of modern digital technologies. The use of educational platforms, in particular, Moodle, Kahoot, Google Classroom, Microsoft Teams, Blackboard and Edmodo, contributed to the improvement of the teachers' technical literacy and pedagogical competencies. The productivity of the EG participants increased by 22% compared to the CG, which emphasizes the significant potential of adaptive programmes and interactive tools in the development of professional skills.

The survey of teachers revealed a high readiness to use digital technologies, while confirming the need to improve their qualifications for the effective implementation of interactive teaching. Adaptive programmes provided a personalized approach, which enhanced the motivation and academic confidence of the participants.

The academic novelty of the research lies in the implementation of an integrated approach that combines technical and pedagogical aspects of teacher training, with an emphasis on interactivity, gamification and personalization of learning.

The practical value of the research is the possibility of applying the obtained results to improve educational programmes, implement modern digital platforms and develop recommendations for improving the teachers' qualifications. This creates a basis for training teachers who meet the requirements of a modern digital society.

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