



DOI: 10.54919/physics/55.2024.287hd7

Development of methodological recommendations for teaching physics based on the development of spatial imagination

Syrga Berdibekova*

Osh Technological University named after M.M. Adyshev
723503, 81 Isanova Str., Osh, Kyrgyz Republic

Muktarbek Aldashov

Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic

Damira Asanbekova

Kyrgyz National University named after J. Balasagyn
720033, 547 Frunze Str., Bishkek, Kyrgyz Republic

Gulzat Ismailova

Kyrgyz National University named after J. Balasagyn
720033, 547 Frunze Str., Bishkek, Kyrgyz Republic

Anarbek Attokurov

Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic

Abstract

Relevance. In modern education, much attention is paid to the development of critical thinking and cognitive skills of students, including the ability to spatial reasoning. This is important for the successful mastery of subjects, especially physics, where understanding of three-dimensional objects and phenomena is of key importance.

Purpose. The purpose of this study is to create a methodology for teaching physics with an emphasis on the development of students' spatial imaginations. To test the effectiveness of the developed methodology, an experiment was conducted to assess the level of spatial imagination development of the participating students and to compare the results before and after the application of the methodology.

Methodology. One of the key methods developed by the study is the use of visualizations and three-dimensional models in the learning process.

Results. The main results of this study are related to the development of methodological recommendations for teaching physics based on the active development of students' spatial imaginations. This allows students to better understand abstract physical concepts, such as the structure of an atom or vector operations, through visual images. The study also identified effective techniques for developing students' spatial abilities. These include the inclusion of three-dimensional puzzle elements in assignments or solving problems involving the construction of spatial models, which helps students to better understand the geometric relationships and interactions of bodies in space. In addition, the importance of using

Suggested Citation:

Berdibekova S, Aldashov M, Asanbekova D, Ismailova G, Attokurov A. Development of methodological recommendations for teaching physics based on the development of spatial imagination. *Sci Herald Uzhhorod Univ Ser Phys.* 2024;(55):2877-2889. DOI: 10.54919/physics/55.2024.287hd7

*Corresponding author



Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (<https://creativecommons.org/licenses/by/4.0/>)

interactive teaching methods, such as conducting virtual experiments or discussing three-dimensional simulations, was identified as contributing to a deeper understanding of the material.

Conclusions. The practical significance of this study is to provide a specific methodology for physics teachers, which will optimize the learning process, increase students' understanding of the theory and develop their spatial imagination more effectively.

Keywords: educational process; cognitive skills; data visualization; interactive learning; conceptualization.

Introduction

Teaching physics is a complex process, as it involves not only the transmission of information about physical phenomena and laws, but also the development of various cognitive skills in students. Cognitive skills cover a wide range of abilities, including the ability to analyse information, make decisions, and understand abstract concepts. In the context of physics, cognitive skills are particularly important because physics is a science that requires students to think abstractly, see relationships between different phenomena, and use mathematical and logical models to explain and predict physical processes. One of the key aspects influencing the successful acquisition of physical concepts is the development of students' spatial imaginations. In the context of physics, where three-dimensional models, vectors, graphs, and diagrams are often used to visualize physical phenomena, the development of spatial imagination is essential for a deep and complete understanding of the material.

The problem of this study is the lack of attention to the development of spatial imagination in students in various physics education programmes. In modern education, considerable attention is often paid to the acquisition of theoretical knowledge and concepts, but spatial skills, such as the ability to analyse three-dimensional objects and represent them in space, remain relatively underestimated and undeveloped. Thus, it is necessary to improve the educational process by integrating specially designed methodological approaches aimed at developing students' spatial imaginations, which will increase their level of understanding and mastery of physical concepts and their ability to solve problems in physics.

Other authors have also analysed problems in this area, one of which is the insufficient effectiveness of methods and approaches for the development of methodological competence, especially of physics teachers. Raising this issue, A.Kh. Sarybayeva et al. [1] analyse various approaches and tools used to assess and develop methodological skills, focusing on the analysis of current trends in physics teaching and the identification of effective strategies to improve the quality of student learning. At the same time, G.B. Nafasova and B.S. Abdullayeva [2], studying the same issue, focus on the formation of a scientific and scientific world-view in physics teachers. The authors conclude that the formation of this competence in physics teachers will further improve the quality of teaching and provide a deeper and more systematic understanding of physical concepts among students. However, despite the valuable results of the study, the authors did not consider the use of modern educational technologies, such as virtual reality, artificial intelligence, interactive applications, in the context of developing physics teachers' competence. This aspect is quite important, since modern technologies have great

potential for creating learning tools that can stimulate students to be active and participate in interactive tasks.

The problem of ineffective methods and approaches in teaching physics is relevant due to the need to effectively develop students' intuitive imagination, which plays a key role in understanding complex physics concepts. The study by J. Gao et al. [3] presents an interesting approach, proposing the design of a learning model focused on the intensive development of intuitive imagination using NetPad technology. This can greatly increase students' interest in learning physics and help them to understand abstract physics concepts more deeply. On the other hand, the work of M.R. Rahman et al. [4] focuses on the creation of physics learning materials using the problem-based learning methodology. This approach encourages students to actively search for and solve problems, which contributes to the development of critical thinking skills and analytical competence. This methodology can also contribute to deeper learning and increase student motivation to learn. At the same time, the authors' research did not address the issues of evaluating and monitoring the effectiveness of the proposed methods in a real educational environment. Understanding how the methods interact with teachers, how they are accepted by students, and how well they adapt to the learning process is also an important aspect to consider when developing and implementing new educational approaches.

Another problem in this area is the lack of attention to approaches to developing students' critical thinking. M. Jamil et al. [5] draw attention to the importance of developing this skill in the context of physics. Their study analyses existing programmes and teaching methods, but does not delve into specific approaches and technologies that contribute to the development of this important competence. Another issue that requires further research is the development of effective multimedia physics learning modules based on multi presentation. The work of R.B. Prahastiwi and Z. Zain [6] points to the importance of such modules for facilitating the understanding of complex physics concepts, but does not fully analyse their effectiveness and impact on the development of critical thinking in students.

The main problem existing in the field under study is the need to improve the efficiency of physics teaching through the use of modern educational technologies. In this context, it is worth noting the study by V.A. Drougas and S.Z. Bin-Tahir [7], which presents an innovative approach to the use of real 3D models to improve students' critical thinking creativity, personal receptivity, and learning ability. N.A. Shektibaev and T.E. Torekhan [8] consider the use of computer models as a means to improve the effectiveness of physics teaching. This problem was also studied by B. Arymbekov and K. Turekhanova [9], analysing the use of augmented reality in physics teaching

as a tool for intellectual teaching. However, these studies do not address the issues of integrating new technologies into the educational process, preparing teachers to work with them, and evaluating their effectiveness in terms of learning and student outcomes.

The analysis revealed the potential for improving modern educational technologies for teaching physics by developing students' critical thinking, creativity and analytical skills. However, there are still unaddressed problems of educational methods. Thus, the main goal of this paper is to create methodological tools that will improve the quality of physics teaching by focusing on spatial visualization skills. The main objectives are to study the theoretical foundations of spatial thinking and its relationship to the understanding of physical phenomena; to identify the key aspects of spatial thinking that affect the successful learning of physics; to analyse existing approaches and methods of teaching physics with regard to the development of spatial

Materials and methods

To test the developed methodology for the development of spatial imaginations, an experimental study was conducted, including a questionnaire and statistical analysis of the data. To evaluate the effectiveness of the developed methodology, the study used an experimental design, which included teaching students using the new methodology and comparing its effectiveness with traditional teaching methods. The study was conducted at 5 universities in Kyrgyzstan, including B. Osmonov Jalal-Abad State University, Kyrgyz-Uzbek University, Osh State Pedagogical University, Osh State University, Osh Technological University named after M.M. Adyshev, and Osh State University. To implement the study, specialized teaching materials were developed, including methodological manuals, assignments, tests and practical tasks aimed at developing students' spatial thinking. Modern educational technologies, visualization and interactive teaching methods were also used to ensure more effective learning. The experiment was organized as part of the educational process, which made it possible to take into account the real conditions and context of the new methodology in educational practice.

The study collected data on the development of students' spatial imagination, including the results of special tests and questionnaires aimed at assessing the level of spatial thinking. The level of understanding of physical concepts and students' ability to apply them to solve problems were also analysed. In addition, the teachers who used the developed methodology provided data on the course of study and the results of students' performance in the context of the development of spatial imagination. The sample for this study was formed from students of five universities in Kyrgyzstan. From each university, 50 students were selected, studying in the 1st-4th year of study, for a total of 250 participants. The sample was drawn in such a way as to take into account the diversity of educational levels and age groups, including both junior and senior students. A random sampling method was used to form the sample, which ensured the objectivity and reliability of the research results. To analyse the data, the study used a Student's t-test. This statistical method was used to calculate the average level of spatial imagination

development in students in the experimental and control groups. Comparison of the average values before and after the introduction of the new methodology allowed us to determine the effectiveness of the training. Correlation analysis was also used to determine possible links between the level of understanding of physical concepts and the development of spatial thinking. Graphical representation of the data was used to visualize changes in students' performance after the application of the new teaching methodology.

The participants were divided into two groups: an experimental group (students of B. Osmonov Jalal-Abad State University, Kyrgyz-Uzbek University) – 100 people, where the new methodology of developing spatial imagination was applied, and a control group (students of Osh State Pedagogical University, Osh State University, Osh Technological University named after M.M. Adyshev) – 150 people, where traditional approaches to teaching physics were used. Students in the experimental group were taught using the developed methodology, which included steps to develop spatial imagination, including solving spatial imagination problems, using a systematic approach and visualizing concepts through graphs and diagrams. They also participated in interactive activities and practical exercises to improve their understanding of the material. Students in the control group continued their studies using the traditional methodology. The experiment was divided into several stages. At the first stage, the initial level of knowledge and skills of the students was assessed. This was followed by training, including theoretical study of the material, interactive classes, practical exercises and game techniques. The training lasted 3 months. At the end of the training, a control test was conducted, where students from both groups took tests and solved problems to compare their performance before and after the training. Thus, the combination of different methods of scientific knowledge has revealed the potential of the new methodology to improve students' ability to think spatially and solve problems.

Results

Spatial thinking is a complex cognitive process that not only allows a person to navigate in three-dimensional space, but also includes the ability to perceive three-dimensional shapes, estimate distances, predict the movement of objects and manipulate them in space. This process is based on a set of neurophysiological and cognitive mechanisms that allow us to integrate sensory information and form an idea of the three-dimensional structure of the world around us. Spatial reasoning has a wide range of applications, from everyday tasks such as navigating in space and solving geometric problems to complex scientific disciplines, including physics. In the context of physics, spatial reasoning plays a key role in understanding and interpreting three-dimensional concepts such as the motion of bodies, the interaction of forces and energy transformation.

The analysis of the theoretical foundations of spatial thinking and its relationship to the understanding of physical phenomena has revealed key aspects that influence the successful learning of physics. One of these aspects is the ability of students to visualize abstract

concepts and transform them into concrete images. This ability plays an important role in the learning of physics. For example, when students study vectors and directional quantities, they are faced with abstract concepts. Students with developed spatial reasoning can easily visualize the direction and length of a vector on a three-dimensional plane, which helps them to concretize these abstract concepts. If we consider a velocity vector in physics, a student with developed spatial reasoning can visualize this vector as directed from an initial point to an end point, which allows them to better understand its physical nature and application in problems [10]. Another example can be found in the study of electric fields. Students with developed spatial reasoning can easily imagine the lines of field voltage and visualize how they are distributed in space. This allows them to understand the interactions between charges and how electric fields are formed in different conditions. For example, they can easily visualize an electric field around a charged body or between two charges, which helps them to better understand the physical processes involved in electrostatics.

Another important aspect of spatial reasoning is related to understanding the relative position and orientation of objects, which is important when studying physical phenomena such as electromagnetism. For example, when analysing a system of magnetic and electrical elements, students need to understand how they are located relative to each other, as this directly affects their interaction and the way the fields change [11]. Representing the directions of forces, positions of objects, and trajectories of charges is an important part of the analysis. Students with developed spatial reasoning have the ability to easily imagine these relationships and visualize the processes of interaction between system elements. For example, they can imagine a magnetic field around a conductive coil with a current and determine the direction of the Lorentz force acting on a moving charge in this field.

Spatial reasoning plays a significant role in the analysis of visual information, especially in the study of optics. It makes it easy to analyse light ray diagrams that show the directions of reflection or refraction of light on different surfaces [12]. If a student looks at a graph of light rays incident on a mirror surface, they can visualize how the light rays are reflected at a certain angle and what changes occur to their direction after reflection, thanks to their spatial thinking. Students can also analyse light refraction graphs through optical media with different refractive indices, which helps them understand how the path of light changes when it passes from one medium to another. In addition, spatial reasoning plays an important role in analysing optical phenomena such as diffraction and interference. If considering the study of the three-dimensional structure of an interference grating as an example, it is possible to note that students with developed spatial reasoning are able to visualize this structure and understand how changes in the distance between the slits affect the interference pattern. By analysing the changes in light intensity on the screen when the grating or diffraction slit parameters are changed, thanks to their spatial imagination, students can clearly see how changes in the grating structure affect the interference result, which allows them to better understand the principles of light diffraction and interference [13]. Thus, the development of

spatial thinking in students is a key factor for the successful learning of physics material, as it provides an opportunity for a deeper understanding of three-dimensional objects and phenomena, and contributes to a more effective use of visual teaching methods and understanding of physical concepts.

This study analysed existing approaches and methods of teaching physics that can be used to develop students' spatial imaginations, which helped to identify optimal teaching strategies. One of these methods is the use of three-dimensional models and visualizations. The use of visual aids in physics education through interactive simulations and virtual laboratories is a modern technique that allows students to gain a deeper understanding of physical concepts. This technique includes the use of software tools such as computer simulations, visualizations of physical processes, and interactive applications [14]. For example, virtual laboratories allow students to experiment with different conditions and system parameters, observe changes in real time, and analyse the results. Technologies used in this methodology include virtual reality (VR) software, animation tools, computer simulations of physical phenomena, and other visualization tools. This not only makes learning more engaging and accessible, but also contributes to students' deeper understanding of spatial concepts, and

The methodology of working with tasks and exercises in teaching physics is aimed at developing students' spatial thinking by solving problems that require the analysis of three-dimensional images and configurations of objects. This includes tasks for plotting the trajectories of bodies, considering the spatial arrangements of a system of bodies in different conditions, and analysing the three-dimensional relationships between objects [15]. Such exercises not only help students develop skills in perceiving and analysing spatial objects, but also contribute to a deeper understanding of physical laws, as they require the application of theoretical knowledge in practice and develop the ability to apply it to real-life situations. This methodology also involves the use of different types of tasks with a gradual increase in complexity, which allows students to gradually deepen their knowledge and skills in spatial thinking and physics.

The active learning methodology includes a variety of techniques aimed at actively engaging students in the learning process. This includes organizing group discussions where students exchange opinions, analyse problem situations and find solutions together. Another important element is the collective solution of problematic tasks that require a non-standard approach and the use of spatial thinking [16]. During such classes, students learn to develop strategies for collaboration, analysis and critical thinking, which contributes to a deeper and more comprehensive understanding of spatial concepts in physics. This methodology also promotes the development of communication skills, independence, and confidence in their knowledge, which is important for the successful adaptation of students to complex physics tasks and situations.

The use of multimedia resources in physics education covers a wide range of tools aimed at visualizing and explaining complex concepts. It includes not only video lectures and animations, but also interactive presentations,

simulations and virtual laboratories. Video lectures allow teachers to demonstrate concepts in practice, review examples and explain theoretical aspects. Animations and interactive presentations help to visualize processes that cannot be observed in real time or at scale, such as the interaction of molecules in thermodynamic phenomena or electromagnetic waves [17]. These resources make the material more accessible and understandable for students, improving their spatial thinking and promoting deeper learning. In addition, multimedia materials make the learning process more interactive and engaging, which stimulates students' motivation to learn and actively participate in the learning process. In general, the use of multimedia resources not only improves the quality of learning, but also contributes to the development of key skills necessary for the successful mastery of physics concepts.

In addition, gaming technologies and educational games are an effective tool in physics education. They

allow students to participate in interactive scenarios where they can interact with physical phenomena and laws through game mechanics. This approach stimulates active student participation and increases the level of interest in learning physics, as it makes the learning process more interesting and engaging [18]. Within the framework of gaming technologies and educational games, students can experiment, make assumptions and observe the results of their actions, which contributes to a deeper and more conscious learning of the material. In addition, such methods combine learning and entertainment, which creates a positive environment and helps reduce stress, which in turn contributes to more effective learning. Based on the data obtained, we developed methodological recommendations (Table 1) aimed at the effective development of students' spatial imagination, which in turn contributes to a deeper and better learning of physical concepts and phenomena.

Table 1. Methodological recommendations for teaching physics with an emphasis on the development of spatial imagination

Stage	Objective	Implementation steps
I. Preparation	Define the overall objectives of the programme	<ul style="list-style-type: none"> - the main topics and concepts of physics to be included in the curriculum; - to assess the level of students' prior knowledge in physics (introductory testing).
II. Theory	Introducing basic physics concepts and laws through visualizations and animated models	<ul style="list-style-type: none"> - theoretical lectures, during which the teacher explains the basic physical laws and phenomena; - use of video lectures with visual demonstrations, animations, and graphs to explain complex concepts in a clear way; - use of special software and tools to create animated models of physical phenomena; - showing animations during lectures or in the form of videos to visualize illustrations of physical processes; - Explaining relationships and principles by demonstrating changes in animated models when parameters or conditions change.
III. Virtual experiences	Conducting virtual laboratory work to study physical phenomena and laws through interactive simulations	<ul style="list-style-type: none"> - creation of virtual laboratory scenarios involving various physical phenomena and processes; - conducting experiments with the ability to change parameters, conditions and observe results in real time; - providing students with the opportunity to actively interact with virtual facilities, such as changing parameters, starting and stopping experiments; - support for interactive functions such as interaction with objects, measurement of parameters and data generation; - collecting and analysing data obtained as a result of virtual experiments; - Discussion and interpretation of the results obtained in the context of the physical concepts and laws studied.
IV. Interactive game scenarios	Use of educational games and game scenarios to consolidate knowledge	<ul style="list-style-type: none"> - development of game scenarios in which students have to solve problems and conduct experiments related to physical phenomena; - use of gamification to motivate students and create interesting educational tasks; - incorporation of elements of three-dimensional modelling, route planning or spatial puzzles into game tasks; - creating an interactive environment where students can interact with objects, conduct experiments and see the results of their actions in real time.
V. Collective research of physical phenomena	Organizing group classes to teach students through discussion of physical concepts and solving problems	<ul style="list-style-type: none"> - providing tasks requiring analysis of spatial configurations and relationships between objects; - conducting group problem-solving exercises aimed at developing spatial thinking and the ability to see relationships; - facilitating the exchange of ideas and experiences between group members to enrich their knowledge and understanding of the topic; - organizing discussions and debates to stimulate critical thinking and analysis of physical phenomena.

	requiring spatial thinking	
VI. Conclusion	Summarizing and assessing progress	- Conducting final tests and assessing the level of knowledge and skills.

Source: compiled by the authors.

Defining the overall objectives of the programme is the first and key step in developing a physics curriculum. At this stage, it is necessary to identify the main topics and concepts of physics that will be included in the curriculum. For example, the programme may focus on the study of mechanics, electromagnetism, thermodynamics, and optics. Specific topics may include Newton's laws, electrostatics, the laws of conservation of energy and momentum. Defining the overall objectives will help shape the structure of the curriculum and ensure that the material is taught consistently. Next, an important step in the preparation is to assess the level of students' prior knowledge of physics. For this purpose, an introductory test is conducted to identify students' initial knowledge and understanding. The test may include questions about basic physics concepts such as force, energy, heat transfer, and electricity. After analysing the test results, it is possible to identify areas where students need more in-depth study, as well as to determine their strengths in physics. This will help to adapt the curriculum to the level of training of the audience and make learning more effective and convenient for students.

The introduction of basic physical concepts and laws through visualization and animation models begins with theoretical lectures. The teacher uses this format to explain basic physical laws and phenomena. For example, a lecture on mechanics may include an explanation of Newton's laws or conservation laws. Another important tool is video lectures with visual demonstrations, animations, and graphs that help to explain complex concepts in a clear way. For example, to illustrate the law of conservation of energy, it is possible to use an animation showing the transformation of energy into different forms when an object moves. A variety of technologies and software can be used to implement this stage. For example, software such as Blender, Autodesk Maya, Cinema 4D, and Unity can be used to create animations and visualizations of physical phenomena [19]. These programs provide a wide range of tools for modelling, animating and creating interactive scenes, making it possible to demonstrate complex physical processes. In addition, there are specialized platforms and software, such as PhET Interactive Simulations, which offer interactive modelling and simulations of physical phenomena, allowing students to experiment and explore different scenarios [20]. Such technologies and applications allow for the creation of engaging and visual learning materials, contributing to a deeper understanding of physics concepts among students.

Conducting virtual laboratory activities to study physical phenomena and laws through interactive simulations begins with the creation of laboratory scenarios. For this purpose, various software tools can be used, such as Labster, which offers a wide range of virtual physics laboratories with the ability to interact and change the parameters of experiments [21]. An example of a virtual experiment is a simulation of Ohm's law, where students can change the resistance in a circuit and observe

the changes in current and voltage in real time. Finally, after the virtual experiments are completed, the results are analysed and discussed. Specialized software tools, such as DataStudio or Logger Pro, can be used to collect and analyse data, allowing for graphical display and analysis of the data [22]. Discussion and interpretation of the results takes place in the context of the physical concepts and laws being studied, which helps students to better understand the material and see its application in practice.

The use of educational games to consolidate knowledge begins with the development of game scenarios in which students have to solve problems and conduct experiments related to physical phenomena [23-25]. For example, it is possible to create a game where players need to control the forces and movements of objects in space, taking into account physical laws (a game about falling bodies under the influence of gravity or controlling electrical circuits). Gamification is used to motivate students and create interesting educational tasks. It is recommended to introduce a system of achievements, rewards, and difficulty levels that will encourage students to actively participate and achieve goals. In addition, game tasks can include elements of three-dimensional modelling, route planning or solving spatial puzzles. For example, a game using VR technology will allow students to immerse themselves in a three-dimensional space and interact with objects, which will enhance learning and develop spatial thinking.

The organization of group lessons for student learning begins with the provision of tasks that require the analysis of spatial configurations and relationships between objects. Students can explore three-dimensional objects and analyse their shape, volume, surface and other characteristics. The task may be to determine the volume of a complex three-dimensional figure or to find its centre of mass. Next, group problem-solving exercises are conducted to develop spatial thinking and the ability to see relationships between objects. For this purpose, various technologies can be used, such as virtual whiteboards for teamwork on tasks or specialized software for modelling three-dimensional spatial configurations. Organizing discussions and debates is another method of stimulating critical thinking and analysis of physical phenomena [26]. During such discussions, students can express their opinions, argue their points of view, analyse data and facts, and identify cause-and-effect relationships in physical processes. Debates, in turn, allow students to develop the skills of persuasive presentation, analysis of opposing points of view and compromise, which contributes to a deeper understanding and mastery of the concepts and laws of physics [27; 28].

Summing up and assessing progress is the final part of the educational process. Summative tests allow assessing the level of knowledge and skills acquired by students at the end of a study programme. In addition to testing, it is also important to evaluate students' progress throughout the course of study. This may include regular reports on

assignments, participation in discussions and group sessions, and analysis of the results of virtual experiences and game scenarios [29]. For example, students can present their projects, give presentations, or demonstrate their skills in analysing physical phenomena through team research. Assessment of progress and summative evaluation should be tailored to the objectives of the curriculum, as well as to the specific tasks and techniques used in physics education [30].

To test the effectiveness of the developed methodology, this study conducted an experimental study with students from different universities in Kyrgyzstan. The experimental group, consisting of students from B. Osmonov Jalal-Abad State University and Kyrgyz-Uzbek University, was trained using a new methodology focused on the development of spatial thinking. This methodology included specialized teaching materials and interactive technologies designed to improve learning and develop skills in analysing spatial concepts. While the control group, consisting of students from other universities (Osh State Pedagogical University, Osh State University, Osh Technological University named after M.M. Adyshev), continued their studies using traditional methods of teaching physics, which did not include new innovative approaches and technologies. This approach allowed for a

comparative analysis of the effectiveness of the new methodology in relation to traditional methods.

The experiment collected data on the development of students' spatial imaginations, their level of understanding of physical concepts, as well as pre- and post-test results. After analysing the collected data, the following results were revealed. Students in the experimental group who were taught using the new methodology showed a significant improvement in their level of understanding of physical concepts. They learned the material better and successfully applied it in practice, as evidenced by the test results. The results of the study also show a significant improvement in the academic performance of students taught using the new methodology compared to traditional approaches. They demonstrated higher efficiency in solving problems related to spatial thinking, as well as a deeper understanding of physical concepts. A comparison of their performance before and after the training showed a significant increase in the level of knowledge and skills in this area. The average test score of the students before the training was 73%, and after the training it increased to 92% (Figure 1). The experimental group also demonstrated higher practical skills in applying spatial thinking concepts to various tasks, including those related to physical phenomena and relationships in space.

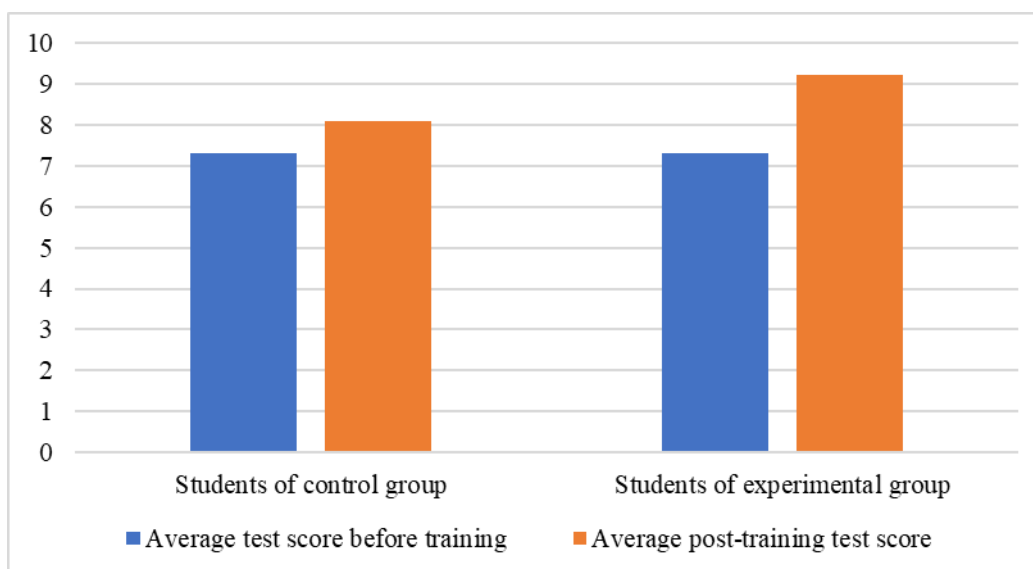


Figure 1. Learning outcomes of the experimental and control groups.

Source: compiled by the authors.

The results of the data analysis clearly indicate that the new teaching methodology has successfully coped with the task of developing spatial imagination and increasing the level of understanding of physical concepts among students. The participants in the experimental group showed significant progress in learning the material and were more confident in applying their knowledge in practice compared to those who were taught using traditional methods. First and foremost, the new methodology provided students with a wider range of learning tools, including visualizations, interactive tasks and modelling, which enabled them to better grasp complex concepts and apply them in real-life situations. The use of animations and interactive graphs allowed students to present abstract physical phenomena and processes in a more visual way. In addition, an important component of the new methodology was the opportunity

for students to actively participate in the learning process. Interactive classes, practical exercises and group discussions contributed to a deeper understanding of the material and encouraged students to work independently and find solutions. It should also be noted that the use of modern educational technologies, including online resources and specialized programmes, enabled students to access additional materials and exercises, which also contributed to their learning.

Thus, the results confirm that the use of innovative approaches in education based on interactivity, visualization and active participation of students has great potential to achieve higher learning outcomes and develop key competences.

Discussion

The analysis of the study results confirmed that the development of spatial thinking in students is a key factor for the successful learning of physics. This aspect provides an opportunity for a deeper understanding of three-dimensional objects and phenomena, and also contributes to the effective use of visual teaching methods and a better understanding of physical concepts. Thus, the developed methodological recommendations based on the development of spatial thinking have a significant potential to improve the quality of physics teaching and stimulate students' interest in this discipline.

Comparison of the results obtained in the study with the works of other authors also confirms the importance of spatial thinking in physics education. In particular, M. Kozhevnikov et al. [23] studied the relationship between spatial thinking and successful problem-solving in physics. The authors noted that students with developed skills of such thinking have a more accurate and complete visualization of physical objects, which significantly contributes to the understanding of complex physical concepts. We should agree with the authors' conclusions, as this hypothesis was confirmed in the results of the experiment with students. The training aimed at developing spatial thinking did indeed help students to visualize three-dimensional objects and phenomena more effectively, which had a positive impact on their ability to understand and analyse physical concepts [31-33].

Studies conducted by E. Giannetto [24] and F. Salis [25] focus more on the importance of visual interpretation of physical phenomena for their deeper understanding. E. Giannetto emphasizes in his paper that the development of effective visualization is sufficient for the analysis of three-dimensional objects and processes in physics. The author argues this by analysing the evolution of visual thinking in the physical and mathematical context from the era of Descartes to quantum physics, as well as highlighting the transformations in the ways of perceiving and visualizing physical phenomena that accompanied scientific discoveries. The work of F. Salis also emphasizes the importance of this aspect in the study of physics, as the ability to visualize plays a key role in understanding and interpreting complex phenomena and patterns. We can partially agree with the author's conclusions. Indeed, the introduction of visualization into the developed teaching methodology has shown that the active use of visual methods simplifies the understanding of complex physical concepts and contributes to a deeper learning of the material by students [34]. However, we should also disagree that this is sufficient for a full understanding and application of physical concepts in different contexts and tasks. Visualization is an important tool, but its effectiveness is enhanced and complemented by other educational approaches, such as active discussion, solving practical problems, and educational games [35; 36].

C.C. Wang et al. [26] concluded that the development of scientific imagination is a key factor for the successful mastery of physical concepts. Students with a more developed scientific imagination show a higher level of understanding and perform better in tasks requiring the analysis and application of scientific knowledge. We should agree with these research results, which were also confirmed in the context of the development of a

methodology aimed at developing such imagination, as well as the successful testing of this methodology. However, when analysing the authors' work, attention should be paid to their development of special methods and tools that can be used to measure and evaluate progress in the development of these skills. Among these tools is the Scientific Imagination Test, which includes creative problem-solving tasks and visual modelling of scientific concepts. It should be agreed that the use of such a tool will allow for an objective assessment of students' ability to apply knowledge in non-standard situations and monitor the development of the level of visualization of complex scientific processes.

Most authors note the need to use various technologies in physics teaching, such as visual methods, virtual laboratories, and educational games [37-40]. They emphasize that these technologies can significantly improve the learning process and increase students' interest in physics. However, at the same time, some researchers also emphasize that the use of technology is not sufficient for the full acquisition of physics concepts [41; 42]. T.P. Socrates et al. [27] in their study focused on the use of educational games in the context of ethnoscience content. They investigate how such games can be used to teach physics regarding students' cultural and ethnic backgrounds. The authors point out that a game-based approach can make learning more engaging and fun for students, especially when taking into account their socio-cultural context. Although the use of educational games is an effective method of stimulating interest and improving understanding of physics concepts, it is still worth disagreeing that educational games should necessarily consider cultural and ethnic characteristics [43]. Focusing only on such aspects can reduce the universality of games and limit their applicability in different educational environments. Instead, one should strive to create more comprehensive and universal educational games that can be adapted to different cultural contexts, but not limit oneself to this aspect in the process of developing educational games [44].

The work of E. Okono et al. [28] on virtual labs in physics education found that such technologies do contribute to improving learning outcomes. The authors note that virtual laboratories allow students to dive deeper into the learning material and experiment with various physical phenomena and laws. This creates a more interactive and engaging learning environment, which can stimulate interest in physics and increase student motivation. Virtual laboratories were also used in the context of the development and testing of the new methodology, which confirmed the effectiveness of using modern technologies in physics teaching and demonstrated their potential to improve the quality of education [45; 46]. But we should also agree with another conclusion of the authors, that virtual laboratories can be especially useful in the context of remote education, when access to real laboratories is limited. This allows students to gain practical experience and conduct experiments without leaving home.

M. Arlim et al. [29] analyse the needs for interactive multimedia materials for teaching physics based on scientific literacy in their study. The authors use digital technologies and multimedia approaches to create more

interactive and engaging learning materials, which helps to increase the level of student engagement in the learning process. One of the key results of the study is the identification of the need to adapt teaching materials to the individual needs and level of scientific literacy of students. The same conclusion was reached by P.D. Sundari et al. [30] in their work, emphasizing that personalized approaches make learning more effective, as they allow teachers to better adapt to the individual needs of students and create more accessible and understandable learning materials for them. But this statement is only partially true. Educational institutions do not always have sufficient resources to adapt each learning material to the individual needs of each student [47-49]. In addition, the individual needs of students may be ambiguous, and in this case, it will be difficult to take them into account in the general methodological practice [50]. Therefore, more universal methodologies should be developed to cover a wide range of student needs.

L.J. Thoms et al. [31] focus on a very important issue in this area, namely the importance of digital literacy and competencies related to the digitalization of education in the context of teaching and learning physics. The authors' study emphasizes that modern technologies play a key role in the educational process and require appropriate skills and knowledge from teachers. Thus, we should agree with the authors that in order to improve the digital literacy and competencies of physics teachers, it is necessary to organize regular trainings and seminars on the use of modern digital tools and technologies in the educational process, as well as to create specialized courses that will help teachers master the basic skills of working with digital learning platforms and programmes.

In general, the results of this study confirm the hypothesis that the development of students' spatial imagination significantly affects the effectiveness of their learning of physics. Based on the data obtained during the analysis and experiments, it can be argued that students with developed spatial thinking have a higher level of understanding of physical concepts, are better able to visualize complex physical phenomena, and, as a result, are more successful in solving problems and applying the knowledge gained in practice.

Conclusions

The study on the development of a new physics teaching methodology aimed at developing students' spatial imagination has yielded significant results. The analysis of these results confirmed that the emphasis on the use of visualization, interactive simulations and virtual reality in physics teaching methods contributes to a significant improvement in students' understanding of spatial concepts.

The developed methodology is based on the active use of modern technologies and innovative approaches to learning. It includes the creation of interactive learning materials using visualization, interactive simulations, and virtual reality. These tools allow students to visualize complex physical concepts, conduct virtual experiments and interact with the material on a deeper level. In addition, the methodology includes interactive classes, solving practical problems aimed at developing students' spatial thinking and critical thinking. The new methodology also

makes extensive use of educational games and tasks specially designed for in-depth study of physical phenomena. These games not only help students learn the material better, but also stimulate their learning motivation and interest in the subject.

The experimental study conducted as part of this work has confirmed the effectiveness of the new physics teaching methodology. The introduction of modern technologies has made it possible to create a learning environment that is as close as possible to real physical phenomena and processes. Students who used this methodology showed a significant increase in their understanding of physical concepts and academic performance. An analysis of the results showed that the average score of students taught using the new methodology increased from 73% to 92%. This is a significant performance indicator, which indicates the positive impact of methodological recommendations based on the development of spatial imaginations on the educational process. However, the small scale of the experiment and the need for additional testing methods on a wider selection of students should be taken into account. Thus, the use of modern technologies in physics teaching methods has a positive impact on the educational process, providing students with a more interactive and understandable approach to learning complex spatial concepts. This opens up prospects for the further development of teaching methods using new technologies and innovative approaches to the formation of knowledge and skills in students.

Further research in this area could be aimed at integrating the latest technologies, such as artificial intelligence and machine learning, into physics teaching methods based on the development of spatial imaginations. The use of artificial intelligence can help automate the process of adapting learning to individual student needs, optimizing the content of educational materials and creating personalized learning paths. In addition, it is important to develop systems for assessing students' competence that are adapted to the specifics of this teaching methodology. This may include the creation of algorithms and tools for assessing the level of spatial thinking, understanding of physical concepts and students' ability to apply them in practice. Such assessment systems will allow not only to monitor students' progress, but also to identify their strengths and weaknesses, which will help to adapt the learning process more effectively. Finally, it is important to develop a methodology for in-service training of teachers in accordance with this methodology. The training of teachers should be focused on developing their competencies in spatial thinking and the introduction of modern educational technologies to achieve better results in the learning process.

Acknowledgements

None.

Conflict of Interest

None.

References

- [1] Sarybayeva AKh, Ormanova GK, Batyrbekova AZh, Usembayeva IB. Research methods for the development of methodological competence of future physics teachers. *Bull Karaganda Uni. Ped Series*. 2023;111(3):64-74. <https://doi.org/10.31489/2023ped3/64-74>
- [2] Nafasova GB, Abdullayeva BS. Forming the scientific and logical outlook of future physics teachers. *Sci J Fergana State Uni*. 2023;29(1):208-211. https://doi.org/10.56292/SJFSU/vol29_iss1/a147
- [3] Gao J, Li J, Wang J, Zhou Q, Zhang C, Guan H. Design of teaching model for intuitive imagination development supported by NetPad. In: *Computer Science and Education* (pp. 146-156). Singapore: Springer; 2023. https://doi.org/10.1007/978-981-99-2446-2_14
- [4] Rahman MR, Suyidno S, Suryajaya S. Development of physics teaching material with problem-based learning to train students' problem-solving skills. *J Ilmiah Pendidik Fisik*. 2023;7(3):459-470. <https://doi.org/10.20527/jipf.v7i3.9395>
- [5] Jamil M, Hafeez FA, Muhammad N. Critical thinking development for 21st century: An analysis of physics curriculum. *J Social Org Matter*. 2024;3(1):1-10. <https://doi.org/10.56976/jsom.v3i1.45>
- [6] Prahastiwi RB, Zain ZA. Multirepresentation-based physics E-Module development. *Konst – J Fisik Pendidik Fisik*. 2023;8(1):45-52. <https://doi.org/10.20414/konstan.v8i01.193>
- [7] Drougas VA, Bin-Tahir SZ. Real 3d model for physical sciences contribution to the creative capacity of critical thought, personal perception and the educational ability of the students. *Uniq J Exact Sci*. 2021;2(3):1-10. <https://www.neliti.com/publications/545718/real-3d-model-for-physical-sciences-contribution-to-the-creative-capacity-of-critical-thought>
- [8] Shektibaev NA, Torekhan TE. Computer models as a means of improving the effectiveness of teaching physics. *News Khoja Akhm Yassawi Kazakh-Turk Int Uni*. 2023;27(4):29-41. <https://doi.org/10.47526/2023-4/2524-0080.03>
- [9] Arymbekov B, Turekhanova K. Observation of augmented reality in teaching physics as a tool of intellectual teaching. *Bull Al-Farabi Kazakh Nation Uni, Series Educ Sci*. 2022;73(4):128-141. <https://doi.org/10.26577/JES.2022.v73.i4.12>
- [10] Brewer H. Carceral witnessing and the spatial imagination. In: *Contemporary Representations of Forced Migration in Europe* (pp. 135-163). Cham: Palgrave Macmillan; 2024. https://doi.org/10.1007/978-3-031-47831-4_6
- [11] Stinner A. Scientific method, imagination, and the teaching of physics. *Phys Canada*. 2003;59(6):335-346. <https://pic-pac.cap.ca/index.php/Issues/showpdf/article/v59n6.0-a3031.pdf>
- [12] Ismael J. Time and the visual imagination: From physics to philosophy. In: *Oxford Studies in Philosophy of Mind* (pp. 217-247). Oxford: Oxford Academic; 2022. <https://doi.org/10.1093/oso/9780192856685.003.0007>
- [13] Liao J, Chen X, Fu Q, Du L, He X, Wang X, Han S, Zhang D. Text-to-image generation for abstract concepts. *Proceed AAAI Conf Artifc Intell*. 2024;38(4):3360-3368. <https://doi.org/10.1609/aaai.v38i4.28122>
- [14] Eleo MC, Manguilimotan YB. Physics education technology (PhET) interactive simulations as a teaching aid in enhancing students' performance in physics. *Epra Int J Multidiscip Res*. 2024;10(3):60-64. <https://doi.org/10.36713/epra15991>
- [15] Watzka B. Interactive exercise tasks in physics education: Comparison between online, face-to-face and self-study instruction. *Lesson Learn*. 2022;2(2):1-11. <https://doi.org/10.25369/ll.v2i2.53>
- [16] Adebisi TA, Feyijimi, T. Influence of spatial ability levels on the performance and attitude of physics students. *Eduk: J Educ Innov*. 2023;3(1):15-25. <https://doi.org/10.56916/ejip.v3i1.476>
- [17] Nyirahabimana P, Minani E, Nduwingoma M, Kemeza I. Students' perceptions of multimedia usage in teaching and learning quantum physics: Post-assessment. *J Baltic Sci Educ*. 2023;22(1):37-56. <https://doi.org/10.33225/jbse/23.22.37>
- [18] Cuong LH, Giang NTH. Designing digital educational games by integrating the teaching process into the technology platform of entertainment games. *Int J Curr Sci Res Rev*. 2024;7(3):1479-1488. <https://doi.org/10.47191/ijcsrr/V7-i3-10>
- [19] Ramya MV, Tippannavar SS. Virtual reality lab using Unity3D for educational applications using ESP8266 for digital electronics. *GRENZE Int J Engineer Tech*. 2024;10(1):1590-1596. <https://thegrenze.com/index.php?display=page&view=journalabstract&absid=2441&id=8>
- [20] Yunitasari Y, Firdaus ML, Wardana RW, Putra S. Applying PhET interactive simulations media with a guided investigation approach to improve student's critical thinking skills. *Int J Res Educ*. 2024;4(1):169-178. <https://doi.org/10.26877/ijre.v4i1.17327>
- [21] Mosqueda CEH. Effect of utilising interactive virtual lab on student performance in physics. *Int J Advan Res*. 2023;11:1718-1741. <http://dx.doi.org/10.21474/IJAR01/17041>
- [22] Kumaş A. Designing technological content curriculum materials supported by logger pro: An action research. *Int J Progress Educ*. 2022;18(1):147-173. <https://doi.org/10.29329/ijpe.2022.426.9>
- [23] Kozhevnikov M, Motes MA, Hegarty M. Spatial visualisation in physics problem solving. *Cognit Sci*. 2010;31(4):549-579. <https://doi.org/10.1080/15326900701399897>

- [24] Giannetto E. The transformations of physico-mathematical visual thinking: From descartes to quantum physics. In: *Scientific Visual Representations in History* (pp. 237-248). Cham: Springer; 2023. https://doi.org/10.1007/978-3-031-11317-8_8
- [25] Salis F. Scientific imagination. In: *The Routledge Encyclopedia of Philosophy* (pp. 134-138). Abington: Taylor and Francis; 2023. <https://doi.org/10.4324/9780415249126-Q154-1>
- [26] Wang CC, Ho HC, Cheng CL. Examining the learning progression of undergraduate students' scientific imagination: A measurement perspective. *SAGE Open*. 2022;12(4). <https://doi.org/10.1177/21582440221144981>
- [27] Socrates TP, Afrizon R, Hidayati H, Hidayat R. The needs analysis for an educational physics game with scientific literacy and ethnoscientific content. *J Pendidik Fisik Teknol*. 2023;9(1):151-162. <https://doi.org/10.29303/jpft.v9i1.5079>
- [28] Okono E, Wangila E, Chebet A. Effects of virtual laboratory-based instruction on the frequency of use of experiment as a pedagogical approach in teaching and learning of physics in secondary schools in Kenya. *Africa J Empir Res*. 2023;4(2):1143-1151. <https://doi.org/10.51867/ajernet.4.2.116>
- [29] Arlim M, Afrizon R, Hufri H, Dewi WS, Sundari PD. Need analysis of interactive multimedia based on scientific literacy in physics learning. *Phys Learn Educ*. 2023;1(2):91-99. <https://doi.org/10.24036/ple.v1i2.36>
- [30] Sundari PD, Hidayati Saputra D, Sari SY, Anusba EB. Analysis of teaching materials needs for digital module development in physics learning: Teachers perception. *J Penelit Pendidik IPA*. 2024;10(2):674-680. <https://doi.org/10.29303/jppipa.v10i2.6093>
- [31] Thoms LJ, Becker S, Kremser E. Teaching and learning physics with digital technologies – What digitalisation-related competences are needed? In: *New Challenges and Opportunities in Physics Education* (pp. 313-326). Cham: Springer; 2023. https://doi.org/10.1007/978-3-031-37387-9_21
- [32] Doroshkevich AS, Lyubchik AI, Shilo AV, Zelenyak TY, Glazunova VA, Burhovetskiy VV, Saprykina AV, Holmurodov KT, Nosolev IK, Doroshkevich VS, Volkova GK, Konstantinova TE, Bodnarchuk VI, Gladyshev PP, Turchenko VA, Sinyakina SA. Chemical-electric energy conversion effect in zirconia nanopowder systems. *J Surface Investig*. 2017;11(3):523-529. <https://doi.org/10.1134/S1027451017030053>
- [33] Shylo A, Doroshkevich A, Lyubchik A, Bacherikov Y, Balasoiu M, Konstantinova T. Electrophysical properties of hydrated porous dispersed system based on zirconia nanopowders. *Appl Nanosci*. 2020;10(12):4395-4402. <https://doi.org/10.1007/s13204-020-01471-2>
- [34] Auyeshov AP, Arynov KT, Yeskibayeva CZ, Zhylykybayev OT, Beisbekova RD, Alzhanov KB. Effect of α - and β -polymethyle nenaphthalenesulfonate upon properties of cement grout and concrete. *Modern Appl Sci*. 2015;9(6):173-183. <https://doi.org/10.5539/mas.v9n6p173>
- [35] Davlatshoevich ND, Ashur KM, Saidali BA, Kholmirezotagoykulovich K, Lyubchik A, Ibrahim M. Investigation of structural and optoelectronic properties of N-doped hexagonal phases of TiO₂ (TiO₂-xNx) nanoparticles with DFT realization: OPTIMIZATION of the band gap and optical properties for visible-light absorption and photovoltaic applications. *Biointerf Res Appl Chem*. 2022;12(3):3836-3848. <https://doi.org/10.33263/BRIAC123.38363848>
- [36] Makarova TL, Zakharchuk I, Geydt P, Lahderanta E, Komlev AA, Zyrianova AA, Lyubchik A, Kanygin MA, Sedelnikova OV, Kurennya AG, Bulusheva LG, Okotrub AV. Assessing carbon nanotube arrangement in polystyrene matrix by magnetic susceptibility measurements. *Carbon*. 2016;96:1077-1083. <https://doi.org/10.1016/j.carbon.2015.10.065>
- [37] Grigore E, Pantea O, Bombos D, Calin C, Bondarev A, Gheorghe C. Effect of inhibitors based amine derivates on some carbon steel corrosion. *Rev Chim*. 2015;66(5):685-690.
- [38] Coutinho ML, Miller AZ, Rogerio-Candelera MA, Mirão J, Cerqueira AL, Veiga JP, Águas H, Pereira S, Lyubchik A, Macedo MF. An integrated approach for assessing the bioreceptivity of glazed tiles to phototrophic microorganisms. *Biofoul*. 2016;32(3):243-259. <https://doi.org/10.1080/08927014.2015.1135242>
- [39] Lopushnyak V, Polutrenko M, Hrytsulyak H, Plevinskis P, Tonkha O, Pikovska O, Bykina N, Karabach K, Voloshin Y. Accumulation of Heavy Metals in Silphium Perfoliatum L. for the Cultivation of Oil-Contaminated Soils. *Ecol Engin Environ Technol*. 2022;23(3):30-39. <https://doi.org/10.12912/27197050/147145>
- [40] Litvinova O, Tonkha O, Havryliuk O, Litvinov D, Symochko L, Dehodiuk S, Zhyla R. Fertilizers and Pesticides Impact on Surface-Active Substances Accumulation in the Dark Gray Podzolic Soils. *J Ecol Engin*. 2023;24(7):119-127. <https://doi.org/10.12911/22998993/163480>
- [41] Dikanbayeva AK, Auyeshov AP, Satayev MS, Arynov KT, Yeskibayeva CZ. Researching of sulfuric acid leaching of magnesium from serpentines. *News Nat Acad Sci Rep Kazakhstan, Seri Geol Techn Sci*. 2021;5(449):32-38. <https://doi.org/10.32014/2021.2518-170X.95>
- [42] Mihai S, Bondarev A, Negoiu M. Complexes of Pt(II) and Pd(II) with symmetrical bipodal N,N-bis-antipyrine-N'pyridinethioureas. *Rev Chim*. 2013;64(2):191-194.
- [43] Bondarev A, Gheorghe C-G. Adsorptive removal of crystal violet dye from aqueous solutions using natural resource systems. *Desalin Water Treatm*. 2022;264:215-223. <https://doi.org/10.5004/dwt.2022.28560>
- [44] Subhoni M, Kholmurodov K, Doroshkevich A, Asgerov E, Yamamoto T, Lyubchik A, Almasan V, Madadzada A. Density functional theory calculations of the water interactions with ZrO₂ nanoparticles Y₂O₃ doped. *J Phys: Conf Ser*. 2018;94(1):012013.

- [45] Lyubchik A, Filonovich SA, Mateus T, Mendes MJ, Vicente A, Leitão JP, Falcão BP, Fortunato E, Águas H, Martins R. Nanocrystalline thin film silicon solar cells: A deeper look into p/i interface formation. *Thin Sol Films*. 2015;591:25-31. <https://doi.org/10.1016/j.tsf.2015.08.016>
- [46] Petrov EG, Shevchenko YV, Gorbach VV, Lyubchik S, Lyubchik A. Features of gate-tunable and photon-field-controlled optoelectronic processes in a molecular junction: Application to a ZnPc-based transistor. *AIP Adv*. 2022;12(10):105020. <https://doi.org/10.1063/5.0119257>
- [47] Palianytsia B, Kulik T, Dudik O, Cherniavska T, Tonkha O. Study of the thermal decomposition of some components of biomass by desorption mass spectrometry. *Spring Proceed Phys*. 2014;155:19-25. https://doi.org/10.1007/978-3-319-05521-3_3
- [48] Bondarev A, Popovici DR, Călin C, Mihai S, Sîrbu E-E, Doukeh R. Black Tea Waste as Green Adsorbent for Nitrate Removal from Aqueous Solutions. *Mater*. 2023;16(12):4285. <https://doi.org/10.3390/ma16124285>
- [49] Asgerov EB, Beskrovnyy AI, Doroshkevich NV, Mita C, Mardare DM, Chicea D, Lazar MD, Tatarinova AA, Lyubchik SI, Lyubchik AI, Doroshkevich AS. Reversible Martensitic Phase Transition in Yttrium-Stabilized ZrO₂ Nanopowders by Adsorption of Water. *Nanomater*. 2022;12(3):435. <https://doi.org/10.3390/nano12030435>
- [50] Petrov EG, Gorbach VV, Ragulya AV, Lyubchik A, Lyubchik S. Gate-tunable electroluminescence in Aviram-Ratner-type molecules: Kinetic description. *J Chem Phys*. 2020;153(8):18574. <https://doi.org/10.1063/5.0018574>

Розробка методичних рекомендацій з навчання фізики на основі розвитку просторової уяви

Сирга Бердибекова

Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка

Муктарбек Алдашов

Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка

Даміра Асанбекова

Киргизький національний університет імені Ж. Баласагына
720033, вул. Фрунзе, 547, м. Бішкек, Киргизька Республіка

Гульзат Ісмаїлова

Киргизький національний університет імені Ж. Баласагына
720033, вул. Фрунзе, 547, м. Бішкек, Киргизька Республіка

Анарбек Аттокуров

Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка

Анотація

Актуальність. У сучасній освіті велика увага приділяється розвитку критичного мислення та когнітивних навичок учнів, зокрема здатності до просторового мислення. Це важливо для успішного засвоєння предметів, особливо фізики, де розуміння тривимірних об'єктів і явищ має ключове значення.

Мета. Метою даного дослідження є створення методики навчання фізики з акцентом на розвиток просторової уяви учнів. Для перевірки ефективності розробленої методики було проведено експеримент з метою оцінки рівня розвитку просторової уяви учнів, які брали участь у дослідженні, та порівняння результатів до і після застосування методики.

Методика. Одним із ключових методів, розроблених у дослідженні, є використання візуалізацій та тривимірних моделей у навчальному процесі.

Результати. Основні результати дослідження пов'язані з розробкою методичних рекомендацій щодо викладання фізики на основі активного розвитку просторової уяви студентів. Це дозволяє учням краще розуміти абстрактні фізичні поняття, такі як будова атома або векторні операції, через візуальні образи. Дослідження також визначило ефективні прийоми для розвитку просторових здібностей учнів. Серед них - включення до завдань елементів тривимірних головоломок або розв'язування задач на побудову просторових моделей, що допомагає учням краще зрозуміти геометричні взаємозв'язки та взаємодію тіл у просторі. Крім того, було визначено важливість використання інтерактивних методів навчання, таких як проведення віртуальних експериментів або обговорення тривимірних симуляцій, як таких, що сприяють глибшому розумінню матеріалу.

Висновки. Практичне значення цього дослідження полягає в наданні конкретної методики для вчителів фізики, яка дозволить оптимізувати навчальний процес, покращити розуміння учнями теорії та ефективніше розвивати їхню просторову уяву.

Ключові слова: навчальний процес; когнітивні навички; візуалізація даних; інтерактивне навчання; концептуалізація.