INTEGRATING STEM AND ARTIFICIAL INTELLIGENCE IN TEACHING NANOTECHNOLOGY TO PROSPECTIVE PHYSICS TEACHERS

Authors: Anas B.[1], Ali C.[2], Skakov M.[3]
Affiliation: PhD candidate, Sarsen Amanzholov East Kazakhstan University (Kazakhstan, Öskemen)[1]; PhD, Professor, Sakarya University (Turkey, Sakarya)[2]; Doctor of Physical and Mathematical Sciences, Professor Sarsen Amanzholov East Kazakhstan University (Kazakhstan, Öskemen)[3].
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ABSTRACT

This article analyzes the pedagogical possibilities of integrating STEM-educational methodologies and artificial intelligence technologies in the teaching of nanotechnology to future physics teachers. The relevance of the study is determined by the need for a new organization of teaching physics in the conditions of rapid development of science and technology. The goal is to identify innovative approaches aimed at improving the professional competence of future teachers, developing their research skills and increasing the level of digital literacy.

The research methods used were a review of scientific literature, comparative analysis, observation of pedagogical practice and a survey. As a result, it was found that STEM-projects and artificial intelligence tools (virtual laboratories, intelligent testing systems, adaptive learning platforms) increase students' interest in the subject and facilitate the mastery of complex nanotechnological concepts. In addition, it was noted that this approach develops creative thinking and research competence of future teachers.

During the discussion, along with the advantages of this method, some limitations were also highlighted: insufficient material and technical base, the level of teachers' mastery of new technologies, the complexity of integration into the curriculum. In conclusion, it was proven that the integration of STEM and artificial intelligence is an effective way to improve the professional training of future physics teachers. This direction allows for the formation of an innovative model in pedagogical education that meets modern requirements.

Keywords: nanotechnology, STEM education, artificial intelligence, future teachers, physics methodology, innovative teaching.

INTRODUCTION

The rapid development of science and technology in the modern education system requires future teachers to be provided with new professional training. In particular, the use of innovative technologies in teaching physics allows not only to form students' scientific attitudes, but also to develop their research abilities. One of such new directions is the introduction of nanotechnology into the educational process. Nanotechnology is widely used today in various fields, from medicine to electronics, and has become one of the leading directions of science. Therefore, mastering the basic concepts and methods in this field for future physics teachers is an important part of professional competence.

The STEM paradigm (Science, Technology, Engineering, Mathematics) plays a special role in education in the 21st century. STEM education focuses on solving real-life problems by integrating traditional subjects rather than teaching them separately. This approach develops students' practical skills, creative thinking, and the ability to work in a team. Future teachers can adapt the educational process at school to modern requirements by mastering the methodological foundations of STEM education.

Artificial intelligence (AI) technologies are also increasingly being used in modern education. The advantages of AI tools are obvious: they personalize the learning process and allow for accurate analysis of student progress; create conditions for modeling complex nanotechnological phenomena; make experiments safe and accessible through virtual laboratories. However, there are also problematic aspects in the use of AI: insufficient material and technical base, uneven level of digital training of teachers, as well as issues of academic integrity and data security.

Taking into account these advantages and difficulties, the purpose of the study is to identify scientific and methodological opportunities for integrating STEM education and artificial intelligence technologies into the teaching of nanotechnology for future physics teachers and analyze its effectiveness.

In recent years, interest in the introduction of nanotechnology into the education system has been growing. One of the studies published in 2024 analyzed the experiences in teaching nanotechnology through meta-synthesis and showed that most programs and methods in this area are aimed at developing students' research skills [1]. However, the authors note that such practices are still not systematic, and that programs need to be aligned with specific educational standards.

There are also works on integrating nanotechnology with STEM. For example, a 2024 study showed that teaching nanotechnology concepts to high school students using the TRIZ–STEM approach significantly develops their critical thinking skills [2]. This is also important for future physics teachers, as it helps students master methods for conveying complex scientific concepts in a practical and creative way.

Kazakh scientists have also studied the effectiveness of STEM teaching in physics. A 2024 study shows that teachers' introduction of STEM approaches to their lessons enhances their professional competence and increases students' interest in the subject [3]. This is a useful direction that can be applied in practice for future teachers.

The issue of introducing artificial intelligence (AI) into the educational process has also been frequently discussed in recent years. A review published in 2025 examined the opportunities and challenges of AI in science education, highlighting ethical issues, data quality, and teachers' digital competence as key challenges [4].

There are also examples of practical use of AI in physics. A study published in 2024 demonstrated that individual learning systems based on large-scale language models can deepen students' understanding and develop their ability to work independently [5]. In addition, a 2023 study showed that using generative AI in explaining STEM concepts can develop analogical thinking and make it easier to convey complex concepts in visual-multimodal ways [6].

Overall, research over the past three years has shown that integrating STEM approaches and AI technologies in teaching nanotechnology to future physics

teachers is an effective way to improve their professional competence and develop students' research and critical thinking skills. However, the main problems in this direction include the incomplete formation of a methodological system, as well as ethical and technical limitations in the use of AI tools.

RESEARCH METHODOLOGY

This research work was aimed at identifying the possibilities of integrating STEM education and artificial intelligence into nanotechnology teaching for future physics teachers. The survey method was used as a tool for collecting empirical data during the study. This approach allows for a comprehensive analysis of the attitudes, experiences, and professional values of the respondents and the level of acceptance of innovative technologies by future teachers.

Research design and methodological justification

The main principle in choosing methods is the descriptive nature of the study. This work was not aimed at conducting a specific pedagogical experiment, but at collecting the opinions, attitudes, and subjective experiences of future teachers regarding the learning process. Therefore, the survey was considered an accessible, reliable, and a tool that allows obtaining a lot of information in a short time.

During the study, the structure of the survey was developed based on scientific works published in the last three years (AI in Education, STEM Integration, Nanotechnology Teaching). This data ensured compatibility with internationally recognized pedagogical methodologies.

Survey content and structure

The survey consisted of three main blocks:

1. Level of readiness for nanotechnology. This section asked questions about students' experience at school and higher education, their level of mastery of the topic of nanotechnology, its place and relevance in physics. The answers revealed the students' theoretical knowledge base and their professional outlook.

2. Approach to STEM pedagogy. Here, the importance of integrated teaching methods, the experience of implementing interdisciplinary connections, and the possibility of creating new physics lessons through STEM were considered. Students' opinions on the advantages and potential difficulties of STEM methods were collected.

3. Use of artificial intelligence. This block was aimed at identifying respondents' recognition of AI tools, their experience of using them in the educational process, and obstacles to the introduction of AI (material and technical base, teacher qualifications, ethical issues). In addition, students' hypothetical thoughts about the future role of AI were analyzed.

The survey questions were made in closed and open types. Closed questions were aimed at obtaining quantitative data, while open questions allowed students to freely express their opinions.

The study involved 3rd-4th year students studying in the pedagogical direction. The selection method was purposive, since this audience will be directly involved in teaching physics at school in the future. The age of the participants, their interest in the specialty, and the curriculum corresponded to the research topic.

In general, all students who participated in the survey voluntarily gave their consent and were explained that the results of the survey would be used for scientific

purposes only. The principle of anonymity was observed, and the names, educational institutions, or other data of individuals were not recorded.

Data collection and analysis

The survey was conducted online, which increased the accessibility of participants and saved time and resources. The analysis of the collected data was carried out in two directions:

1. Quantitative analysis. The answers to closed questions were described in terms of frequency and percentages. This made it possible to determine the opinions of the majority of students, the prevailing trends, and the general level of attitude.

2. Qualitative analysis. The answers to the open-ended questions were analyzed in terms of content, and the respondents' opinions were grouped. Here, students' views on the difficulties in using AI, their suggestions, and their thoughts on the introduction of STEM education were identified.

To increase the reliability of the research data, the survey questions were previously discussed with experts and methodologically checked. In addition, when analyzing the survey results, qualitative additions were made by interpreting the opinions of students, not limited to quantitative indicators.

To ensure validity, the survey questions were designed in accordance with the specific research objectives and were aimed at covering factors that contribute to improving the professional competence of future teachers.

The requirements of scientific ethics were strictly observed during the study. The purpose of the study was explained to the participants in advance, and their voluntary participation and anonymity were ensured. Participants had the right to refuse to participate in the survey at any time. The collected data were used only for scientific analysis and were not provided to third parties.

The methods used allowed for a systematic collection of the views of future physics teachers on the integration of STEM and artificial intelligence in nanotechnology teaching. The survey method was an effective tool for identifying their needs, advantages and difficulties in professional training and identifying the potential for introducing innovative pedagogical technologies.

RESULTS

The survey results comprehensively described the attitudes of future physics teachers towards teaching nanotechnology, STEM-educational approaches, and the use of artificial intelligence (AI). In general, the collected data showed that students are ready to accept innovative educational technologies, but certain difficulties and obstacles were also identified.

Level of readiness for nanotechnology

63% of the students who participated in the survey highly appreciated the place and importance of nanotechnology in modern science. However, only 37% of them believe that nanotechnology topics can be adequately covered in the school curriculum. This result indicates the lack of materials on nanotechnology in the curriculum and the methodological difficulties of explaining it.

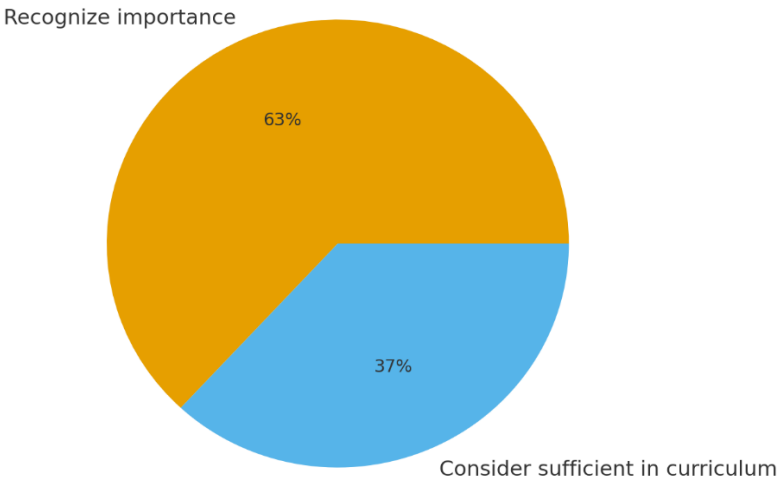

Figure 1. Level of readiness for nanotechnology

In their responses to open-ended questions, the majority of students noted the lack of special laboratory work and practical tools for teaching nanotechnology. This issue is a pressing obstacle for future teachers.

Approach to STEM pedagogy

72% of respondents recognized that STEM education brings a new impetus to physics lessons and strengthens interdisciplinary connections. In particular, the effectiveness of explaining nanotechnology topics through group projects was especially noted.

In addition, 18% noted the lack of time for the full implementation of the STEM approach and the risk of increasing the learning load, while 10% noted that this approach requires additional training from the teacher. This highlighted the need for organizational and methodological support in the implementation of STEM education.

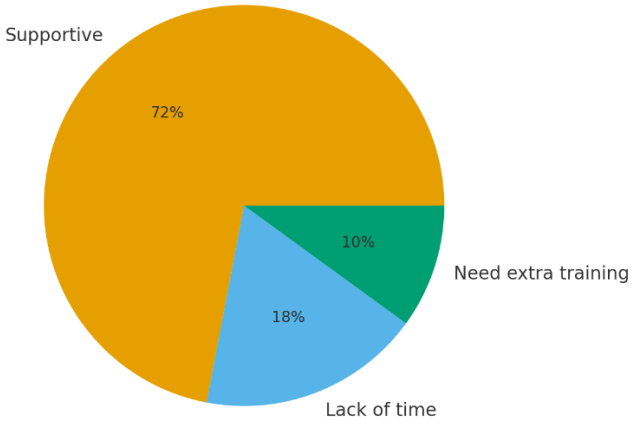

Figure 2. Approach to STEM pedagogy.

The study found that 54% of students were interested in using AI tools in the learning process, and 26% had experience using them in real lessons. The most

commonly used tools were automated calculation programs, virtual laboratories, and educational platforms.

At the same time, 46% reported a number of difficulties in using AI. These included:

· insufficient material and technical base (25%);
· low level of teacher qualification (14%);
· data confidentiality and academic integrity issues (7%).

In their responses to open-ended questions, students noted the potential of AI to improve the quality of teaching, but they also emphasized the need for special training for teachers for its full implementation.

General trends

The survey results revealed that most future teachers are inclined to adopt innovative technologies. However, there are methodological and material difficulties in teaching nanotechnology, time and organizational constraints in implementing the STEM approach, and infrastructural and ethical issues in using AI require resolution.

DISCUSSION

The main goal of this study was to identify the opportunities for future physics teachers to integrate STEM education and artificial intelligence (AI) technologies in teaching nanotechnology. The survey results not only revealed students' attitudes towards innovative teaching methods, but also identified several issues that need to be addressed in the current education system.

Barriers to teaching nanotechnology and solutions

The survey data showed that future teachers highly value the place of nanotechnology in science. However, the main obstacle is the lack of sufficient time and methodological tools for teaching this topic in the school curriculum. One way to solve this is to teach nanotechnology through STEM projects. For example, modeling the operation of nanolayers in solar panels or introducing simple virtual experiments to study the properties of nanomaterials. Such approaches allow for understanding complex scientific concepts at the school level.

Potential and limitations of STEM education

The survey results showed that the majority of students support the STEM approach. For them, interdisciplinary integration enlivens the learning process and creates conditions for the development of students' critical thinking. However, it was found that there are limitations in the full implementation of the STEM approach, such as lack of time and increased workload.

To solve this problem, it is recommended to introduce STEM elements in the form of small modules. That is, it is enough to give small project tasks related to each topic. Also, using the form of group work is considered an accessible approach for future teachers, both in terms of organization and methodology.

Possibilities for integrating artificial intelligence

The results of the study showed that students are very interested in AI technologies, but their practical application is still insufficient. The main obstacles here are the material and technical base and teacher training. In this regard, several effective ways to gradually introduce AI tools can be noted:

1. Automate and explain physics problems. Platforms such as PhysicsAI develop students' logical thinking by showing the solution to the problem step by step. And

Mindgrasp AI helps to create a brief synopsis of the educational material and conduct a review in the form of a test or question and answer.

2. Virtual laboratories. WhimsyLabs and EON Reality Virtual Labs allow students to conduct physics and nanotechnology experiments in a safe and visual format. This allows for the interpretation of complex experiments without the need for specific equipment.

3. Personal learning trajectories. The Siml.ai platform allows students to learn complex physical models at their own pace through digital simulations, taking into account their initial level. 3D/VR platforms such as Virtual Lab.io support students' independent research and implement independent learning.

Using these tools allows future teachers to consider AI not just as an additional assistant, but as a strategic direction that ensures the education process reaches a new level.

Ways to solve the problems

In general, the study revealed several relevant problem areas:

· Lack of methodological tools for teaching nanotechnology;

· Time and organizational barriers to implementing the STEM approach;

· Infrastructural and qualification limitations in the use of AI technologies.

The following recommendations were made to address these issues:

· Development of special teaching aids on nanotechnology;

· Introduction of the STEM approach through small modules, project tasks and group work;

· Phased introduction of AI tools and training of teachers through special courses.

Scientific and practical significance

The scientific significance of this study is to identify the potential of innovative approaches to teaching nanotechnology based on the perspectives of future teachers. And the practical significance is to suggest specific directions for introducing STEM and AI technologies into the educational process.

Thus, the results of the study not only describe the opinions of students, but also offer modern solutions for improving the education system. This will contribute to increasing the professional competence of future physics teachers and raising the quality of teaching to a new level.

CONCLUSION

This study examined the importance of integrating STEM education and artificial intelligence (AI) technologies into nanotechnology education for future physics teachers. The survey results showed that, despite the high interest of students in innovative approaches, there are a number of practical obstacles. In particular, the lack of methodological tools for teaching nanotechnology, the lack of time to implement the STEM approach, and infrastructural limitations in the use of AI technologies were identified.

Based on the results of the study, the following conclusions were drawn:

· The introduction of STEM projects in nanotechnology education allows future teachers to adapt complex scientific concepts to the school level;

· Implementing the STEM approach through small modules and project tasks makes the learning process more effective and accessible;

• The use of AI technologies, in particular, tools such as PhysicsAI, Mindgrasp AI, WhimsyLabs, EON Reality Virtual Labs, Siml.ai, and Virtual Lab.io, takes the educational process to a new qualitative level.

Overall, this study not only demonstrates the effectiveness of innovative approaches aimed at improving the professional competence of future teachers, but also suggests practical ways to improve the education system. The gradual, targeted introduction of STEM and AI technologies is an important direction for ensuring the professional training of future physics teachers in accordance with modern educational requirements.

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REFERENCES

1. Gocmen, A., Karabulut, H., & Kariper, I. A. (2024). Review of studies conducted in nanotechnology education: A meta-synthesis study. Discover Education, 3, 169. https://doi.org/10.1007/s44217-024-00277-6
2. Cavdar, O., Yıldırım, B., Kaya, E., & Akkus, A. (2024). Exploring the Nanoworld: Middle School Students Use TRIZ–STEM in Nanotechnology Education. Journal of Chemical Education, 101(3), 1049-1061. https://doi.org/10.1021/acs.jchemed.3c01031
3. Sydykova, Z. K., & Naushabekov, Z. (2024). The effectiveness of STEM education in school physics. Modern Scientific Method, (6). https://ojs.publisher.agency/index.php/MSM/article/view/3398 ojs.publisher.agency
4. • Lee, G., Yun, M., & Zhai, X. et al. (2025). Artificial Intelligence in Science Education Research: Current States and Challenges. Journal of Science Education and Technology. https://doi.org/10.1007/s10956-025-10239-8
5. Jiang, Z., & Jiang, M. (2024). Beyond Answers: Large Language Model-Powered Tutoring System in Physics Education for Deep Learning and Precise Understanding. arXiv Preprint. arXiv:2406.10934. https://doi.org/10.48550/arXiv.2406.10934
6. Cao, C., Ding, Z., Lee, G.-G., Jiao, J., Lin, J., & Zhai, X. (2023). Elucidating STEM concepts through generative AI: A multi-modal exploration of analogical reasoning. arXiv Preprint. arXiv:2308.10454. https://doi.org/10.48550/arXiv.2308.10454