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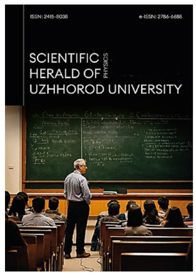

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Methodological foundations for teaching nanotechnology in the training of future physics teachers

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Abstract

Relevance. The relevance of the study lies in the fact that methodological foundations for teaching nanotechnology is a new specialisation that is in the interest of training future physics teachers who want an engaging career in the labour market. Advanced materials and nanotechnology is a unique field of study run by the Faculty of Physics, with the aim of teaching the science of advanced materials as efficiently as possible. Understanding of their functioning and the principles of their design and construction requires a thorough knowledge of physical phenomena at the quantum level.

Purpose. The purpose of the study is to train young people in physics with a professional knowledge of modern tools and mechanisms at the scale of nanotechnology applications.

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Methodology. This methodology specialisation, future teachers can develop their knowledge and skills in the following practices: problem analysis and design of modern microelectronic devices; modern solid state physics research methods for testing electronic materials; theoretical modelling of composite material designs and analysis of their physical properties; the ability to work in a team of specialists working in the research laboratories of industrial companies that offer the use of modern technology.

Results. The basis of the training is built on classes that deal with the issues related to the physical elements of nanostructured technology, nanosensors and computational technology, the foundation of which is the laboratory study of structural programmes involving the use of various microscopes and atomic forces.

Conclusions. The practical significance of the study lies in the provision of methodological foundations for the teaching process with the introduction of nanotechnology in the training of future physics teachers, as well as the possible use of the approaches under consideration in the modern educational system.

Keywords: biomaterials; competence; professional skills; modern devices; educational process.

Introduction

The extremely dynamic development of modern civilisation challenges society to develop ever more sophisticated methods of learning and teaching. The progress of science opens up the possibility of consciously shaping methodological foundations, structures and properties. Nanotechnology is a set of processes characterised by the creation of materials on a volume scale. It is currently one of the most rapidly growing areas of knowledge. It is increasingly being used in many areas of life, allowing it to spread as an independent academic field of study. The basis of many development programmes and national strategies that view nanotechnology as a foundation for building a knowledge-based society and a driving force for progress in today's world is the opportunity to improve the competitiveness of the economy and the labour market as a whole [1; 2]. Nanotechnology is driven by an interdisciplinary field of science that combines many basic disciplines and therefore the emphasis on a particular educational profile may vary slightly depending on the chosen field of study. In this case, it is engaged in production and development, which is now perceived as a field of science that defines the development of the modern educational process. The training programme focuses on a well-rounded education, providing an excellent opportunity to choose the profile of knowledge acquired, from the theoretically advanced, more oriented to modelling and numerical methods, to materials engineering oriented to specific aspects [3-6].

Through the methodological foundations of nanotechnology teaching, future physics teachers are able to apply their knowledge of basic physics and physical materials with particular emphasis on specificity and the ability to find information in a variety of modern databases. With the ability to interpret and quantify physical phenomena in condensed matter, students are guided by the principles of research equipment used in the study of nanostructures, introducing methods for obtaining and testing the relevant components. It is important to use basic knowledge and skills related to computer software and calculating the properties of small systems [7]. In addition, the future specialist needs to have an English language proficiency that allows easy communication and use of English-language specialist literature in the field of physics and nanotechnology. The quality of available teaching materials often determines the feasibility of future engineering projects. Therefore, the development of physics contributes to the development of knowledge about the structure of materials, their properties, methods and characteristics. Understanding the structure of nanomechanisms and the development of research methods enables the production of ever better materials and even the development of materials with previously unprecedented properties [8-11].

Future physics teachers, with the introduction of nanotechnology methodology, can easily adapt to the ever-changing demands of the labour market and are prepared for technological and engineering work in various fields related to the production and use of nanomaterials that can revolutionise life in the science world. By performing professional tasks related to physical materials science and nanotechnology, teaching personnel solve technological tasks using nanostructures and are responsible for the reliable assessment of students' trends in the education system. By using nanometric structures in practical activities, the quality of students' training improves considerably thanks to the materials used. The chances of employment are greatly increased if the prospective candidate for the position has a high degree of knowledge of modern technology, which the student receives within the natural science training cycle. In addition to lectures, students also undergo practical training in laboratories, where they learn how to produce nanostructures and conduct structural research. The ability to adjust subjects to one's own interests makes nanotechnology attractive even to students who have no interest in it, enabling them to acquire skills useful in many areas of knowledge in different ways, usually in engineering and using computer science processes [12; 13]. The purpose of the study is to train young people in physics with a professional knowledge of modern tools and mechanisms at the scale of nanotechnology applications.

Materials and Methods

Within the framework of the study, the following approaches were used: systemic, competence-based, personal. The systematic method implies a particular way of organising nanotechnological actions that covers the activity area of physics direction for future teachers, while revealing a specific interconnection and pattern of effective use models. It characterises the setting of objectives in order to reveal a full understanding of an object which operates under certain conditions and ensures the achievement of objectives by cumulative elements in relation to each other. The functional structure of the teaching methodological foundations takes into account the properties of the holistic structure, indicating the intrinsic belonging of a future physics teacher to the set of elements necessary for creating the ways to implement the tasks that allow for the expediency of the training system properties. Structural analysis defines the components of boundaries and relationships for the practical use of teaching aspects consisting in discovering the physical dependencies between the elements of nanotechnology and the general definitions of the object's internal organisations. The systematic method involves a careful consideration of the resources, features and properties that provide an integrated set of stages for the possible prospective development of modern technologies.

The competence-based approach enabled the introduction of the phenomenon of nanotechnology into the educational process to enable more efficient application of skills, knowledge and qualities in practical experience in order to succeed in the future. It is a procedural and multidimensional concept that manifests itself in the image of a future physics teacher who is able to combine the applied and theoretical components of training by mobilising the acquired professional skills. The particularities of competence analysis include the reliability and sustainability of assessment results, the suitability of the educational process implementation taking into account the introduction of innovative technologies, as well as the diagnosis of the competence formation degree on the basis of teaching criteria. A focus on the needs of the labour market enables the development of indicative models of learning levels and the ability to integrate acquired skills into professional activity. According to the nature of competence formation, this approach distinguishes two main assessments: quantitative and qualitative. Quantitative includes a combination of physics student questionnaire results through the indicator method or testing, and qualitative includes a modular rating system that develops cases and methods through developmental cooperation.

The personal paradigm includes a theoretical framework focused on pedagogical activities using nanotechnology through interconnected ways and actions that provide personalised support for methodological processes for self-realisation and self-discovery of future physics teachers. The students' behavioural patterns are built on the principles of freedom of choice and cooperation in implementing this approach in the educational process. The essence of the personal method relies on the dynamic formation of the society in the Republic of Kazakhstan, while developing an individual and independent personality capable of quickly integrating and orientating to the canons of the modern labour market. By studying the basics of the individual's formation from a current perspective, it is possible to consider its practical application in the teaching process. Students achieve the best competent development using nanotechnology by applying a personal methodology that introduces the practical aspects of learning and analyses the problems of the teaching foundations by considering the directions in physics and the experiences of the teaching staff.

Results and Discussion

Nanotechnology is one of the specialisations in the field of technical physics. It is an interdisciplinary approach that aims to prepare students first and foremost to deal with problems that are becoming increasingly important in the modern world and have enormous practical implications. The emergence of new Internet platforms, such as YouTube, raises the question of interest in creating information resources for young people and teachers, influencing cognitive didactic principles, multimedia form and complexity level adapted for both teachers and students. The materials created are both individual laboratory experiments and collections of real objects and their virtual reflections, introducing the students to specific physical concepts, diagrams, models, experiences, descriptions of applications, biographies of the researchers. The platforms also include shorter videos from films on selected topics, such as the absorption of ionising radiation or models of sea current formation and subtropical winds. After all, it is important for a physics teacher to interest a student in the ever-increasing content of the curriculum and the increasing choice of appropriate additional classes, tutoring, and trips abroad [14]. If successful, students will not even notice when they start learning. Once resources and platforms have been used, young people are much more likely to introduce new forms of knowledge transfer, and teachers are willing to transfer their resources for widespread use within their statutory activities [15].

Rapid changes in information technology and access to knowledge in the Republic of Kazakhstan, with the negative demographic trends, are reducing interest in technical and exact sciences. Special methodological programmes are rather superficially organised and do not reflect the specific nature of pedagogical activity; they only temporarily improve the situation without encouraging staff to change the way they teach. Consequently, there is a need to change teaching methods: to increase the efficiency and attractiveness of knowledge transfer, to form experimental, mathematical and practical skills as well as professional competences. Multimedia tools can fulfil these functions perfectly, and video collections are an advanced form of presenting the information or physical phenomena. Such activities turn individual encyclopaedic articles into structured knowledge, which is important for developing intellectual skills. Compared to traditional teaching methods, a multimedia form or video recording allows content to be conveyed more comprehensively, integrating knowledge into a single integrated network. Furthermore, the ability to cover students with different cognitive predispositions through visual and verbal means, as well as laboratory demonstrations, is underestimated and reflected in individual learning styles. Multimedia nanotechnology synthesises different media into standard teaching practices, requiring the teacher to use a new educational methodology.

Nanotechnology in practice is a practical approach to the key synthesis and analysis methods currently used in the training of future physics teachers. It is a holistic set of laboratory activities that enables students to acquire practical skills by supplementing theoretical knowledge with descriptions of methods for producing nanostructures, investigating their properties and discussing the results of their use in everyday life [16]. This concept as a valuable source of practical and theoretical knowledge for students, is a ready laboratory manual of natural sciences to conduct laboratory experiments and investigations of obtained nanomaterials [17; 18]. A wide range of materials are also used in audio-visual devices, the research of which brings new elements of a universal knowledge set that develops students and enables them to develop an interest in innovative technologies. Their development generates productive results in a relatively short time. These devices are based on the objective of facilitating teacher education and improving its quality. Nano-science is integrated as an environment for developing scientific thinking, information literacy of students using the teacher's dialogue-based modelling methodology. Students' cooperation with specialists during their studies promotes the development of optimal monitoring and appropriate analytics with a set of video and audio exercises supported by specific databases available in the form of online courses.

Many educational institutions produce a huge amount of multimedia technologies, but make them available only to their students, i.e. fee-payers. For instance, large institutions provide their users with separate online collections, including full lectures and broadcasts, but only a small proportion of these resources are freely available. Properly prepared models enable variance to be reconstructed as a function of time, which is not usually considered in traditional educational solutions. They allow for an interactive search for different conditions of reflection and the process of the phenomenon, which is reflected in practical or laboratory solutions, but they are not intuitive enough for the learner. In recent years, the content and forms of teaching have expanded considerably. During planning and scenario development, materials are categorised for optimal use, which in turn takes into account content, cognitive functions, target audiences and statistical data on access to industry websites. Some examples are: videos of a few seconds to 2 minutes to measure the dependence of force on angular velocity; thematic collections of several films illustrating a given field or a scientific law in action in maximum detail; portals where sometimes complex physical laws are explained using simple didactic exhibits.

Particularly productive in the teaching process are the following nanotechnologies: online experiments, online physical modelling, video-recorded lessons and lectures, video-recorded experiments, lectures in multimedia form. The level of didactic efficiency of individual resources is not always proportional to the complexity level of their preparation [19]. Online experiments are the most challenging form of training future physics teachers, requiring the presence of a measuring instrument in motion and in a specific laboratory. Online physics modelling presents a conceptual sequence of moving from a real experience through a video recording to an online experiment, for example, measuring the charge of electrons on microscopic drops of oil [20]. Lectures, despite their complex structure, do not provide greater efficiency than video recording, as it is difficult to identify a properly organised experiment. Videos, especially those prepared specifically for this purpose, have the authenticity of a university class, with reverberation in the classroom and different intonation of the teacher's voice. In addition to their great cognitive value, they also have the function of recording a particular moment or place. The complexity degree and individual style differ, but they all fit into the relevant basic curriculum. However, the advantage of large multimedia lectures is the ability to fully explain a certain phenomenon. So it is necessary to separate the phenomenon into its individual aspects [21].

The cognitive aspects of nanotechnology are as important as the subject content. In the context of effective transmission of information, it should have the following characteristics: addressability, timeliness, accessibility, accuracy, unambiguity and clarity. Consequently, a scientifically and didactically correct presentation of physical issues is only one of the challenges when designing the training of future physics teachers. Current technologies should be structured and enhanced accordingly from the student's perspective. This enhancement is particularly relevant with the emergence of new physics fields. By analysing the statistics, it can be assumed that higher education students make up the highest percentage of people who visit websites. In many cases, they refer to the materials intended for them when working on their homework lab assignment. This arrangement of content helps to expand the didactic material aimed at supporting multimedia methods and technologies in the student's free time. Another area of development in physics didactics on the Internet is the access to external websites, as the number of films about physics on such portals is enormous. Most of them are scientifically correct, but some of them fail to follow basic principles by reducing reasoning and not referring to the real facts. The right material should clearly explain the main issues and clearly define what it covers.

For the majority of future physics teachers, nanotechnology, particularly virtual reality, is associated only with science fiction. Some time ago, this technology has been used in fields such as aviation and medical imaging, as well as in all kinds of simulators, and in the future this technology will enter educational institutions, opening up new possibilities for the students [22-24]. The main purpose of this methodology is to present examples of good practice and experience in the Republic of Kazakhstan with links to national sources where teachers can find suggestions and tips for successful teaching. The portals collect all the necessary materials in one place, which is a very modern and reliable learning tool. The whole portal provides tested physics ideas and task sets that can be useful for conducting interesting classes. Their objective is to popularise physics, its achievements and to discuss the issues in pedagogical science. Examples of successful experiences with the considered and described criteria and assessments for improving physics education can be introduced through high levels of professionalism and competence. The intention of this initiative is to support teachers who are trying to introduce nanotechnology into the learning process, and to make teaching and learning physics more interesting and engaging. The new curriculum tends to shift from a memory load, i.e. from study to testing, repetition and algorithms. It aims to promote a new systematic approach to learning, reasoning and logical thinking [25; 26].

A set of nanotechnology tasks can help teachers develop students' skills without abandoning the general requirements of the basic educational programme. The modern methodological foundations include both general and specific requirements for teaching and learning. There are certain criteria for their content, including the mastery of certain types of information and knowledge related to complex skills within the framework of interdisciplinary elements. They relate to reasoning and arguments, searching for, acquiring and creating information, knowledge of research methods in the development of physics. It should be noted that general requirements take precedence over specific ones and that some contain complex skills, such as those relating to innovative research methodology, and are only preserved in general requirements, which are gradually enriched and updated. Training and stimulating a new generation of young physicists who want to build their future in terms of educational and professional aspects creates a new language of communication developed on the basis of nanotechnology projects [27]. Their interaction makes it possible to gain experience for new innovations. The feedback from consumers of learning content plays a key role in the creation of new quality technology elements. It is also possible to use popular mass media, as the main idea of teaching using nanotechnology is to be able to demonstrate the exciting aspects of physics. The main result of this process is an interactive, dynamic educational system with modern graphics that stands out from other traditional solutions.

A novelty among other learning tools is a kind of competition with prizes, as well as frequently organised exchanges of materials and physical experience. An innovation introduces the possibility of direct contact with experts who can help move forward through the activities available on the respective portals. Experts collaborate with users in blogs, forums and stand out not only for their knowledge, but also for their attitude to the professional cause. This kind of improvement includes an additional interface for mobile devices, where the authors abandoned the typical look and moved towards free computer conventionality. The teaching of physics in the Republic of Kazakhstan has undergone many changes in recent decades. There is no doubt that physics is an important subject in the curriculum that solves many tasks by requiring a specific demonstration of experiments. Innovative nanotechnology is changing the way students learn and is disrupting established patterns of learning. There is now a great emphasis on the need for a breakthrough and teaching paradigm, which creates quite an interesting innovation. Even if it is the best innovation to date, it still does not bring the expected results from student involvement. The activity, which encourages students to be active, is innovative in nature. However, this requires attention to some key issues aimed at increasing independence and responsibility for the learning process [28; 29].

Total independence from learning content is available by introducing nanotechnology for individual learning style and pace, recreating definitive transferable content. Respect for each student's personal predispositions plays an important role in encouraging discoveries and experiments. Due to the need for more student interest, it is important to break through didactic patterns in order to conduct classes in a more engaging and motivating way. Deviating from the traditional pattern certainly contributes to active participation during lessons. Modern education depends on very independent learners, so it is necessary to increase the involvement level in order to demonstrate the significance of their own participation. In this context, one should present things that create and improve the quality of learning and teaching in a way that is effective and creative, breaking stereotypes and patterns. Modern education should focus on the efficient organisation of the nanotechnological learning process. This is because teachers obviously need to focus their efforts on achieving better performance in improving the necessary conditions. Their analysis of the causes of poor activity levels affects the design of methods for teaching, inspiring and stimulating. An interesting thesis is that human knowledge is not necessarily stored in the mind. This proves that the student can use available devices and information gathered from external resources to complete a specific task. The modern student simply needs to receive information and then analyse, use and apply it – this is the key to the most important human competencies in the digital age.

Teaching physics requires a well-equipped and functional laboratory for performing experiments, demonstrations and tasks [30]. In this area, the teacher should boldly organise lessons and introduce nanotechnological techniques into the learning process that emotionally engage students in implementing new tasks. The very idea of such education is based on giving greater value to independence and responsibility for completing relevant tasks. The availability of open resources and online learning has opened up new opportunities and methodologies for learning, causing the initial activity of future teachers and an introduction to the concept of self-education. Thus, the primary task of the teacher is to be able to indicate the sources of information and the scope of the material. Nanotechnology enables the understanding and control of materials and devices that are designed with the aim of demonstrating new or enhanced physical properties of already known components [31]. New and better ways of acquiring knowledge and skills are actually being created. Consequently, the field has an enormous potential and has an impact on many areas of science, ranging from energy, transport or agriculture. The term covers the use of materials that have at least one dimension determined by the natural unit of measurement. Therefore, in recent years there has been an explosion of new areas in science and technology, particularly in physics, where objects on the nanometre scale have become the subject of cognition and synthesis.

The aforementioned technologies have their advantages and disadvantages, based on the many examples and prototypes known in nature, using self-replicating systems. This method has many supporters because the desired effect is seen in the short term at a relatively low cost. Device methods make it easier to design objects, but the disadvantage is that they require high costs arising over a comparable period of time. All teachers engaged in the area of nanoproblems emphasise the need to intensify interdisciplinary research, enabling the development of the classification of safe nanotechnologies, the unification of methods, adequate risk assessment and the provision of a set of legal regulations [32]. If used properly, they can help solve many pressing issues and bring a number of benefits. But it may also lead to a future disaster. The Republic of Kazakhstan has a sufficient research and development potential, which refers to the resources of the research and development sphere. This potential is one of the prerequisites for the development of teaching nanotechnology in the country. The examples of success stories had a huge impact on improving education at all levels. Future physics teachers are productively engaged in the development of critical thinking and subsequent application skills, as demonstrated by open learning strategies. Developing the language skills among young teachers enables them to communicate freely and to use the large amount of teaching materials available. All this contributes to the formation of individual tasks in a world surrounded by physical phenomena [33].

The global trend towards the miniaturisation of technological systems has led to the intensive development of nanomaterials-based nanotechnology. The methodological foundations of nanostructures aim to create new or often improved physical properties compared to already known materials. The specific properties of nano-objects, due to their small size, are of great interest to the involved circles of future physics teachers. Teaching in the field of advanced technology and nanotechnology turns into a laboratory activity of physical materials in order to learn about materials as efficiently as possible. Students get to know the field of physics better by improving their knowledge in theoretical and advanced courses to make progress and provide themselves with simple tools. Students with an interdisciplinary general education in materials science and technology for the production of advanced materials have an advanced professional qualification within the framework of acquiring scientific knowledge. Students of this area of study find employment in research institutions and laboratories related to the chemical, electronics and pharmaceutical industries, optoelectronics and industrial companies that use technologies based on new advances in the study of materials in manufacturing [34]. Dynamic development leads to qualitative and quantitative changes in learning technology, making it possible to use ever newer didactic tools.

New methodological models of nanotechnology bring many modern, valuable solutions, but it is necessary to remember that the progress is also accompanied by toxic effects. Nano-objects, due to their small size, generate new threats due to their high reactivity and danger. The great involvement of teachers in the development of nanotechnology contributes to the exploration of new and emerging applications for students [35]. The discovery of their unique properties provides an opportunity to develop many areas of modern technology, but at the same time requires detailed research to ensure their safe use. The educational market in Kazakhstan is currently overloaded with theoretical teaching concepts and not much attention is given to experimentation and practical activities. Practical experience is ignored by teachers due to lack of financial resources. Thanks to the platforms and resources compiled in the respective portals, teachers have the opportunity to make use of a huge range of tools oriented towards visualising experiments and nanotechnological phenomena. They especially appreciate the current nanotechnological form of teaching, as this methodology is very effective and quite easy to use with the right tools and mechanisms that can be used independently during classes [36]. Thus, the study of the methodological foundations of nanotechnology teaching in the training of future physics teachers facilitates the process of detailed analysis of functional and structural phenomena that support the connection between the laws of fundamental physical theory. Examples of the introduction of integrated methodological curricula to support the teaching of physics present a picture of the trends in using modern and innovative solutions in the context of the education system of Kazakhstan. The period of emphasis on developing new nanotechnological methods has developed slowly on the basis of already implemented prototypes of new learning forms, such as experiment support, virtualisation and e-learning.

Conclusions

A great deal of attention is now being paid to cooperation between industries, which receive a marketing aspect in the form of experience exchange. This proves that physics, as a branch of science and a speciality, is a good choice when it comes to further planning a career in the education field. Providing solutions to support the nanotechnological learning process remains the main focus of teaching, but it seems that in the future the focus will shift to collaboration between industry partners and teacher development through the use of innovative tools and materials collected within the learning methodology. Working in interdisciplinary fields requires acquiring knowledge from books, magazines, platforms and websites. Consequently, anyone who wants to achieve something today has the opportunity to use, for instance, libraries, which still relate to traditional educational components, but in the future they will be based on hypertext systems. Interactive resources can only be used to their full potential if the teacher and students are able to understand all the commands and tasks.

A course towards nanotechnology should mean a change in the training of future teachers so that they can design and create their own teaching materials with the least amount of effort and time. Such materials provide teachers with the freedom of choice and enable them to adapt to the needs of students, from the most talented to the weakest. After all, the poor infrastructure of their own physics laboratories limits access to the latest technology during classes. Among the numerous tasks of the methodological foundations, a key element in the successful implementation of nanotechnology is the introduction of seminars for the teaching staff, the main purpose of which is to discuss issues and activities that are in the process of being implemented. They are also designed to engage teachers and experts in further project activity related to the planning, design, implementation and dissemination of nanotechnology resources and structures.

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Conflict of Interest None.

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Методологічні засади навчання нанотехнологій у підготовці майбутніх учителів фізики

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Анотація
Актуальність. Актуальність дослідження полягає в тому, що методологічні основи викладання нанотехнологій є новою спеціалізацією, яка відповідає інтересам підготовки майбутніх вчителів фізики, які бажають мати цікаву кар'єру на ринку праці. Новітні матеріали та нанотехнології - це унікальна галузь знань, якою займається фізичний факультет, з метою якомога ефективнішого викладання науки про новітні матеріали. Розуміння їх функціонування та принципів проектування і конструювання вимагає ґрунтовних знань фізичних явищ на квантовому рівні.

Мета. Метою дослідження є підготовка молодих фахівців з фізики, які володіють професійними знаннями про сучасні інструменти та механізми в масштабах застосування нанотехнологій.

Методика. За даною методичною спеціалізацією майбутні вчителі можуть розвивати свої знання та навички в наступних практиках: аналіз проблем та проектування сучасних мікроелектронних пристроїв; сучасні методи дослідження фізики твердого тіла для тестування електронних матеріалів; теоретичне моделювання конструкцій з композитних матеріалів та аналіз їх фізичних властивостей; вміння працювати в команді фахівців, що працюють в науково-дослідних лабораторіях промислових компаній, які пропонують використання сучасних технологій.
Результати. Основу навчання побудовано на заняттях, які розглядають питання, пов'язані з фізичними елементами наноструктурованих технологій, наносенсорів та обчислювальної техніки, фундаментом яких є лабораторне вивчення структурних програм із застосуванням різноманітних мікроскопів та атомних сил.

Висновки. Практична значущість дослідження полягає у забезпеченні методологічних засад навчального процесу з впровадженням нанотехнологій у підготовку майбутніх учителів фізики, а також у можливому використанні розглянутих підходів у сучасній системі освіти.

Ключові слова: біоматеріали, компетентність, професійні вміння, сучасні прилади, навчальний процес.