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Innovative approaches to the formation of mathematical competence of future primary school teachers

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Abstract. The purpose of the study was to investigate the impact of interactive methods, digital technologies and an interdisciplinary approach on the formation of students' mathematical competence and the effectiveness of knowledge acquisition. The methodology included comparative analysis, pedagogical experiment, analysis of strengths and weaknesses, opportunities and threats, and identification of innovative approaches to the formation of mathematical competence of higher education students in the Primary Education programme. The results of the study showed that keeping progress diaries promotes self-reflection of students, improves their ability to plan the learning process and increases motivation. Students' self-assessment confirmed the growth of confidence in their knowledge and skills, as well as the development of independence. Improvements were found in planning their own learning and setting realistic goals using new approaches. This indicated an increase in their learning motivation and active participation in the educational process. Innovative teaching methods, such as problem-based learning, modelling, interactive technologies and gamification, have improved the understanding of mathematical concepts. Comparative analysis showed a higher level of success in the experimental group – the average score of test tasks increased by 23%. The diaries helped students to understand their own learning progress, which increased their motivation and engagement. The use of digital tools, such as GeoGebra and Desmos, improved the visualisation of mathematical processes. The main challenges were adaptation to new learning formats and the need for teacher training. The findings can be used to improve methodological approaches to teaching mathematics in higher education and to develop recommendations for the introduction of innovative technologies in the educational process

Keywords: educational process; gamification; critical thinking; latest methods; individual needs

INTRODUCTION

Developing students' mathematical competence requires the implementation of effective teaching approaches that consider their individual needs and future professional activities. The use of adaptive online platforms, integration of project work and modelling of real-life situations contribute to the understanding of mathematical concepts and the development of analytical thinking. In addition, the combination of mathematical disciplines with other fields of knowledge helps students to see the practical value of the skills they have acquired.

The relevance of the study is due to the reform of educational standards, which involve the development of not only subject knowledge but also the ability to apply mathematical models in practical situations. In particular, European and international educational trends emphasise the importance of developing critical thinking, mathematical literacy and an interdisciplinary approach to learning. The emphasis on interactive methods, such as team tasks, case discussions and digital simulations, increases motivation to learn and develops the ability to solve complex

problems. Such approaches contribute not only to the successful learning of the material, but also to preparing students for future professional challenges, where mathematical competence plays an important role (Hetmanenko, 2024).

The issue of forming and developing the mathematical competence of students and teachers with the help of new technologies has been studied by a number of researchers, in particular, J. Piñero Charlo *et al.* (2022) found that the process of algorithmisation significantly influenced the formation of mathematical competence of students who studied Algoritmos Basados en Números and Counting-Based Calculation using game technologies. The study showed that students who were taught using the Algoritmos Basados en Números methodology showed better results in arithmetic operations and understanding of numerical relationships compared to students who used the traditional Counting-Based Calculation approach. The study by P. Frejd & P. Vos (2022) analysed innovations in the assessment and development of mathematical modelling. They found that new approaches can help improve competences in mathematical modelling. The main findings relate to teaching methods, assessment, and the importance of understanding context when teaching modelling. T. Zaporozhchenko *et al.* (2022) examined ways to improve the mathematical competence of future primary school teachers in Ukraine. They concluded that the use of innovative methods, in particular the integration of STEM education and problem-based learning, contributes to improving the level of students' training. In addition, they emphasised the need to expand the practical component in the educational process, which allows future teachers to better understand how to effectively teach mathematics to younger students. O. Onoprienko & S. Skvortsova (2024) analysed the educational programme "Methodology of Forming Mathematical Competence of Primary School Students", considering it as a resource for teachers' professional development. They found that the programme helps to improve teachers' methodological skills, allowing them to more effectively develop students' mathematical competence. The authors noted that the introduction of the programme into the teacher training system has a positive impact on teachers' readiness to use active methods of teaching mathematics.

A. Kolomiiets *et al.* (2023) focused on improving the cognitive component of mathematical competence of students of technical specialities. They concluded that the use of practice-oriented methods and digital technologies significantly improves the quality of mathematical training. The authors emphasised the success of integrating problem-based learning and modelling of real technical processes into the curriculum, which contributes to improving students' mathematical literacy. M. Kandemir & N. Eryilmaz (2025) found that mathematical modelling with the help of digital tools not only improves the quality of learning but also stimulates students' interest. The authors proved that the integration of technology into the educational process contributes to the development of analytical thinking and the ability of students to apply the acquired knowledge in practical tasks. Y. Wulandari *et al.* (2024) found that future mathematics teachers demonstrated different levels of mathematical literacy in graph theory, with the most difficult tasks requiring abstract thinking and applying concepts in new contexts. The authors highlighted that it is necessary to strengthen teaching methods focused on the development of logical analysis and solving non-standard problems. L. Zhang *et al.* (2025) conducted a systematic review of interventions in mathematics education aimed at supporting and assessing the process of formulating mathematical problems. They found that the most effective approaches were those that combined guided learning with independent research, as they promoted the development of students' creative thinking and mathematical skills.

The main aspects of students' mathematical training in the context of their professional self-realisation were studied by M. Astafieva *et al.* (2020). They found that combining traditional methods with modern digital resources significantly improves the learning process. The authors emphasised the need to expand the use of interactive technologies in teaching to develop critical thinking and adapt students to real professional challenges. M. Munaji *et al.* (2025) analysed flexibility in teaching mathematics in interactive classrooms and found that the effectiveness of this approach depended largely on the role of teachers in creating a dynamic learning environment. They found that flexibility facilitated the adaptation of teaching methods to individual student needs, which improved understanding of mathematical concepts. B. Williner (2024) investigated the impact of tasks using GeoGebra software on the development of mathematical competence. The author found that the use of this resource allows students to better understand mathematical relationships, improves their motivation to learn, and contributes to more effective mathematical problem-solving. Despite a considerable amount of research, the influence of individual cognitive styles of students on the effectiveness of using information technology in mathematics teaching remains insufficiently studied.

The aim of the study was to investigate different methods that influence the formation of mathematical competence in future primary school teachers through the introduction of interactive approaches, digital technologies and interdisciplinary learning. Objectives of the study were:

- to analyse innovative methods of forming mathematical competence in higher education students majoring in Primary Education;
- to compare the effectiveness of the methods used in the formation of mathematical competence of the study participants;
- to identify factors that facilitate or hinder the effective application of innovative approaches in the educational process.

MATERIALS AND METHODS

The pedagogical experiment, which was conducted at Pavlo Tychyna Uman State Pedagogical University, involved 50 students majoring in Primary Education, who were

divided into two groups: control (25 students) and experimental (25 students). The control group consisted of 5 boys and 20 girls, and the experimental group consisted of 5 boys and 20 girls. The age of the participants ranged from 18 to 22 years. The experiment lasted from September 2023 to May 2024. Students were selected to participate in the experiment based on their level of mathematical competence and digital skills. The level of mathematical knowledge was assessed through pre-testing, which allowed to identify students with the appropriate level of training for each group. Students were randomly assigned to the control and experimental groups. All ethical standards were met during the study. Students voluntarily participated in the study and received full information about its objectives, methods and possible consequences. Data confidentiality was ensured, and none of the participants' personal information was disclosed without their permission. The study also received ethical approval from the Pavlo Tychyna Uman State Pedagogical University's Ethics Committee, which confirmed that all procedures met ethical requirements and standards for scientific research.

The group of teachers who assessed the students' results consisted of 2 women. All teachers had higher qualifications and more than 5 years of experience in teaching mathematics, with PhD degrees. They participated in the assessment of students' results and actively adjusted teaching approaches. Standardised test tasks developed on the basis of the curriculum were used to determine the initial level of students before the experiment. Written tests with open and closed questions, as well as matching and short answer tasks were used to measure the level of knowledge (for example, the geometry task included calculating the area of a triangle with sides of 6 cm, 8 cm and 10 cm, where the correct answer was 24 cm^2; in the section "Elements of Mathematical Logic", students had to determine the number of ways to arrange 5 different books on a shelf. The correct answer was 120. After group assignment and pre-testing, teaching was carried out according to innovative approaches for the experimental group and traditional methods for the control group. The assessment of mathematical tasks was carried out by the number of correct answers to test tasks, as well as by the level of participation and involvement of students in the learning process. The specific criteria were as follows:

- 5 points – the student successfully completed the task with a high level of accuracy and confidence, actively participated in the class, and demonstrated a positive attitude towards the methods used;
- 3 points – the student performed the task with some mistakes, the level of his/her involvement in the learning process was average, motivation, and performance varied;
- 1 point – the student had significant difficulties in solving problems, showed a low level of participation and motivation, and failed to complete assignments.

Forms of work included lectures, seminars, practical classes, group projects, and independent work in mathematics in accordance with the educational and professional programme "Primary Education". The control group was taught using traditional methods, with an emphasis on explaining the material by the teacher, while the experimental group was introduced to digital technologies, problem-based learning, and an interdisciplinary approach. Problem-based learning for students in the experimental group included working on open-ended mathematical problems. Using the project method, these students conducted research based on real statistical data, creating analytical reports and presentations. Interactive digital technologies included GeoGebra, Desmos, and Moodle for process visualisation and self-testing. Modelling and simulations helped analyse economic and physical processes, while gamification in the form of mathematical quests and quizzes enhanced learning. The data obtained allowed to evaluate the effectiveness of the methods and compare the results of the experimental and control groups.

The students kept diaries, recording: self-assessment of performance (level of understanding of the material, complexity of tasks, individual progress), comparison of the results of exercises (analysis of changes at each stage of learning) and feedback from teachers (recommendations, correction of errors, comments). Content analysis was used to analyse the diaries, i.e., the students' entries were coded into main categories (e.g., "improved understanding", "difficulties", "need for additional explanations") and then evaluated qualitatively and quantitatively.

After the experiment, students' performance was assessed by means of repeated tests, quizzes, analysis of practical problem-solving and oral responses. Teachers compared the average score in the two groups, analysed the quality of problem-solving, the level of independence and the ability to apply mathematical knowledge in practical situations. To compare the results of the experimental and control groups, the student's t-test for independent samples was used, as the data under study had a normal distribution. The statistical error was considered significant at the level of $p < 0.05$, which allowed to assess the reliability of changes in the level of students' mathematical competence.

For the analysis, several innovative methods of forming the mathematical competence of future primary school teachers were selected: problem-based learning, project-based learning, digital technologies, modelling, and gamification. The ratings were provided by teachers on a 5-point scale, where: 5 – very high level, 4 – high, 3 – medium, 2 – low, 1 – very low. The methods were evaluated according to the following criteria: analytical thinking (test results with comparison of alternative solutions, where 5 is all completed tasks), applicability in real life (success in completing practical tasks that simulated real problems, where 5 is all solved problems), efficiency (5 is providing logical justifications for all tasks), motivation (5 – providing detailed answers in class, attending all classes), independence (5 – all tasks completed without the help of a teacher), interactivity (5 – high level of engagement through digital tools, group projects, simulations). The comparative analysis allowed to identify the most effective methods for

developing mathematical competence in future primary school teachers, taking into account these criteria. A SWOT analysis of the innovative forms of work of the experimental group was conducted, which allowed to assess the factors that contributed to better student results and effective formation of mathematical competence.

RESULTS

Before the experiment began, an initial test was conducted to assess the participants' level of competence in key mathematical knowledge. Analysis of the data helped to establish the baseline and identify potential areas for improvement (Table 1).

Table 1. Pre-experimental testing results for both groups

Categories	Points	Before the experiment begins	
		Control group	Experimental group
Algebra	1	33%	28%
	3	47%	47%
	5	20%	25%
Functions and graphs	1	40%	34%
	3	43%	44%
	5	17%	22%
Geometry	1	27%	22%
	3	50%	50%
	5	23%	28%
Logical thinking and combinatorics	1	23%	19%
	3	53%	53%
	5	24%	28%
Applied problems	1	30%	25%
	3	50%	50%
	5	20%	25%

Note: percentages are the number of students in the corresponding category
Source: compiled by the author

The forms of work during the experiment included lectures, seminars, practical classes, group projects, and independent work. The control group used traditional approaches that focused on explaining the material by the teacher, taking notes, and reproducing tasks. The main emphasis was placed on the mechanical learning of algorithms and solving standard problems according to a model, which helped to develop skills but did not always stimulate a deeper understanding of mathematical concepts.

The implementation of teaching methods in the experimental group was based on modern pedagogical approaches aimed at improving students' mathematical competence. The main criteria for choosing methods were their effectiveness in developing analytical thinking, practical orientation and motivation to learn. One of the key approaches was the integration of digital technologies into the learning process. The use of mathematical simulators allowed students to visualise functions, geometric structures and analyse graphical dependencies, which increased their understanding of mathematical concepts (Sirakov, 2022; Kulimova, 2024). The use of interactive tests in Google Forms provided prompt feedback, which facilitated the correction of knowledge and independent work. The use of the Moodle online platform allowed for distance learning by providing access to learning materials, tests, and discussions. In addition, the introduction of an interdisciplinary approach allowed for the integration of mathematical knowledge with other disciplines, such as physics, economics, and computer science. For instance, when studying the topic "Linear Equations", students modelled financial processes, analysed economic indicators and predicted changes in exchange rates, which demonstrated the practical importance of mathematical methods in professional activities.

The project-based learning method also played an important role in developing mathematical competence. Students worked in groups to develop their own mini-research, create presentations and demonstrate the application of mathematical principles. For example, as part of the Functions and Graphs topic, students analysed statistical data on demographic changes in different countries, identified trends and made predictions based on the results. This contributed to the development of teamwork skills, analytical thinking and effective communication. To increase student motivation, gamification elements were introduced into the learning process. The use of mathematical quests, contests, interactive quizzes and competitions made learning more interesting and dynamic (Neugebauer *et al.*, 2023). For example, students competed in the speed of solving problems, participated in mathematical marathons and collective logic games, which stimulated interest in the subject and contributed to better learning.

The analysis of the students' progress diaries of both groups allowed to assess not only the level of learning, but also motivation, independence in learning, reflective skills and the effectiveness of the methods used. In the control group, where traditional teaching methods (lectures, standardised exercises, testing) were used, students generally demonstrated passivity in the learning process.

It was recorded that 68% of students reported difficulties in memorising problem-solving algorithms without a deep understanding of their application, and only 32% noticed improvements in solving mathematical problems during the course. In addition, 47% of students reported problems with applying the formulas they had learnt in new or unusual situations. In terms of motivation, 55% of students perceived the learning process as monotonous, and 61% completed assignments mainly to get a grade rather than to learn the material. Only 28% enjoyed solving mathematical problems. An analysis of students' reflections showed that only 25% tried to analyse their own mistakes, while 40% noted the need to repeat the material multiple times because of its rapid forgetting. Teachers noted that the control group's diary entries were mostly descriptive, without an in-depth analysis of their own achievements or difficulties. At the same time, students in the experimental group, who studied using problem-based learning, the project method, interactive digital technologies, modelling, and gamification, demonstrated much more active engagement in the learning process. For example, 84% of students said that the use of new methods helped them better understand mathematical concepts and make it easier to apply knowledge in practical situations, and 79% reported a significant improvement in their ability to analyse complex mathematical problems and look for alternative solutions. Overall, 88% of students reported significant progress in their understanding and application of mathematical concepts over the course of the course. In terms of motivation, 82% of students said that the new methods made learning more interesting and interactive, and 76% reported an increase in intrinsic motivation due to the ability to find solutions on their own through simulations and digital platforms. In addition, 91% of students enjoyed group discussions and explaining the material to their classmates, which improved their understanding of the topic. In the area of reflection, 91% of students actively analysed their progress, comparing the results at the beginning and end of each stage of learning, and 76% described their own mistakes in detail, formulating strategies to avoid them in the future. Teachers noted that students in the experimental group showed a deeper analysis of their own achievements and difficulties, and used self-reflection and critical thinking more often.

A comparative analysis of the results of the control and experimental groups revealed significant differences. While the control group mostly perceived learning as an obligation, the experimental group showed a much higher interest in the subject (82% vs. 55%). Only 25% of students in the control group analysed their own mistakes, while in the experimental group this figure reached 76%. Students in the experimental group also showed a higher level of independence in learning, actively using digital tools, simulations, and group methods to find solutions on their own. The data obtained confirmed the effectiveness of innovative teaching methods, especially in terms of developing analytical thinking, reflection and independent work of students. The results of the repeated testing indicate that the use of such pedagogical technologies has significantly increased the effectiveness of learning and contributed to the formation of a deeper understanding of mathematical concepts (Table 2)

Table 2. Post-experimental testing results for both groups

Categories	Points	At the end of the experiment	
		Control group	Experimental group
Algebra	1	20%	6%
	3	50%	31%
	5	30%	63%
Functions and graphs	1	27%	3%
	3	50%	28%
	5	23%	69%
Geometry	1	20%	9%
	3	53%	31%
	5	27%	60%
Logical thinking and combinatorics	1	17%	6%
	3	57%	34%
	5	26%	60%
Applied problems	1	23%	6%
	3	53%	31%
	5	24%	63%

Note: percentages are the number of students in the corresponding category
Source: compiled by the author

A comparative analysis of the results before and after the experiment showed that the traditional teaching methods used in the control group, although they contributed to a certain improvement in students' knowledge, this progress was not as pronounced as in the case of interactive teaching methods. In the control group, the improvement in mathematical knowledge was moderate. The analysis of the results showed that the number of students with a low level of mathematical knowledge decreased by 7-13%, depending on the category of tasks. At

the same time, the proportion of students who achieved a high level of proficiency increased by an average of only 5-10%. These results indicate that traditional teaching methods, while having some positive impact, are not always able to provide a deep understanding of the material, especially when it comes to complex mathematical topics. The smallest improvements were recorded in the categories of Functions and Graphs and Applied Problems. This may be due to the fact that in order to master these topics effectively, students need not only to memorise theoretical material, but also to develop skills in its practical application, which requires the use of more interactive teaching methods. In contrast, the experimental group showed a significant increase in the level of mathematical competence. The test results show that the number of students with high results increased by 35-45% in all assessment categories. This was a strong proof of the effectiveness of the methods used, such as problem-based learning, modelling, and the integration of digital technologies. The progress was particularly pronounced in the categories of Functions and Graphs (+47%) and Applied Problems (+38%). Such a significant increase indicated that the use of visual models, interactive digital tools and real-life practical tasks contributed to a better understanding of the material. Digital technologies allowed students to simulate functions in a virtual environment, observe changes in parameters in real time, and analyse the results, which greatly facilitates the understanding of complex mathematical concepts.

Another important aspect is the reduction in the number of students with low levels of mathematical skills in the experimental group. For example, in the category "Functions and Graphs" this figure decreased from 34% to 3%, and in the category "Applied Problems" – from 25% to 6%. This indicates that the teaching methods used not only contributed to the development of strong students, but also provided support for those who had initial difficulties with mathematics. It is important to note that the innovative methods helped students with low levels of preparation to overcome the main barriers to learning mathematics by making the material more accessible and understandable. In addition, the results confirm the importance of developing logical thinking and combinatorics. In the experimental group, the proportion of students with a high level in this category increased from 28% to 60%. This indicates the effectiveness of gamification, interactive tasks and problem-based learning in the development of analytical skills. The use of gaming elements in the learning process allowed students to learn the material better, as such teaching methods stimulate active thinking, promote the development of a strategic approach to problem-solving and increase the level of cognitive flexibility. The effectiveness of the above-mentioned teaching methods was then determined by five key criteria, as shown in Table 3.

Table 3. Analysis of the effectiveness of innovative teaching methods

Teaching methods	Analytical thinking	Applicability in real-world conditions	Student motivation	Independence	Interactivity
Problem-based learning	4.5	4.7	3.5	4.6	3.8
Project method	4.6	4.8	4.5	4.7	3.9
Interactive digital technologies	3.5	3.7	4.6	3.6	4.8
Modelling and simulations	3.6	4.8	4.6	3.7	4.7
Gamification	2.8	3.5	4.7	2.5	4.7

Note: ratings are given on a 5-point scale, where: 5 – very high level, 4 – high, 3 – average, 2 – low, 1 – very low
Source: compiled by the author

Problem-based learning and the project method had the highest rates of analytical thinking development. This is because these approaches are focused on solving complex problems that require in-depth analysis, critical thinking, and information synthesis. Participants in the learning process must find ways to solve problems on their own, which helps to develop logic and argumentation. Instead, gamification demonstrated the lowest level of analytical thinking. This is due to the fact that it focuses more on motivation and engagement rather than in-depth analysis. Game mechanics often use simpler tasks, which reduces the level of cognitive load.

Gamification had the highest motivation scores. This is because the use of game elements, such as points, ratings, rewards, and interactive scenarios, increases students' interest and engagement. Students often perceive learning through game-based mechanisms as less stressful and more attractive. The project-based method and simulation also had a high level of motivation, as students see clear results of their work. In contrast, problem-based learning has an average level of motivation, as solving complex problems can cause cognitive load, which is not always attractive to all students.

An important aspect is that, although the motivational indicators differ, each approach also affects the level of student autonomy. Problem-based learning and the project method greatly contribute to the development of independence, as students must research a problem, formulate questions, analyse information, and propose solutions on their own. Gamification, on the other hand, has a low level of autonomy development, as most gamified learning platforms provide structured, directed interaction that does not always require deep independent analysis. But the highest level of interactivity is observed

in gamification and interactive digital technologies. This is due to the use of visualisation, interactive simulations, game scenarios and multimedia elements, which allows students to actively interact with the material. In addition, problem-based learning and the project method have an average level of interactivity, as they are based more on group work and discussions than on interactive technologies.

After analysing students' progress diaries, testing, and comparing the results of the control and experimental groups, a SWOT analysis of innovative methods of developing mathematical competence was conducted. This made it possible to identify the main advantages and disadvantages of each approach, as well as to assess their impact on the level of student learning. The analysis helped to identify the factors that contributed to the improvement of learning outcomes and the possible risks associated with the introduction of new methods. Particular attention was paid to the effectiveness of digital technologies, problem-based learning, project-based learning, modelling, and gamification. This made it possible to draw conclusions about the feasibility of further use of these methods in pedagogical practice and to identify the best strategies for their implementation. Table 4 below presents the results of the SWOT analysis of the innovative teaching methods used in the experimental group.

Table 4. SWOT-analysis of the applied innovative methods of mathematical competence formation

Methods	Strengths	Weaknesses	Opportunities	Threats
Problem-based learning	Development of critical thinking and analytical skills	Requires more time to prepare and conduct classes	Development of independent research skills	There may be a lack of sufficient support from teachers
	Increase motivation to learn	Can be difficult for students with insufficient background knowledge	Adaptation to real professional situations	It is difficult to assess the individual contribution of a student in group work
	Improving teamwork skills			
Project method	Stimulate students' creativity and independence	High workload for teachers in the assessment process	Improving interdisciplinary learning	Possible difficulties in accessing the necessary resources
	Practical tasks increase engagement	Some students may take a passive role in team projects	Development of time and resource management skills	Lack of standard criteria for evaluating project results
	Enhances the integration of mathematical knowledge across disciplines			
Interactive digital technologies	Visualisation of complex mathematical concepts	High technical requirements (appropriate software is required)	Distance learning and individualisation of the process	Dependence on technical infrastructure
	Increasing student engagement through multimedia resources	Not all students have sufficient digital competence	Use of artificial intelligence for adaptive learning	Possible difficulties in integrating new technologies into the traditional educational process
	Flexibility in learning (access to materials online)			
Modelling and simulations	Allows visually exploring complex mathematical processes	High level of difficulty for beginners	Integration with other disciplines (physics, engineering, economics)	High cost of developing high-quality simulations
	Increase the accuracy and understanding of the application of mathematical models	Not all aspects of mathematics can be modelled effectively		Possible overload of students with complex models
	Develop skills in solving practical problems			
Gamification	Increase student motivation and engagement	A limited number of topics are suitable for the game format	Use of gaming platforms for independent learning	Possible reduction in the seriousness of the perception of educational material
	Promotes better learning through a playful approach	May distract students from the main material	Increasing interest in learning through game elements	Requires considerable effort to develop high-quality educational games
	Develops competitive spirit and self-control			

Source: compiled by the author

The conducted SWOT-analysis allowed evaluating the effectiveness of various innovative methods of forming mathematical competence among students of the experimental group. It was found that the most effective approaches were interactive digital technologies and modelling and simulation. They have significantly improved students' understanding of complex mathematical concepts by visualising processes that remain abstract in traditional teaching settings. At the same time, the use of digital tools provided individualised learning and the opportunity to work

independently on the material, which had a positive impact on academic performance. Gamification has demonstrated a significant motivational effect, increasing student engagement in the learning process. However, its effectiveness was selective, as not all mathematical topics can be effectively adapted to game formats. Another important factor was the need to carefully select game mechanics so that they did not distract students from the main content of the material.

Problem-based learning and project-based learning methods ensured the development of critical thinking, analytical skills, and an interdisciplinary approach to problem-solving. They contributed to the active involvement of students in the learning process and increased their independence in learning mathematics. However, their implementation required significant time and organisational resources from both teachers and students. One of the challenges was assessing the contribution of each participant to the collective activity, which sometimes made it difficult to objectively determine the level of learning. Among the main risks of implementing innovative teaching methods was the dependence on technical infrastructure, which is critical for interactive digital technologies and modelling. In addition, some students had insufficient training to work with new learning formats, which could complicate the adaptation process. An important condition for the successful application of these methods is their gradual introduction, taking into account the characteristics of the student population and ensuring proper methodological support for teachers. In general, the analysis showed that the integration of innovative methods contributes to the development of students' mathematical competence, their motivation, and engagement in the learning process. At the same time, the effective application of these approaches requires a flexible methodological strategy that combines traditional and modern educational technologies.

DISCUSSION

The results of this study have shown that the use of digital technologies, adaptive learning and interactive platforms contributes to improving the level of mathematical competence of future specialists. This is consistent with the findings of A. Berciano *et al.* (2024), who in their systematic review of STEAM projects in primary education in Spain, found that the integration of an interdisciplinary approach contributes to the development of mathematical and scientific competences. In particular, their results confirm that the use of digital technologies and project-based learning has a positive impact on students' mathematical thinking. The study also showed that mathematical modelling remains an effective tool for developing students' analytical skills. L. Zhang *et al.* (2024) noted that students who actively used mathematical modelling demonstrated a significantly higher level of understanding of abstract concepts and were able to apply the knowledge gained in practical situations. In addition, the results of this work showed that early involvement of children in logical and mathematical tasks improves their cognitive skills and mathematical thinking. The same conclusion was reached by I. Menacho *et al.* (2024), who emphasise the need to establish clear standards for assessing children's mathematical competence, which helps teachers to adapt teaching methods to the needs of students. The study by D. Nordqvist *et al.* (2023) supplemented this idea. They tested new approaches to the development of written mathematical communication among students and proved that such methods contribute to a better understanding of mathematical concepts. In particular, the use of structured writing tasks and reflective journals allowed students to formulate their own mathematical reasoning more clearly and logically. The results show that the development of written mathematical communication skills not only improves academic performance, but also contributes to deeper learning.

This study also found that alternative methods of teaching mathematics, such as interactive algorithms, contribute to improved understanding of mathematical operations. This coincides with the findings of M. Canto López *et al.* (2022), who analysed the main innovative and alternative methods of teaching written algorithms in primary school. They note that the use of non-traditional approaches, such as visualisation of algorithms and the use of digital tools, improves students' mathematical thinking and increases the level of learning. The integration of innovative programmes into teaching also improves their mathematical competences. This correlates with the study by F. Chacón *et al.* (2024). The researchers confirmed that the use of these programmes contributes to the development of mathematical thinking in students of pedagogical specialities. They note that interactive tools allow students to better understand complex concepts. The study also found that personalised mathematics learning using artificial intelligence contributes to the development of competence in solving mathematical problems among primary school students. D. Chau *et al.* (2025) also proved the effectiveness of AI chatbots in teaching mathematics in Vietnam. They note that such technologies help to adapt the learning process to the level of each student, which positively affects their learning outcomes. This is also in line with the study by M. Krause *et al.* (2024), who found that students who actively use mobile devices for learning demonstrate a higher level of mathematical competence. At the same time, they note that problems associated with excessive use of smartphones and the fear of missing out on important information can have a negative impact on learning outcomes. This also correlates with the study by N. Sirakova & N. Sirakov (2023). The use of online resources helps to increase students' motivation to learn foreign languages and develop their listening and speaking skills. These approaches can be useful for increasing students' motivation and competence in various fields, including systems programming or mathematics.

The results of this study also showed the importance of interactive tasks and tools in the development of mathematical competences, which is consistent with the findings of P. Ester *et al.* (2022), who found that the use of video games in mathematics teaching contributed to the development of

mathematical skills, especially in the areas of logical thinking and spatial imagination. The study also showed that game-based methods increased students' motivation and contributed to their active involvement in the learning process. This study also found that the use of an interdisciplinary approach promotes deeper learning of mathematical concepts and the development of critical thinking. Similar results were obtained by A. Rashidov (2020), who focused on the development of students' creative and informational competences in mathematics. He argues that students who actively use mathematical methods in analysing information demonstrate a higher level of creative thinking. These results confirmed this conclusion, as students who participated in project-based learning using real-world mathematical problems had a significantly higher level of competencies. The study by H. Rocha & A. Babo (2024) also highlighted the link between problem-solving and mathematical competence. They found that the development of problem-solving skills contributes to the development of mathematical literacy. This correlates with the findings of the present study. The study also showed that the role of the teacher is crucial in the development of mathematical competence. This is consistent with the findings of L. Hetmanenko (2024), who found that the active use of simulation research in mathematics teaching significantly improves students› engagement and ability to solve complex problems.

Similar results to the present study were obtained by A. Pansell (2023), who studied the use of information technology in teaching physics and mathematics. The author noted that the use of virtual simulations and mathematical models contributes to the development of systemic thinking and analytical skills of students. This study also found that the integration of information technology has a positive impact on the development of mathematical competences. Research by G. Sayeg & M. Rodriguez-Paz (2024) showed that the use of gamification and chatbots (in particular, ChatGPT) in mathematics teaching increases students' interest and improves mathematical modelling. The data obtained confirm this conclusion, as students who participated in learning with elements of gamification demonstrated high results in solving mathematical problems and greater motivation to learn. Therefore, the results of this study confirm the effectiveness of innovative methods and are consistent with the findings of the above researchers. This indicates that the integration of digital technologies, personalised learning, mathematical modelling and alternative methods has a positive impact on the level of mathematical knowledge and skills of pupils and students.

CONCLUSIONS

The results of the study confirmed the effectiveness of using innovative methods in the formation of students' mathematical competence. The introduction of problem-based learning, project-based learning, interactive digital technologies, modelling and simulation, and gamification had a positive impact on the development of analytical thinking, motivation to learn, level of independence, and ability to apply knowledge in practical situations.

A comparative analysis of the experimental and control groups showed a significant difference in the level of learning. Students of the experimental group who were taught using innovative methods demonstrated a much deeper understanding of mathematical concepts and a higher level of success in completing test tasks, solving practical problems and preparing analytical reports. The project-based method helped students apply mathematical knowledge to analyse real-world statistical data, developing their research and critical thinking skills. Gamification increased the level of student engagement and motivation, which was reflected in the growth of their academic performance and activity in the classroom. Compared to the control group, the number of students who actively participated in the classes increased by 29%.

Students' self-assessment data also confirmed the effectiveness of the proposed methods. The progress diaries revealed positive dynamics of self-reflection and awareness of their own learning progress. In addition, students noted improvements in their ability to plan their own learning and set realistic goals. This indicates an increase in their learning motivation and active participation in the educational process. In general, there was a tendency for self-esteem to increase, which confirms the effectiveness of the methods used in developing students' independence.

Thus, the study confirmed that the use of innovative teaching approaches contributes to the more effective formation of students' mathematical competence. In the future, further research can be expanded to different specialities and levels of education, which will allow for a more comprehensive assessment of the effectiveness of innovative methods in the formation of mathematical competence.

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CONFLICT OF INTEREST

None.

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Інноваційні підходи до формування математичної компетентності майбутніх учителів початкової школи

Анотація. Метою дослідження було вивчення впливу інтерактивних методів, цифрових технологій і міждисциплінарного підходу на формування математичної компетентності студентів та ефективність засвоєння знань. Методологія включала порівняльний аналіз, педагогічний експеримент, аналіз сильних і слабких стопін, можливостей і загроз, визначення інноваційних підходів до формування математичної компетентності здобувачів вищої освіти за освітньою програмою "Початкова освіта". Результати дослідження показали, що ведення щоденників успішності сприяє саморефлексії студентів, покращує їхню здатність до планування навчального процесу та підвищує мотивацію. Самооцінка студентів підтвердила зростання впевненості у власних знаннях і навичках, а також розвиток самостійності. Виявлено поліпшення у плануванні власного навчання та постановці реалістичних цілей за допомогою нових підходів. Це свідчить про підвищення їхньої навчальної мотивації та активної участі в освітньому процесі. Інноваційні методи навчання, такі як проблемно-орієнтоване навчання, моделювання, інтерактивні технології та гейміфікація, покращили розуміння математичних концепцій. Порівняльний аналіз засвідчив вищий рівень успішності в експериментальній групі – середній бал тестових завдань зріс на 23%. Щоденники сприяли усвідомленню власного навчального прогресу, що підвищило мотивацію та залученість студентів. Використання цифрових інструментів, таких як GeoGebra та Desmos, покращило візуалізацію математичних процесів. Основними викликами стали адаптація до нових форматів навчання та необхідність підготовки викладачів. Отримані результати можуть бути використані для вдосконалення методичних підходів до викладання математики у вищій освіті та розробки рекомендацій для впровадження інноваційних технологій у навчальний процес

Ключові слова: навчальний процес; гейміфікація; критичне мислення; новітні методи; індивідуальні потреби