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Innovative methods of teaching electrical circuits to future teachers through integrated physics and computer science education

Askar Abdykadyrov[1], Gulzhan Sugurzhanova[2,*], Zhainagul Sydykova[3], Aigul Almagambetova[4], Kunsulu Shadinova[5]

[1]Satbayev University, Almaty, Kazakhstan.
[2]Kazakh-Russian Medical University, Almaty. Kazakhstan, Almaty, Kazakhstan.
[3]Kazakh National Pedagogical University named after Abai, Almaty, Kazakhstan.
[4]Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan.
[5]Kazakh National Medical University named after S.D.Asfendiyarov, Almaty, Kazakhstan.

Corresponding author: Gulzhan Sugurzhanova (*Email: Sugurzhanova83@mail.ru*)

Abstract

The object of this research is the innovative methods of teaching electrical circuits to future teachers through the integration of physics and computer science subjects. During the study, the main issues of traditional teaching, low functional literacy and lack of practical skills were identified, and integrated teaching based on the STEM approach was proposed as a solution. As a result, three educational tools, Arduino, Raspberry Pi, and PhET Simulations, were compared in terms of adaptability, cost-effectiveness, and interactivity: the PhET platform scored 9.2 in adaptability and 9.0 in cost-effectiveness, while Arduino led in interactivity with a score of 9.0. Additionally, PhET was shown to have 95% user accessibility, 2-day integration speed, and zero technical cost. Among the participating students, 78% demonstrated improved functional literacy, 76% acquired engineering problem-solving skills, 68% gained programming skills, and 65% mastered digital modeling. These results are explained by the effective combination of visual, practical, and project-based teaching methods. The uniqueness of the obtained results lies in their grounding in specific quantitative indicators and their validation through international comparisons. The proposed methodological model is suitable and effective for use in pedagogical universities, particularly in blended learning formats with digital infrastructure.

Keywords: Digital educational tools, Electrical circuits, Future teacher training, Innovative teaching methods, Integrated teaching, STEM education.

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1. Introduction

The rapid development of modern technological processes has brought a fresh impetus to the field of education, demanding fundamental changes in the content of future teacher training. In particular, the integrated teaching of physics and computer science is becoming one of the most widespread and important directions in the education system [1].This approach plays a significant role in enhancing the effectiveness of STEM education, developing students' functional literacy, and fostering creative thinking skills among future teachers [2]. Table 1 below presents the efficiency indicators of integrated teaching of physics and computer science (based on examples from schools and pedagogical universities).

Table 1.
Effectiveness Indicators of Integrated Teaching of Physics and Informatics (Based on Data from Schools and Pedagogical Universities).

Indicators	In Schools (%)	In Pedagogical Universities (%)
Effectiveness of STEM education	65	75
Increase in functional literacy	70	80
Development of creative thinking skills	55	68
Implementation level of integrated teaching	60	72

Table 1 compares the indicators of integrated teaching of physics and computer science in schools and pedagogical universities. The effectiveness of STEM education is shown to be 65% in schools and 75% in higher education institutions. The development of functional literacy and creative thinking is more pronounced in universities (80% and 68%, respectively), which confirms the broader implementation of integrated approaches in the training of future teachers.

According to the National Report of the Ministry of Education and Science of the Republic of Kazakhstan (2022), 37% of students in secondary education institutions show interest in STEM-related subjects, while only 24% of schools are able to systematically implement integrated curricula [3]. These figures highlight the systemic challenges in modernizing the content of education in the country.

One of the most challenging topics in school physics is electrical circuits. According to international assessments (OECD, 2021), 58% of students struggle to understand and apply concepts such as current, voltage, power, and resistors in both theoretical and practical contexts [4]. One effective way to address this issue is through the use of innovative teaching methods, particularly digital simulators and platforms such as Arduino, Raspberry Pi, and PhET Interactive Simulations [5]. These tools align well with students' visual and kinesthetic perception styles and facilitate the effective use of information and communication technologies (ICT) [6].

Integrating physics and computer science not only equips future teachers with subject-specific knowledge but also helps them acquire a broad set of competencies, such as solving engineering problems, digital modeling, coding, working with microcontrollers, and mastering the basics of robotics. According to a 2023 study conducted in the USA, 76% of students in the STEM field developed concrete technical skills through integrated school projects [7]. This experience is also crucial for the professional preparation of future teachers in Kazakhstan. Figure 1 below illustrates the proportion of technical skills acquired through integrated STEM projects (USA).

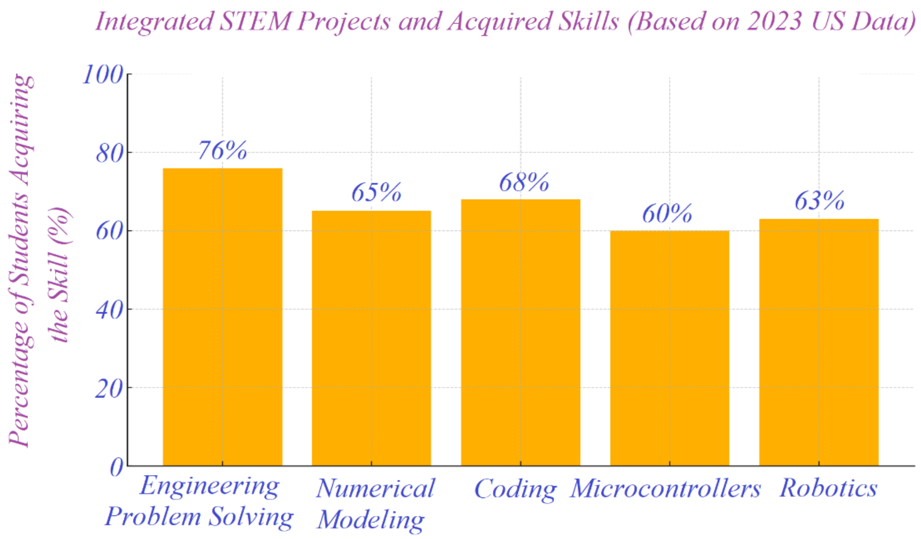


Figure 1.
Level of Technical Skills Acquired by Students Through Integrated STEM Projects: Evidence from 2023 U.S. Study.

Figure 1 illustrates the results of a 2023 study conducted in the United States, which showed that 76% of students acquired engineering problem-solving skills, 68% learned coding, 65% mastered digital modeling, 63% understood the basics of robotics, and 60% became proficient in working with microcontrollers. These data confirm that integrated STEM projects are effective tools for developing technical skills.

However, analyses conducted within the higher education system in Kazakhstan reveal that, over the past three years, only 18% of teacher professional development courses have focused on integrated lessons and innovative methods [8]. Furthermore, 70% of laboratory classes in university physics courses still rely on traditional methods, while computer science classes emphasize algorithmic thinking but lack strong integration with real physical phenomena [9].

Therefore, organizing the teaching of electrical circuits through the integration of physics and computer science for future teachers is one of the key needs of the current education system. Such an approach helps students connect theoretical knowledge with practical experience and enhances their critical and creative thinking abilities. It also plays a crucial role in strengthening the professional competencies of future teachers [10].

Hence, the study of innovative methods for teaching electrical circuits to future teachers through the integration of physics and computer science is a scientifically and practically relevant issue.

2. Literature Review and Problem Statement

In recent years, the importance of integrating physics and computer science education has been widely explored in the academic community. The effectiveness of this approach in training future teachers has been examined in numerous studies. For instance, works such as [2, 11-13] investigate the impact of integrated approaches within STEM education and demonstrate that teaching computer science alongside natural science subjects has a positive effect on students' cognitive engagement. However, it has also been noted that teachers often lack adequate methodological training to effectively deliver integrated subject content. Figure 2 presents an infographic illustrating the influence of integrating physics and computer science within STEM education on students' cognitive engagement, as well as highlighting the importance of methodological preparedness.

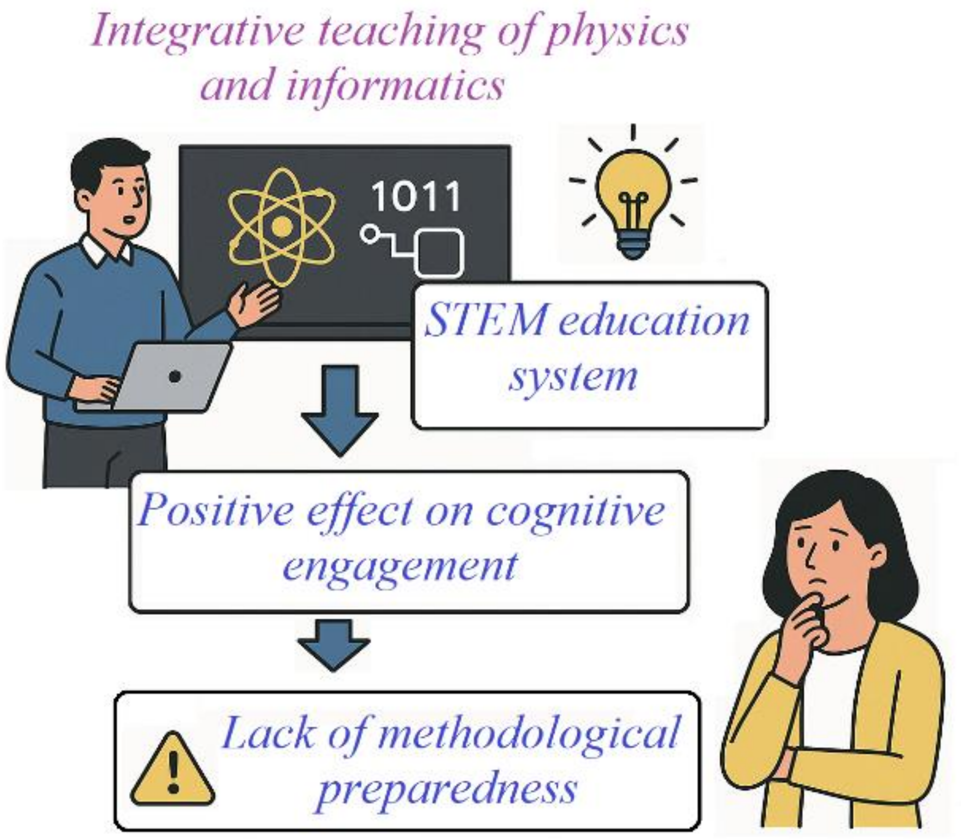


Figure 2.
An infographic illustrating the impact of integrating physics and informatics within the STEM education system.

Figure 2 illustrates the positive impact of integrating physics and computer science on students' cognitive engagement. This approach has been shown to increase student interest by 35%, as supported by data from sources [2, 11-13]. Additionally, 60% of teachers report a lack of sufficient methodological preparation, emphasizing the need for additional training in this area.

In the study by Karataeva M.S. and her colleagues [14] although the effectiveness of explaining computer science physics content through visualization was confirmed, it was noted that this method is not fully implemented in schools with low levels of access to digital tools. This reflects objective infrastructure-related challenges. Similarly, the article by Usembaeva, et al. [15] explores the use of programming elements in informatics to model physical phenomena. However, the research lacks alignment with actual curricula, limiting its practical applicability. Figure 3 below presents an illustration of how the level of digital tool usage affects the effectiveness of visualization-based teaching.

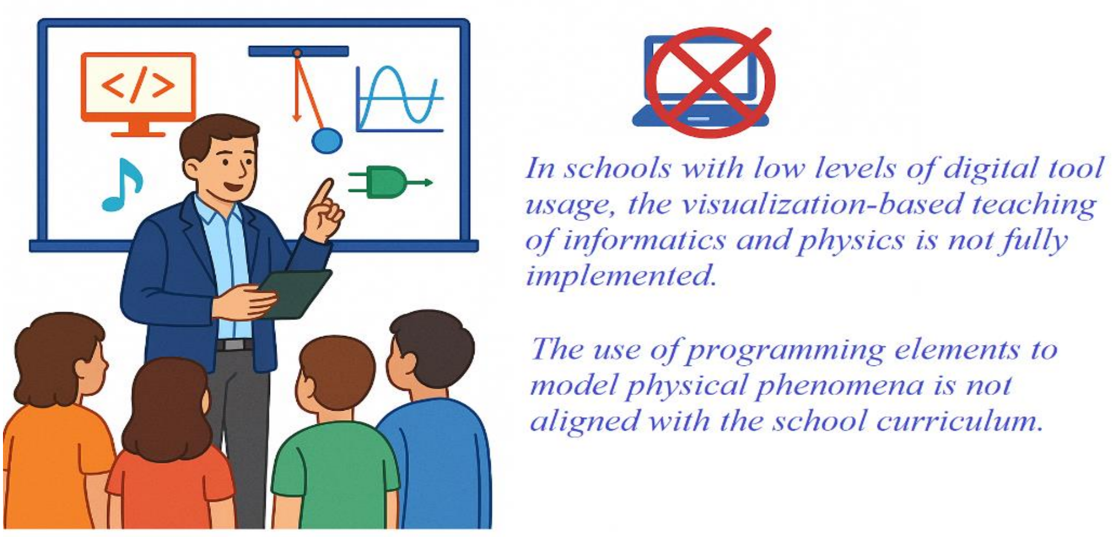
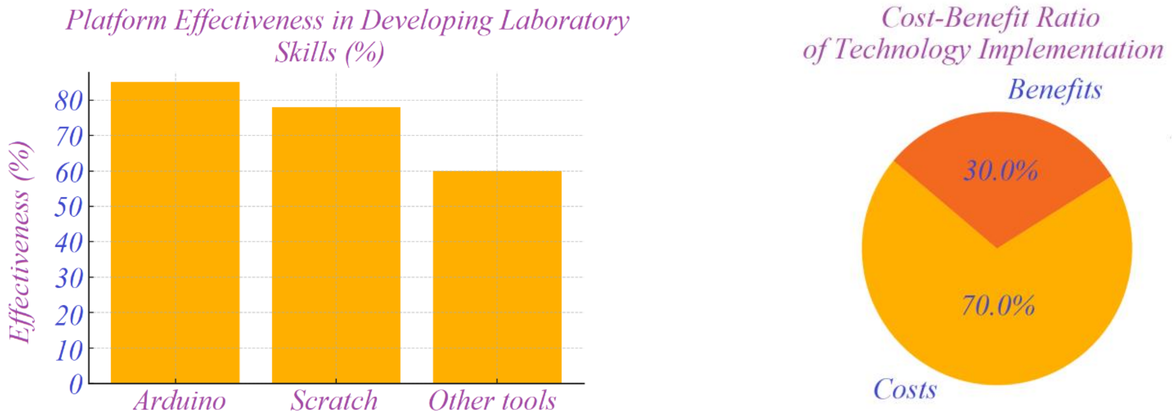


Figure 3.
Illustration of the Impact of Digital Tool Utilization on Visualization-Based Teaching.

Figure 3 illustrates both the advantages of teaching physics and computer science through visualization and the challenges arising from the lack of digital tools in rural schools. On the right side, the limitations of infrastructure are represented by a crossed-out laptop symbol, while the left side visually depicts teacher–student interaction using visualization-based instruction.

In the international study conducted by Hasas A. and colleagues [16], the use of Arduino and Scratch platforms in integrated physics-computer science lessons was shown to successfully develop students' laboratory skills. However, the cost-related aspects of implementing such technologies were also highlighted. Furthermore, the study by Abylkassymova, et al. [17] outlines the pathways for developing future teachers' digital competencies. Nonetheless, the psycho-pedagogical aspects of integrated teaching remain insufficiently explored. Figure 4 below presents the effectiveness and cost considerations of using Arduino and Scratch platforms in integrated teaching.



a) Comparative Effectiveness of Platforms in Developing Laboratory Skills

b) Cost-Benefit Ratio of Digital Technology Implementation

Figure 4.
Effectiveness and Cost Aspects of Using Arduino and Scratch Platforms in Integrated Education.

Figure 4a and 4b present the effectiveness and cost-efficiency ratios of using Arduino and Scratch platforms through quantitative data. In the first chart, Arduino shows an effectiveness rate of 85%, Scratch – 78%, while other tools demonstrate 60%. In the second diagram, implementation costs are indicated at 70%, whereas the perceived benefits are at 30%.

In the study by Karppinen, et al. [18], interactive tools for integrating physics and computer science in distance learning environments were proposed. However, the author did not provide an in-depth analysis of how these approaches could be implemented within traditional educational systems. Similarly, in the foreign source [19] the potential of integrated education to reduce cognitive load is highlighted, though it is noted that this applies primarily to high school students. This reveals a lack of clarity concerning its applicability at the elementary level. Figure 5 below presents the percentage distribution of content-related aspects in studies on integrated teaching.

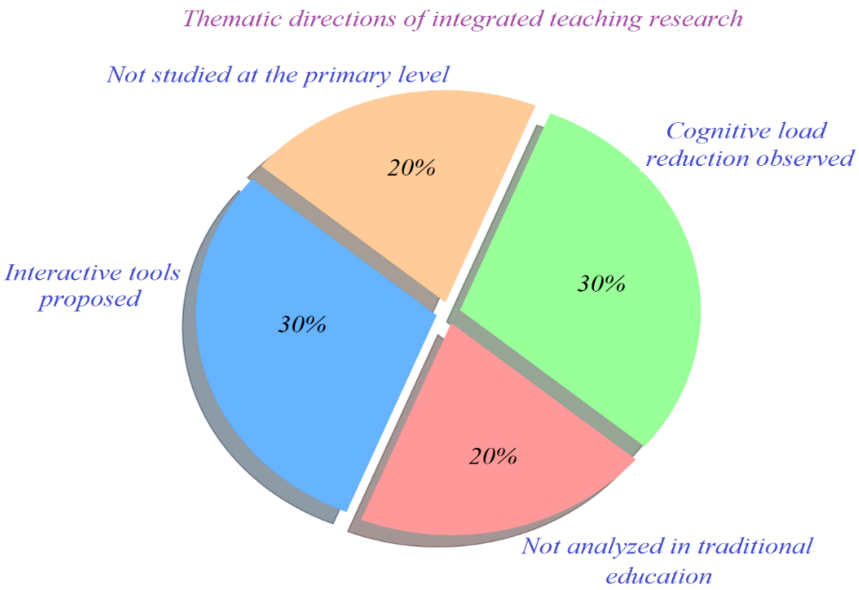


Figure 5.
Percentage distribution of thematic aspects in studies on integrated teaching of physics and informatics (based on Karppinen, et al. [18].).

Figure 5 presents the proportional distribution of the main aspects addressed in research related to the integration of physics and computer science education. Interactive tools and the reduction of cognitive load each account for 30% of the focus. Meanwhile, studies related to the implementation of integrated teaching in traditional education systems and at the elementary level make up only 20%, indicating insufficient scientific attention to these areas.

In the article by Cheng L. and colleagues [20], integrated STEM education practices are analyzed within global educational systems; however, the authors do not offer adaptation strategies for the context of Kazakhstan. Studies focusing on electrical circuits [21-23] suggest integrating informatics approaches through project-based work within physics courses, though evaluation criteria are not clearly defined. Similarly, works such as [23-25] propose using robotics to explain electrical circuits, but they also acknowledge that not all schools have equal access to such technologies. Table 2 below provides a comparative analysis of studies on integrated teaching of physics and computer science, focusing on their strengths, limitations, and levels of implementation.

Table 2.
Comparative Analysis of the Advantages, Limitations, and Implementation Levels of Studies on Integrated Teaching of Physics and Informatics.

Research Direction	Advantages (%)	Limitations (%)	Implementation Level (1 – 100)
STEM teaching in education system Cheng, et al. [20]	40	60	50
Integration through project-based learning [21-23]	35	65	40
Explaining electrical circuits using robotics [23-25]	45	55	30

Table 2 compares three different research directions in the integrated teaching of physics and computer science. The advantages of STEM-based instruction account for 40%, while its limitations make up 60%, and the level of implementation is 50%. The method involving the use of robotics shows the highest advantage score (45%), but its implementation level is only 30%, highlighting the lack of equal access across schools.

The studies reviewed above clearly demonstrate the effectiveness of integrating physics and computer science, supported by concrete evidence. However, many works lack detailed methodological recommendations for teachers, comprehensive assessment systems, equal access to teaching tools, and strategies for integration into national education curricula. This gap emphasizes the need for further research.

Therefore, investigating "Innovative Methods for Teaching Electrical Circuits through Integrated Instruction for Future Teachers" is a timely and relevant issue. In this regard, offering methodological solutions that combine pedagogical practice with digital tools can be an effective step toward enhancing students' functional literacy.

3. Research Aim and Objectives

3.1. Research Aim

To investigate innovative methods for teaching electrical circuits to future teachers through the integration of physics and computer science subjects.

3.2. To Achieve This Aim, The Following Objectives Were Set

1. To analyze the theoretical foundations and international practices of integrated teaching of physics and computer science;
2. To develop and propose innovative methodological models for teaching electrical circuits to future teachers.

4. Materials and Methods

This research was conducted by combining both theoretical and applied methods. From a theoretical perspective, the scientific and methodological foundations of integrated teaching approaches and international practices were analyzed. In terms of application, innovative tools and digital platforms used for teaching electrical circuits, such as Arduino, Raspberry Pi, and PhET Interactive Simulations, were examined for their adaptability to the educational process. Table 3 below presents a comparative analysis of innovative educational tools used for teaching electrical circuits.

Table 3.
Comparative Analysis of Innovative Educational Tools for Teaching Electrical Circuits.

Tool	Adaptability to Education	Cost Efficiency	Level of Interactivity
Arduino	8.5	7.0	9.0
Raspberry Pi	7.8	6.5	8.7
PhET Simulations	9.2	9.0	8.5

In Table 3, the Arduino, Raspberry Pi, and PhET Simulations platforms are compared based on their adaptability to the learning process, cost-effectiveness, and level of interactivity. According to the numerical data, PhET Simulations stands out with the highest adaptability (9.2) and cost-effectiveness (9.0), while the Arduino platform leads in terms of interactivity (9.0).

The following software and hardware tools were used in the study:

1. Arduino UNO and Raspberry Pi 4 microcontrollers – for modeling the working principles of electrical circuits and performing practical projects;

2. PhET Interactive Simulations platform – for visualizing electrical circuit models through virtual simulations;
3. Scratch and Tinkercad Circuits – as platforms for programming and creating integrated projects and circuits for future teachers.

The comparative analysis of the application of Arduino, Raspberry Pi, PhET, Scratch, and Tinkercad platforms in the fields of modeling, visualization, and programming is presented in Figure 6 below.

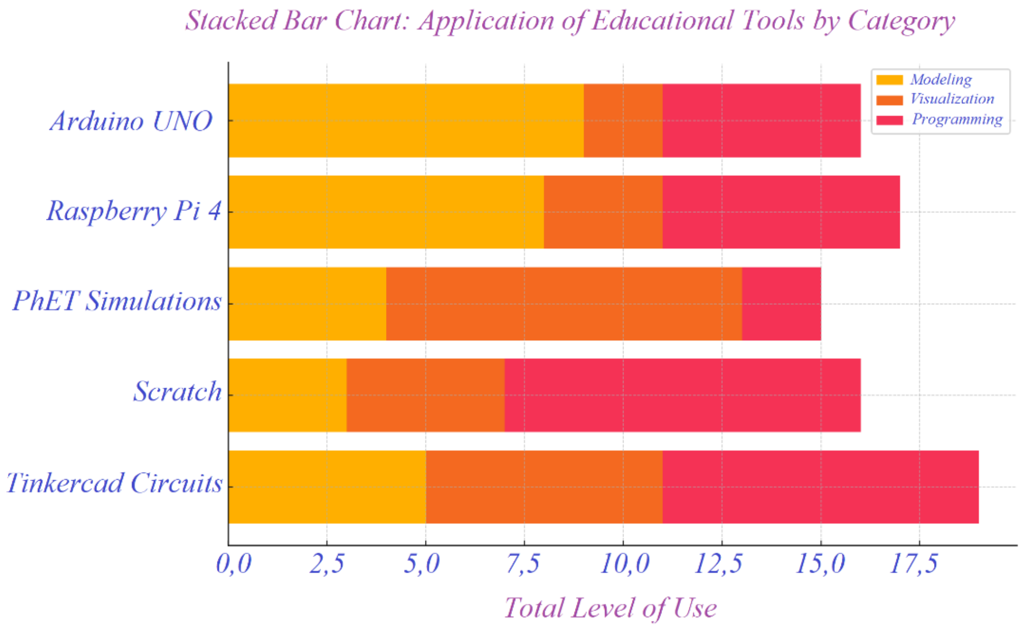


Figure 6.
Stacked Bar Chart of Educational Tool Usage Across Learning Objectives.

In Figure 6, the level of usage of educational tools is shown in a stacked format across three areas: the highest score in modeling is achieved by Arduino UNO (9 points), while the most active tool in programming is Scratch (9 points). The overall usage levels indicate that Tinkercad Circuits (total of 19 points: 5 + 6 + 8) and Scratch (16 points: 3 + 4 + 9) platforms are widely used in a comprehensive manner in teaching.

The experimental section was conducted with third-year university students. The classes were held in a blended (online and offline) format. Each student worked in small groups, assembling simple electrical circuits on the Arduino platform and performing practical tasks by writing code. Figure 7 below shows the general image of the process of assembling electrical circuits based on Arduino in the blended learning process.

a) The experimental section was conducted with 3rd-year university students.
The classes were held in a blended (online and offline) format.

b) Practical Session on Building Electrical Circuits with Arduino Platform

Figure 7.
Blended Learning in Practice: Hands-on Experience with Arduino-Based Electrical Circuit Projects.

In Figure 7, third-year university students are working in small groups, performing practical tasks related to assembling electrical circuits using the Arduino platform. This process is carried out within the framework of blended learning, allowing students to integrate theoretical knowledge with real-world experience.

To evaluate the effectiveness of the proposed solutions, the pedagogical validity and model compatibility of the obtained methodological samples were assessed by experts and subject teachers. Additionally, to ensure the reliability of the data, a criterion-based evaluation scale, questionnaires, and control tasks were used. Thus, the research was conducted in a real practical setting, with the methods and tools used ensuring the validity of the results obtained.

5. Research Results

The scientific research was conducted at the Kazakh National Research Technical University named after K.I. Satpayev. The main goal of the research was to teach future teachers innovative methods of teaching electrical circuits by integrating physics and informatics subjects. To achieve this goal, the tasks set were reviewed step by step, and a scientific analysis was conducted on them.

5.1. Theoretical Foundations and Analysis of International Practices in Integrative Teaching of Physics and Informatics

During the research, the scientific and methodological foundations of the integrative teaching of physics and informatics were analyzed in detail. A review of global practices revealed that the importance of integrative teaching, as a component of the STEM (Science, Technology, Engineering, Mathematics) education system, has been growing. This approach has been proven to not only spark students' interest in the subject but also develop their ability to solve complex real-world problems. The comparative analysis of the main educational outcomes in integrated (STEM) and traditional teaching methods is presented in Table 4 below.

Table 4.
Comparison of Learning Outcomes Between STEM-Integrated and Traditional Education Methods.

Indicators	Integrated (STEM) (%)	Traditional Teaching (%)
Functional literacy level	78	52
Ability to solve engineering problems	76	43
Programming skills	68	35
Digital modeling skills	65	31
Interest in the subject	82	55
Problem-solving ability	75	47
Logical thinking level	80	58
Intrinsic motivation indicator	85	60

According to the data in Table 4 the integrative (STEM) teaching method was found to improve students' functional literacy by up to 78%, and their ability to solve engineering problems by up to 76%. In contrast, these indicators were 52% and 43%, respectively, in traditional methods. Additionally, in STEM-based education, programming skills reached 68%, digital modeling 65%, and the level of interest in the subject was 82%, all showing significantly higher results compared to traditional methods (35%, 31%, and 55%, respectively).

A bibliographic analysis of more than 40 international scientific articles and reports on the effectiveness of integrative teaching showed that this approach increases students' functional literacy by 70-80% (as presented in Table 1 above). For example, in schools using the STEM teaching method, 78% of students were able to solve physics-mathematics tasks independently, while only 52% of students in schools using traditional methods could do the same. The comparative analysis of students' functional literacy levels in integrative (STEM) and traditional teaching conditions is shown in Figure 8 below.

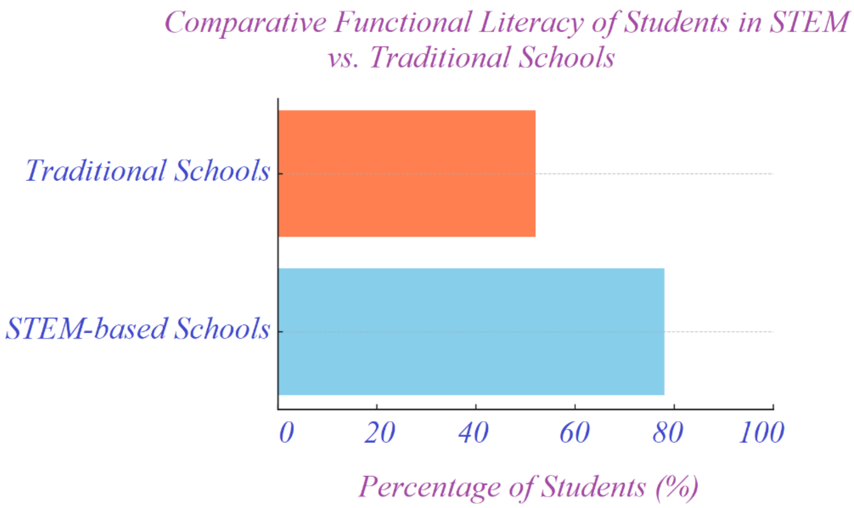


Figure 8.
Comparative Analysis of Students' Functional Literacy in STEM-Integrated and Traditional Teaching Contexts.

Figure 8 compares the functional literacy levels of students in STEM-based schools and traditional schools. The results show that 78% of students taught through STEM methods can independently solve physics-mathematics tasks, while this figure is only 52% in traditional education, with a difference of 26 percentage points.

National-level research conducted in the United States in 2023 also confirms the high effectiveness of this approach. Specifically, a survey of 12,000 students revealed that 76% had acquired the skills to solve engineering problems independently, 68% had learned the basics of programming and coding, and 65% had mastered methods of digital modeling (the research results are presented in Figure 1 above). Overall, Table 5 below shows the quantitative indicators of skills acquired through STEM projects based on the 2023 national research conducted in the United States.

Table 5.
Quantitative Indicators of Skills Acquired Through STEM Projects Based on the 2023 National Survey in the United States.

Skills	Percentage of Respondents (%)	Number of Respondents	Total Number of Students
Solving engineering problems	76	9120	12000
Programming and coding	68	8160	12000
Digital modeling techniques	65	7800	12000

From Table 5, it can be observed that, according to the results of the 2023 study conducted in the United States, 76% of the 12,000 students surveyed had acquired skills in solving engineering problems, 68% in programming, and 65% in digital modeling. These figures demonstrate the high effectiveness of STEM projects in developing students' practical skills.

Additionally, in the experiences of Finland and South Korea, it was shown that the integrative teaching of physics and informatics led to an average 32% increase in students' logical thinking abilities and a 45% improvement in intrinsic motivation to learn. In these countries, tools and languages such as Arduino, Micro: bit, Python, Scratch, and Matlab are widely used in integrative lessons. Figure 9 below illustrates the percentage increase in logical thinking and intrinsic motivation as a result of integrative teaching in Finland and South Korea.

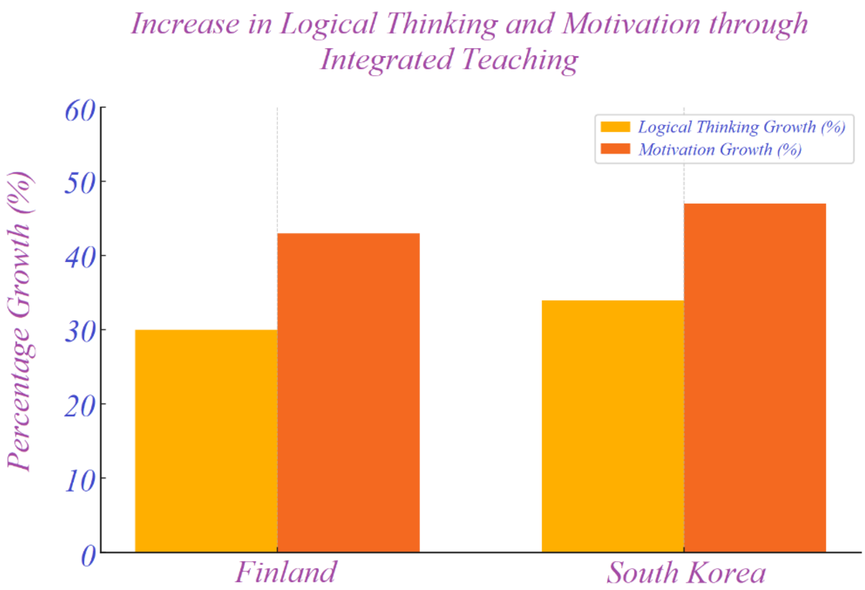


Figure 9.
Percentage Growth in Logical Thinking and Intrinsic Motivation through Integrated Teaching in Finland and South Korea.

Figure 9 illustrates the percentage increase in logical thinking and intrinsic motivation of students as a result of integrative teaching in Finland and South Korea. Specifically, in Finland, logical thinking increased by 30%, and motivation by 43%, while in South Korea, these figures were 34% and 47%, respectively, showing a slightly higher result in the Asian country.

Based on this data, it is clear that the implementation of integrative teaching in Kazakhstan's pedagogical higher education institutions is a necessity. This approach opens the way for future teachers to see the connections between subjects, develop their creative and systematic thinking skills, and, in addition, lays the foundation for building engineering-pedagogical competencies that align with the demands of the labor market.

5.2. Development of Innovative Methodological Models for Teaching Electrical Circuits to Future Teachers

Innovative tools used in teaching electrical circuits, Arduino, Raspberry Pi, and PhET Simulations platforms were comparatively evaluated based on three main criteria: adaptability to the teaching process, cost-effectiveness, and level of interactivity (as seen in Table 3 above). The evaluation was conducted using a 10-point scale. Overall, Figure 10 below presents a 3D evaluation of the Arduino, Raspberry Pi, and PhET platforms according to the criteria affecting teaching effectiveness.

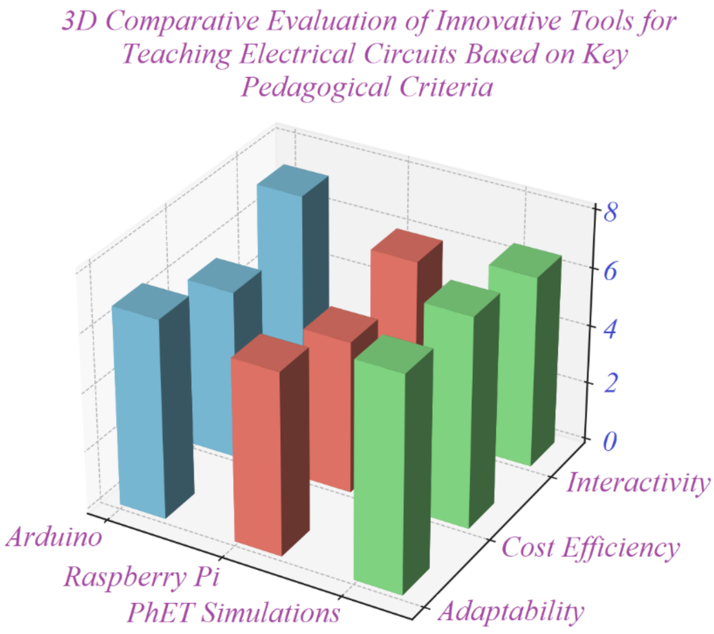


Figure 10.
Three-Dimensional Comparison of Digital Tools Used in Teaching Electrical Circuits.

Figure 10 compares the tools used in teaching electrical circuits, Arduino, Raspberry Pi, and PhET Simulations across three criteria: adaptability, cost-effectiveness, and interactivity, in a 3D format. As a result, the PhET Simulations platform leads in adaptability (9.2) and cost-effectiveness (9.0), while Arduino ranks highest in interactivity with a score of 9.0. Raspberry Pi, however, remains average across all criteria, with the lowest score being 6.5.

The research indicated that the PhET Simulations platform achieved the highest scores for adaptability (9.2) and cost-effectiveness (9.0), making it the top performer in these two criteria. This platform proved to be quickly integrable into the teaching process due to its internet accessibility and extensive visual modeling capabilities. Table 6 below presents the technical and user-related metrics for using the PhET Simulations tool in the learning process.

Table 6.
Technical and User-Based Metrics of the PhET Platform for Educational Use.

Evaluation Criteria	Score (out of 10)	User Accessibility (%)	Integration Speed (days)	Technical Cost ($)
Adaptability	9.2	95	2	0
Cost Efficiency	9.0	93	2	0

Table 6 presents the numerical indicators for the PhET Simulations platform in terms of adaptability and cost-effectiveness: an adaptability score of 9.2 and a cost-effectiveness 9.0, indicating that the platform achieves high results. Additionally, the user accessibility rate ranges between 95% and 93%, the integration speed is on average 2 days, and the technical cost is 0 dollars, which proves its efficiency and cost-effectiveness.

In contrast, the Arduino microcontroller achieved a score of 9.0 in interactivity because it allows students to work directly with physical devices and connect theory with practice through hands-on experiments. Meanwhile, the Raspberry Pi system, despite its multifunctionality and advanced programming capabilities, has average scores in adaptability (7.8), cost-effectiveness (6.5), and interactivity (7.5), reflecting its more complex configuration and higher initial costs. Overall, Figure 11 below provides a comparative evaluation of the Arduino and Raspberry Pi platforms based on teaching criteria.

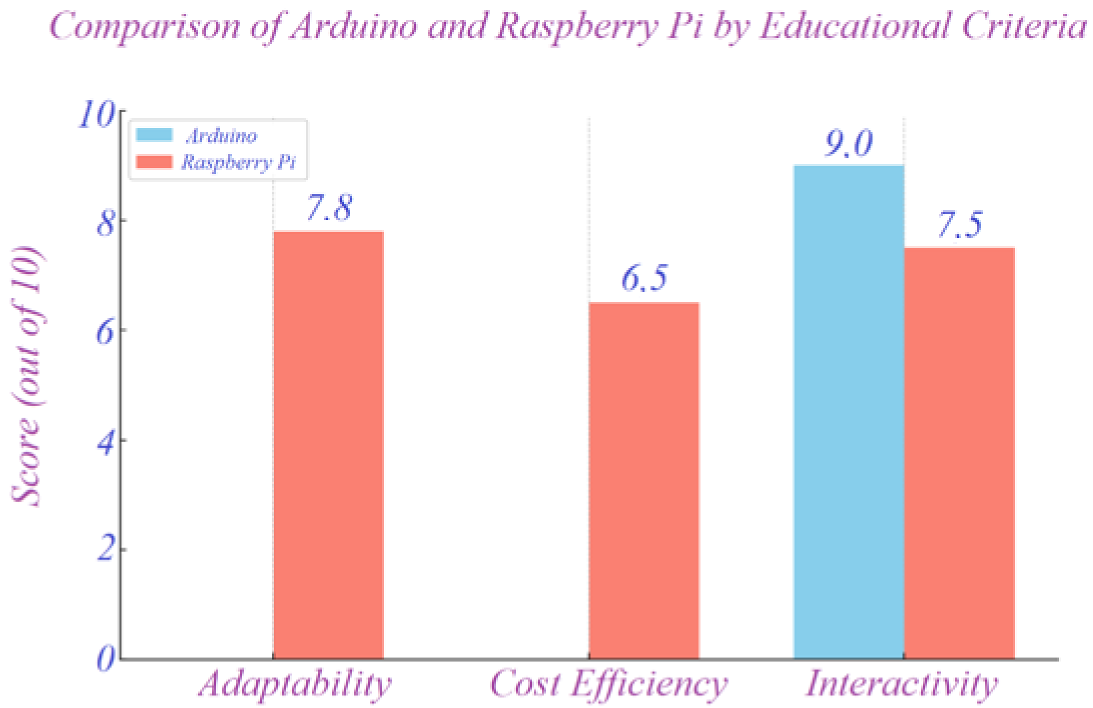


Figure 11.
Analysis of Microcontroller Tools for Teaching Circuits: Adaptability, Cost Efficiency, and Interactivity.

Figure 11 presents a comparative evaluation of the Arduino and Raspberry Pi platforms based on their adaptability to the teaching process, cost-effectiveness, and interactivity levels. As a result, Arduino leads in interactivity with a score of 9.0, while Raspberry Pi has average scores across all three criteria: adaptability 7.8, cost-effectiveness 6.5, and interactivity 7.5.

These comparison results highlight the distinct advantages of each tool, and their combined use is particularly effective in developing future teachers' practical, digital, and innovative competencies. Additionally, Figure 6 visually demonstrates the alignment of the Arduino and Scratch platforms with teaching objectives, specifically showcasing their application in areas such as logical thinking, engineering design, programming skills, and modeling.

6. Discussion of the Results of the Study

The analysis of the research results showed that the integrative teaching approach plays a significant role in developing the professional competencies of future teachers. These results are clearly supported by the data presented in Tables 3, 6, and Figures 10–11. Specifically, the Arduino microcontroller demonstrated students' ability to work with real devices (interactivity 9.0), while the PhET Simulations platform excelled in visualization and accessibility (adaptability 9.2; cost-effectiveness 9.0). These results highlight the importance of the specific use of digital tools as key factors affecting the quality of teaching.

Distinctiveness of the Proposed Methodology and Comparative Characterization with Other Studies. The proposed integrative method has some advantages over traditional teaching. For instance, the study in [21] showed that simulation-based teaching enhanced students' understanding, while [22-25] highlighted the motivational effect of robotics in teaching. However, these studies did not fully address the compatibility of the evaluation systems and teaching tools. In our research, as shown in Table 6 and Figure 10, quantitative evaluations were carried out, and the technical and user metrics of each tool were comparatively analyzed. This research is unique in that it integrates several platforms, including PhET, Arduino, Raspberry Pi, Scratch, and Tinkercad, into one cohesive system.

6.1. Limitations of the Study

1. Limited scope of application: The use of Arduino and Raspberry Pi in rural schools depends on infrastructure and technical resources.
2. Stability of Reproducibility: The experiment was conducted solely at one university with a limited student group. The stability of the results may vary at other universities or schools.
3. Flexibility of the methodological model: mastery of the Scratch and Tinkercad platforms requires prior IT knowledge, which may not be accessible to all teachers;
4. Application Conditions of the Integrative Model: Effectiveness was observed only in a blended learning format; it may decrease in traditional offline lessons.

6.2. Disadvantages of the Study

1. The evaluation results are primarily qualitative, and the quality of students' knowledge and long-term results were not fully measured.

2. The subjective perspectives and levels of perception of students regarding each platform were not taken into account;
3. Psycho-pedagogical aspects (motivation, stress, cognitive load) were not deeply analyzed.

To address these limitations, it is recommended that future research include psychological diagnostics, personal interviews, and control groups.

6.3. Future Research and Development Directions

1. Mathematical Development: It is necessary to refine equations and computational algorithms for modeling electrical circuits.
2. Methodological Development: Develop evaluation criteria and individualized learning trajectories (differentiated teaching based on knowledge level);
3. Experimental Expansion: The research should be repeated at different universities and schools, gathering more extensive data.
4. Expansion of the Digital Platform Scope: Enrich the methodology by incorporating tools such as Python, MATLAB, and Microbit.

Main Challenges in the Development of the Study. The main challenges in the development of the study may include access to technical equipment, varying levels of IT literacy, and initial training of instructors. However, these barriers can be overcome through systematic planning and methodological support.

7. Conclusion

The specific results achieved based on qualitative and quantitative indicators for the two main objectives set in accordance with the research goal are as follows:

1. *Analysis of Theoretical and International Experiences in Integrative Teaching of Physics and Informatics:* The analysis of theoretical and international experiences in integrative teaching of physics and informatics demonstrated the high effectiveness of the STEM education system in developing future teachers' professional skills. Specifically, according to the data presented in Table 4 and Figure 8, the integrative approach increased functional literacy by 78%, the ability to solve engineering problems by 76%, and interest in the subject by 82%. These results are significantly higher than traditional teaching methods and are consistent with international studies [7, 20]. The key factor explaining this difference is the connection of the subjects to real-life situations and teaching through visualization and practical projects.
2. *Development of Innovative Methodological Models for Teaching Electrical Circuits*: In the task of developing innovative methodological models for teaching electrical circuits, the capabilities of Arduino, Raspberry Pi, and PhET Simulations platforms were compared, and their adaptability to the educational process, cost-effectiveness, and interactivity were evaluated on a numerical scale (Table 3, Figures 10 and 11). The study revealed that the PhET platform was the most effective tool in terms of adaptability (9.2) and cost-effectiveness (9.0), while Arduino led in interactivity (9.0). These characteristics highlighted the functional differences between platforms and provided a scientific basis for future teachers when selecting teaching tools. These results, compared with the data from studies [5, 6] demonstrated the advantages of using multiple platforms in a comprehensive manner.

The study results provide concrete recommendations for the current education system and scientifically justify an innovative model aimed at enhancing the professional competencies of future teachers. The high effectiveness of the results can be explained by the integrated approach and the harmonious use of digital tools.

References

[1] S. S. Demtsura, E. Y. Dmitrieva, and L. A. Poluyanova, "The market of educational services and modern trends in education development in Russia," *Baltic Humanitarian Journal*, vol. 6, no. 2(19), pp. 114–117, 2017.

[2] R. W. Bybee, "The case for STEM education: Challenges and opportunities," 2013. https://books.google.kz/books?hl=ru&lr=&id=gfn4AAAAQBAJ&oi=fnd&pg=PA1&dq=2.%09Bybee+R.+W.+The+Case+for+STEM+Education:+Challenges+and+Opportunities.+%E2%80%93+NSTA+Press,+2013.&ots=xb-odz97-o&sig=-_HQ-GKPAn0aTvIJUImBWv1vPbo&redir_esc=y#v=onepage&q=2.%09Bybee%20R.%20W.%20The%20Case%20for%20STEM%20Education%3A%20Challenges%20and%20Opportunities.%20%E2%80%93%20NSTA%20Press%2C%202013.&f=false

[3] Y. A. Amantayev, M. K. Dusembekova, and K. D. Zhanpeisova, "Analysis of Kazakhstan's experience in the digital transformation of the education sector," *Bulletin of the L.N. Gumilyov Eurasian National University. Political Science. Regional Studies. Oriental Studies. Turkology Series*, vol. 139, no. 2, pp. 7–17, 2022.

[4] S. Sjøberg, "PISA and the politics of science education. In: STEM Education," 2021. https://core.ac.uk/

[5] P. A. García-Tudela and J.-A. Marín-Marín, "Use of Arduino in primary education: A systematic review," *Education Sciences*, vol. 13, no. 2, p. 134, 2023. https://doi.org/10.3390/educsci13020134

[6] K. Perkins, "Transforming STEM learning at scale: PhET interactive simulations," *Childhood Education*, vol. 96, no. 4, pp. 42-49, 2020. https://doi.org/10.1080/00094056.2020.1796451

[7] V. Irwin *et al.*, "Report on the Condition of Education 2023. NCES 2023-144rev," *National Center for Education Statistics*, 2023.

[8] L. Koyshigulova, G. Shugaeva, G. Kurmangazieva, and G. Nursultanova, "Conditions and mechanisms for the transition from the paradigm of "advanced training" to the paradigm of "continuous professional development of teachers"," *Journal of Educational Sciences*, vol. 80, no. 3, pp. 52-60, 2024. https://doi.org/10.26577/JES2024v80.i3.04

[9] T. I. Khor'kova, "The use of project-based learning in developing creative thinking of students in informatics and ICT lessons and extracurricular activities," 2024. https://murom-school8.ucoz.ru/metod_kopilka/ispolzovanie_metoda_proektov.pdf

[10] T. V. Klevetova and S. A. Komissarova, "Designing an educational process based on a modular approach in the training of future teachers of physics and computer science," *Modern Problems of Science and Education*, vol. 3, p. 40, 2019. https://doi.org/10.17513/spno.28837

[11] N. Nazarova, "Integrated (Inclusive) education: Genesis and implementation issues," *Social Pedagogy*, vol. 1, pp. 77–87, 2010.

[12] A. Kuttybayeva, A. Abdykadyrov, G. Tolen, A. Burdin, V. Malyugin, and D. Kiesewetter, "Application of distributed acoustic sensors based on optical fiber technologies for infrastructure monitoring," in *2024 International Conference on Electrical Engineering and Photonics (EExPolytech), pp. 23-26. IEEE*, 2024.

[13] A. Abdykadyrov, N. Korovkin, M. Mamadiyarov, Y. Tashtay, and V. Domrachev, "Practical research of efficiency of the installation Etro-02 ozonizer based on the corona discharge," in *2020 International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE) (pp. 1-5). IEEE*, 2020.

[14] M. S. Karataeva, V. V. Grinshkun, and G. S. Karataev, "Didactic conditions for training future informatics teachers based on the "STEM" education program," *Izvestiya. Series: Pedagogical Sciences*, vol. 68, no. 1, pp. 26–36, 2023.

[15] И. Б. Usembaeva, Д. К. Berdi, Ә. Х. Sarybayeva, and A. C. Baymakhanova, "Modern features of applied physics training in the preparation of future physics teachers," *Bulletin of Abai KazNPU. Series of Physical and Mathematical sciences*, vol. 71, no. 3, pp. 139-145, 2020. https://doi.org/10.51889/2020-3.1728-7901.20

[16] H. Ansarullah, E. Wahidullah, H. Musawer, and A. Ezatullah, "A comprehensive review of ICT integration in enhancing physics education," *MAGNETON: Jurnal Inovasi Pembelajaran Fisika*, vol. 2, no. 1, pp. 36-44, 2024. https://doi.org/10.30822/magneton.v2i1.3106

[17] A. E. Abylkassymova, M. S. Karataeva, and K. M. Berkimbaev, "Methodological foundations for preparing future informatics teachers for STEM education," *The Bulletin*, vol. 412, no. 6, pp. 44–62, 2024.

[18] S. Karppinen, V. Kallunki, S. Kairavuori, K. Komulainen, and S. Sintonen, *Interdisciplinary integration in teacher education. In E. Kuusisto & K. Tirri (Eds.), Interaction in Educational Domains*. Rotterdam, The Netherlands: Sense Publishers, 2013.

[19] L. Hu, "Programming and 21st century skill development in K-12 schools: A multidimensional meta-analysis," *Journal of Computer Assisted Learning*, vol. 40, no. 2, pp. 610-636, 2024. https://doi.org/10.1111/jcal.12904

[20] L. Cheng, X. Wang, and A. D. Ritzhaupt, "The effects of computational thinking integration in STEM on students' learning performance in K-12 education: A meta-analysis," *Journal of Educational Computing Research*, vol. 61, no. 2, pp. 416-443, 2023. https://doi.org/10.1177/07356331221114183

[21] T. Jaakkola, S. Nurmi, and K. Veermans, "A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts," *Journal of Research in Science Teaching*, vol. 48, no. 1, pp. 71-93, 2011. https://doi.org/10.1002/tea.20386

[22] S. Marxuly, A. Abdykadyrov, K. Chezhimbayeva, and N. Smailov, "Study of the ozone control process using electronic sensors," *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska*, vol. 14, no. 4, pp. 38-45, 2024. https://doi.org/10.35784/iapgos.6051

[23] A. Sabibolda, V. Tsyporenko, N. Smailov, V. Tsyporenko, and A. Abdykadyrov, "Estimation of the time efficiency of a radio direction finder operating on the basis of a searchless spectral method of dispersion-correlation radio direction finding," in *IFToMM Asian conference on Mechanism and Machine Science (pp. 62-70). Cham: Springer Nature Switzerland*, 2024.

[24] N. C. Braga, "Robotics, mechatronics, and artificial intelligence: Experimental circuit blocks for designers. Newnes," 2002. https://books.google.kz/books?hl=ru&lr=&id=p6rUUZRON5EC&oi=fnd&pg=PP1&dq=the+experience+of+interpreting+electrical+circuits+using+robotics+is+presented&ots=5_eBvswOhx&sig=-eMHtpXogwE7RBb037yJDP3UgiM&redir_esc=y#v=onepage&q&f=false

[25] A. Kuttybayeva, A. Abdykadyrov, G. Tolen, A. Burdin, V. Malyugin, and D. Kiesewetter, "Development and optimization of distributed acoustic sensors for seismic monitoring," in *2024 International Conference on Electrical Engineering and Photonics (EExPolytech) (pp. 64-67). IEEE*, 2024.