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Іван ГАЙНЮК,
здобувач третього (освітньо-наукового) рівня вищої освіти
зі спеціальності 015 Професійна освіта (за спеціалізаціями),
Прикарпатський національний університет імені Василя Стефаника (м. Івано-Франківськ, Україна)

Ivan HAINIUK,
applicant of the third (educational and scientific) level of higher education
in the specialty 015 Professional Education (by specialization),
Vasyl Stefanyk Precarpathian National University (Ivano-Frankivsk, Ukraine)
ivan.hainiuk.22@pnu.edu.ua
ORCID ID 0009-0005-2923-8586

УДК 378:37.011

ОРГАНІЗАЦІЙНО-ДИДАКТИЧНІ ПІДХОДИ ДО ЗАСТОСУВАННЯ STEM-ТЕХНОЛОГІЙ У ПРОЦЕСІ ПІДГОТОВКИ МАЙБУТНІХ УЧИТЕЛІВ ПРИРОДНИЧИХ ПРЕДМЕТІВ

Анотація. Автором на основі контент-аналізу наукових психолого-педагогічних джерел, опрацювання матеріалів зарубіжного досвіду з проблеми дослідження, описано організаційно-дидактичні підходи до застосування STEM-технологій у підготовці майбутніх учителів природничих предметів.

Наголошується, що організаційно-дидактичні підходи до підготовки майбутніх педагогів включають в себе сукупність принципів, методів і технологій, які сприяють оптимізації освітнього процесу та ефективної підготовки здобувачів вищої освіти до професійної діяльності.

Як основні методи дослідження використано: порівняльний аналіз наукових матеріалів з обраної тематики, опис емпіричного досвіду застосування STEM-освіти. На підставі сучасних методологічних підходів (системного, середовищного, компетентнісного, діяльнісного, особистісно-орієнтованого) визначено феноменологічну сутність STEM-освіти, розкрито освітній потенціал та дидактичну роль високотехнологічних засобів STEM-технологій у цілісному освітньому процесі. У рамках вирішення поставлених завдань конкретизовано понятійно-термінологічний апарат, що забезпечує необхідний рівень теоретико-методологічного обґрунтування розробки та ефективного системного застосування високотехнологічного технологічного інструментарію та інноваційних цифрових рішень з метою оптимізації застосування організаційно-дидактичних підходів до застосування елементів STEM-освіти у процесі фахової підготовки майбутніх педагогів.

Автор зазначає, що відповідно до організаційно-дидактичних підходів STEM-освіта – це добре спланований й організований процес, який включає вивчення природничих наук разом із технологією та математикою , який базується на дослідницько-пошуковій діяльності як провідному способі освітньої взаємодії.

У статті вказується, що сучасна психолого-педагогічна наука та шкільна практика визначають STEM-освіту як високотехнологічний інформаційно-дидактичний засіб навчання інноваційний цифровий ресурс, освітньо-виховний потенціал активно реалізуються для оптимізації організації освітнього процесу та всебічного розвитку й саморозвитку зростаючої особистості.

Ключові слова: STEM-освіта, підготовка, цифрові ресурси, технології, природничі шкільні предмети, організаційно-дидактичний підхід, освітній процес.

ORGANIZATIONAL AND DIDACTIC APPROACHES TO THE APPLICATION OF STEM TECHNOLOGIES IN THE PROCESS OF TRAINING FUTURE SCIENCE TEACHERS

Abstract. Based on the content analysis of scientific psychological and pedagogical sources, the author describes organizational and didactic approaches to the application of STEM technologies in the training of future teachers of natural sciences.

It is emphasized that organizational and didactic approaches to the training of future teachers include a set of principles, methods and technologies that contribute to the optimization of the educational process and the effective preparation of higher education applicants for professional activity.

The main research methods used are: comparative analysis of scientific materials on the selected topic, description of empirical experience in the application of STEM education. Based on modern methodological approaches (systemic, environmental, competency, activity, personality-oriented), the phenomenological essence of STEM education is determined, the educational potential and didactic role of high-tech means of STEM technologies in a holistic educational process are revealed. Within the framework of solving the tasks set, a conceptual and terminological apparatus has been specified, which

provides the necessary level of theoretical and methodological substantiation of the development and effective systematic application of high-tech technological tools and innovative digital solutions in order to optimize the use of organizational and didactic approaches to the application of STEM education elements in the process of professional training of future teachers.

The author notes that, according to organizational and didactic approaches, STEM education is a well-planned and organized process that includes the study of natural sciences together with technology and mathematics, which is based on research and search activities as the leading method of educational interaction.

The article indicates that modern psychological and pedagogical science and school practice define STEM education as a high-tech information and didactic means of learning, an innovative digital resource, the educational and educational potential of which is actively implemented to optimize the organization of the educational process and the comprehensive development and self-development of a growing personality.

Keywords: STEM education, training, digital resources, technologies, science school subjects, organizational and didactic approach, educational process.

INTRODUCTION

The problem formulation. The effectiveness of implementing STEM-education in modern secondary education institutions depends on ensuring quality training conditions for future teachers, access to modern equipment and innovative technologies, as well as contemporary teaching methods and techniques. Currently, there is significant interest in the potential of STEM, particularly regarding its application in science, education, and production. This highlights the relevance of optimizing the process of preparing future educators for the application of STEM-technologies in the educational process of secondary schools and identifying effective organizational and didactic approaches to using STEM-technologies in training future teachers of natural sciences.

As I. Sachanyuk-Kavetska notes, «in addition to basic digital skills, modern teachers should be proficient in innovative practices for implementing various models of learning, including adaptive, synchronous and asynchronous, blended, self-directed, e-oriented, distance, cloud-based, mobile learning, virtual classrooms, electronic learning management systems, learning process management systems, CMS courses, gamification, personalization, etc». (Sachanyuk-Kavetska, 2021).

Modern education is undergoing a transformation driven by the demands of the information society and rapid technological development. In this context, the integration of STEM education (Science, Technology, Engineering, Mathematics) into teacher training particularly in the natural sciences becomes especially relevant. STEM education fosters future educators' abilities to combine theoretical knowledge with practical application, work collaboratively, engage in research activities, and develop critical thinking.

Analysis of recent research and publications. The issue of STEM education has been addressed by Ukrainian scholars such as I. Vasyliashko, S. Halata, O. Korshunova, N. Morze, O. Patrykeyeva, O. Shevchenko, among others. The formats of STEM education application in the educational process are the subject of academic investigations by researchers such as O. Buturlina, S. Kyrylenko, N. Morze, I. Slipukhina, and I. Chernetskyi.

Various aspects of STEM implementation in educational institutions attract the attention of both domestic and international researchers. Theoretical and methodological aspects of STEM education development have been explored by foreign scholars such as Heather Gonzalez, Jeffrey Kuenzi, David Langdon, Keith Nichols, among others.

Reviewing literature on the specifics of STEM education by N. Andrushchenko, N. Ivanyk, L. Koltok, O. Kuzmenko, O. Prymak, O. Shevchenko reveals its core principles:

- *Integration of disciplines* – combining content from science, engineering, arts, and mathematics for comprehensive study and optimal integration strategies.
- *Problem-based learning* – elements of problem-based learning help develop critical thinking and creative problem-solving skills, stimulating analytical and creative abilities.
- *Skills development* – focused on basic skills essential for holistic personality development, such as critical thinking, communication, collaboration, and creativity.
- *Project-oriented learning* – using projects and practical tasks based on STEM resources to develop relevant competencies.
- *Encouraging innovation* – exploring innovative learning forms using STEM technologies and applying them across various future professional fields.

THE PURPOSE OF THE RESEARCH

Based on content analysis of psychological and pedagogical scholarly sources and the study of materials describing international experience on the research problem, the article aims to highlight the organizational and didactic approaches to the application of STEM-technologies in the training of future teachers of natural sciences.

RESEARCH METHODS

The primary research methods used include comparative analysis of scientific materials on the selected topic and the description of empirical experience in implementing STEM-education. Based on modern methodological approaches (systemic, environmental, competence-based, activity-based, and personality-oriented), the phenomenological essence of STEM-education has been defined, and the educational potential and didactic role of high-tech STEM tools in a holistic educational process have been revealed. Within the framework of solving the set objectives, the conceptual and terminological framework has been specified, ensuring the necessary level of theoretical and methodological justification for the development and effective systemic use of high-tech tools and

innovative digital solutions aimed at optimizing the application of organizational and didactic approaches to STEM-education elements in the professional training of future educators.

RESULTS OF THE RESEARCH

Presentation of the main material. The acronym STEM is formed from the capital letters of scientific and educational domains where educational activity takes place: Science, Technology, Engineering, and Mathematics.

The term STEM was first proposed by American bacteriologist R. Colwell in the 1990s, but it gained widespread use in the early 2000s. In educational practice, variants of the acronym are known where the letters A (STEAM) or R (STREM) are added. In the first case (STEAM), it includes the component related to the humanities and arts (Art), and in the second (STREM), it emphasizes the technocratic aspect of education (Robotics).

The essence of STEM-education lies in the scientific and technical training of future professionals in various educational fields, including natural sciences, by stimulating interest in acquired knowledge and strong motivation for pedagogical activity in modern educational institutions.

STEM-education is a process of effectively implementing integrative ideas and practical materials in robotics, engineering, modeling, and design, incorporating interdisciplinary and applied approaches.

According to didactic principles, STEM-education is a well-planned and organized process that combines the study of natural sciences with technology and mathematics, based on inquiry-based learning as the leading method of educational interaction.

Modern psychological and pedagogical science and school practice define STEM-education as a high-tech information and didactic tool, an innovative digital resource whose educational and developmental potential is actively utilized to optimize the educational process and promote the comprehensive development and self-development of learners.

Therefore, it is important to note that STEM-education is based on the principles of knowledge integration across different fields and bringing learning closer to real-life situations through the resolution of practice-oriented tasks.

In natural science disciplines, the STEM approach helps reveal connections between geography, biology, physics, chemistry, ecology, and modern technologies. In the educational process of preparing future educators for practical work, methods such as project-based learning, experimentation, situation modeling, laboratory simulations, and problem-based inquiry tasks are especially important.

The implementation of the Concept for the Development of STEM Education «foresees significant changes in the system of teacher training, particularly in higher and professional pre-tertiary education, as well as in postgraduate teacher education, where the process of preparing future natural science teachers to implement STEM technologies should become a key component of professional development, qualification improvement, and the introduction of innovative teaching methods» (Concept for the Development of Science and Mathematics Education, 2020).

The educational environment of higher education institutions should meet the natural curiosity of future teachers, their desire for exploration and discovery. Well-organized STEM education is capable of fulfilling these needs.

The organization of the educational process in natural sciences focuses on developing theoretical knowledge and improving practical skills for successful self-realization in a rapidly changing globalized world. This is supported by enhancing the applied orientation of natural science disciplines, expanding the volume of knowledge, and broadening the range of practical competencies.

As researcher I. Chervinska emphasizes, «STEM is a modern direction of additional education, in which various academic disciplines serve as a means for integrating several subject areas. It is an educational technology that enables the implementation of interdisciplinary project-based research, stimulates children's interest in high technologies and innovations, and serves as a forge for future engineering and technical specialists, who are lacking in today's high-tech industries» (Chervinska, 2017).

STEM (Science, Technology, Engineering, Mathematics) is a concept that involves the integration of four main fields of knowledge: science, technology, engineering, robotics, and mathematics. The application of STEM technologies in education involves using interdisciplinary approaches and integrating engineering and technological components into learning to develop learners' technical skills. This contributes to teaching natural sciences with an emphasis on the practical application of theoretical knowledge.

Organizational and didactic approaches to preparing future teachers of natural sciences for implementing STEM technologies are a crucial component of modern pedagogical education, as they ensure effective learning and the preparation of qualified teachers capable of innovatively teaching natural sciences (biology, chemistry, physics, geography).

These approaches focus on integrating knowledge from various disciplines, using modern pedagogical technologies, and developing the skills and competencies necessary to teach these subjects in accordance with the current educational requirements of the «New Ukrainian School» Concept. Organizational and didactic approaches to teacher preparation include a set of principles, methods, and technologies aimed at optimizing the educational process and preparing students for professional activity. In the case of training future natural science teachers, they are focused on ensuring deep knowledge and skills in areas such as mastering theoretical knowledge in relevant scientific disciplines, developing research skills, critical thinking, and innovative teaching approaches, and enhancing research and practical competencies for organizing and conducting lessons.

Preparing future teachers to implement the tasks of STEM-education in general secondary schools during natural science lessons requires their awareness of psychological and pedagogical courses and professional training disciplines. During their studies, students are introduced to modern approaches to organizing the educational process, options for digitalizing pedagogical activity, educational resources, and learning technologies.

Organizational and didactic approaches to applying STEM-technologies in training future teachers of natural sciences are an important aspect of modern educational reform, as high-quality STEM-education enables the integration of different disciplines, development of critical thinking, and enhancement of students' practical skills, which form the foundation for effective teaching in the future.

«The preparation of future science teachers for the use of STEM-technologies in the classroom involves the integration of these technologies into the educational components studied by students within the relevant educational and professional program, as well as during their teaching practicum». The implementation of these tasks will contribute to the development of relevant professional competencies, particularly those related to working with various digital tools that will be used in the actual educational process (Fig. 1).

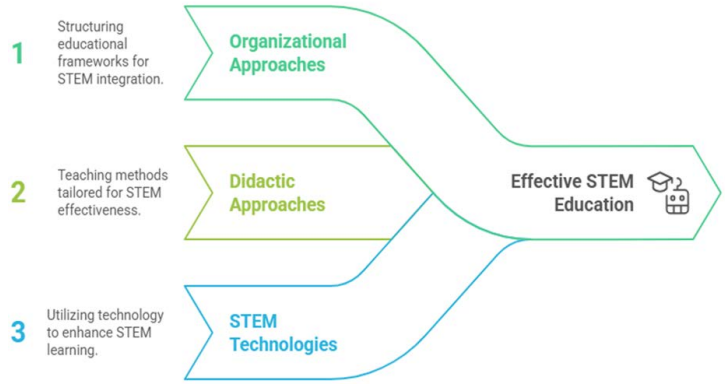

Fig 1. Integration STEM in Teacher Training

Thus, the leading organizational and didactic approaches in the process of preparing future science teachers for the implementation of STEM technologies in lessons at general secondary education institutions (GSEIs) include the following:

Integration of disciplines within educational programs or blocks of educational components.

Modern education is undergoing dynamic development, which necessitates the renewal of approaches to training future educators. STEM education, in particular, has gained significant relevance as it focuses on the development of practical skills, creative and critical thinking, teamwork, and the ability to solve real-world problems. In this context, the integrative approach to teacher preparation especially for science educators becomes increasingly important.

One of the key approaches is the integration of science subjects with other fields of knowledge, as well as interdisciplinary learning. This contributes to the formation of a comprehensive understanding of the world and facilitates learners' acquisition of knowledge. Examples of such integration include combining theoretical knowledge from biology and chemistry courses to explore complex biochemical processes or integrating geography with physics to study climatic phenomena.

An interesting option for integration is the use of project-based learning, during which students work on real interdisciplinary problems. This helps them develop creative and systemic thinking while also enhancing their practical skills. This process is illustrated schematically (in Fig. 2.)

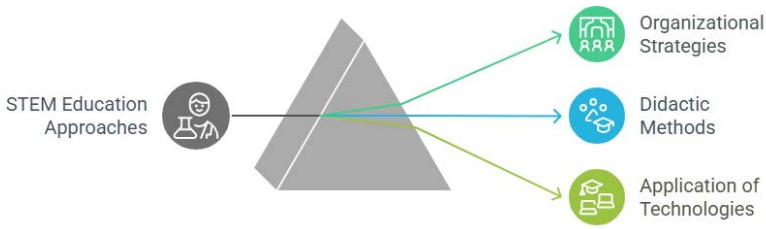

Fig. 2. Exploring STEM education for future science teachers

The integration of academic disciplines within the context of STEM education involves combining knowledge and methods from various fields of science to create a holistic understanding of natural and societal phenomena. This approach enables future educators to better comprehend interdisciplinary connections, design innovative educational projects and research, and apply acquired knowledge in practical activities. Therefore, it is essential to work on the development of professional and integral competencies necessary for the implementation of interdisciplinary learning.

The integration of disciplines into educational programs is a prerequisite for the effective preparation of future teachers for the implementation of STEM education. The realization of this approach within the educational process of higher education institutions not only fosters in-depth knowledge of natural sciences but also ensures the development of universal skills required in the 21st century. Effective implementation of integrated learning requires the renewal of

curriculum content, the introduction of active teaching methods, the professional development of educators, and the creation of a supportive educational environment.

The modern education system demands a rethinking of traditional approaches to teacher training, particularly in the context of STEM education development.

One of the most effective means of preparing future educators for the implementation of STEM education is project-based learning, which promotes interdisciplinarity, practicality, and the development of 21st-century skills.

Preparing future educators for STEM education through project-based learning involves the creation of group-based educational projects such as studying the condition of a local ecosystem or designing STEM lessons for secondary schools. During project-based learning, students collaboratively plan, investigate, present their findings, and defend them in front of an audience, with the teacher acting as a facilitator.

Project-based learning plays a crucial role in the system of STEM teacher training, as it fosters critical and creative thinking, develops teamwork skills, and enhances research competencies through the integration of knowledge from different disciplines and orientation toward real-life problems. By completing educational projects, future teachers learn how to plan, conduct research, analyze results, and present their ideas. These competencies are fundamental for implementing the STEM approach in modern educational institutions.

Future teachers must gain experience working in teams on real-world problems, where they can apply knowledge from various scientific disciplines (geography, mathematics, physics, biology, chemistry), as well as use engineering and technical tools to address these challenges. Students can engage in the creation and implementation of interdisciplinary projects, such as modeling ecological processes, analyzing natural disasters, or designing innovative environmental protection initiatives.

This approach involves creating an environment that fosters collaboration and interaction among students, educators, stakeholders, and other participants in the educational process. The pedagogy of partnership and collaboration includes various forms of interaction, such as working in groups or pairs, where students not only collaborate but also discuss ideas and solve complex learning tasks together.

The pedagogy of partnership and collaboration is a modern approach to learning based on mutual respect, trust, dialogue, shared responsibility, and equality among all participants in the educational process. In the preparation of future teachers of natural sciences (biology, chemistry, physics, geography, etc.), this approach helps develop not only strong subject-specific knowledge but also pedagogical reflection, communication skills, the ability to work in a team, and the capacity to act as change agents. Detailed examples of applying the ideas of the pedagogy of partnership and collaboration are presented in Table 1.

Table 1.

Examples of Implementing Partnership and Collaborative Pedagogy in Geography Lessons

№	Activity Format	Description	Elements of Partnership	Expected Outcomes
1	Project “My City/Village on the Map of Ukraine”	Creating a map with descriptions of the natural and social features of the area	Joint planning, task distribution, group presentation	Development of research skills, teamwork
2	Debate “Globalization: Challenge or Opportunity?”	Discussing a controversial issue in a debate format	Peer learning, exchange of views, respect for others' opinions	Critical thinking, speech development, culture of dialogue
3	Route “Eco Trail”	Creating an interactive route using maps and GPS	Field collaboration, joint decision-making, sharing observations	Environmental awareness, integration of digital technologies
4	Statistics Analysis: “World Population”	Working with open data and visualizing results	Group analysis, discussion of results, collective evaluation	Data literacy, infographic creation, digital competence
5	Case Method: “Energy and Geopolitics”	Solving a real-world problem in a role-playing format	Collective problem-solving, role distribution, shared responsibility	Development of analytical and strategic thinking, empathy

Source: compiled by the author based on test

For the successful implementation of the pedagogy of partnership and collaboration, it is essential to adhere to its core principles:

- Subject-to-subject interaction between educators and higher education students as equal participants in the educational process.
- Dialogue and co-creation in learning through the exchange and joint construction of knowledge.

- Trust and respect, which foster open and tolerant relationships between educators and students.
- Shared responsibilities and accountability among all participants in the educational process, achieved through involvement in the planning, implementation, and evaluation of educational activities.

The advantages of such approaches in the preparation of future teachers of natural sciences, for example, future geography teachers, lie in the development of professional competencies (research, communication, social), and the formation of a pedagogical culture of cooperation. Overall, this contributes to increasing motivation to teach geography in an engaging and interactive manner.

The collective (cooperative) form of organizing educational activities involves learning in small groups united by a common educational goal. In this format, the teacher indirectly guides each participant's work through tasks that direct group activities. Cooperative learning methods offer students the opportunity to collaborate with peers, fulfill their natural desire for communication, and enhance learning outcomes and relevant competencies. These innovative learning methods integrate well and effectively with traditional methods and can be applied at various stages of the educational process.

The positive effect of cooperative learning is achieved through collaborative project work and participation in simulation laboratories. This makes cooperative learning one of the effective digital tools in a teacher's toolkit. Key components of educational interaction include positive interdependence, interpersonal communication that stimulates cognitive activity, individual and group accountability, communication skills, and reflection on interaction outcomes.

There are three main types of cooperative learning: formal, informal, and group-based. The choice of learning type during the educational process depends on its goals and objectives. A successful combination of all types of cooperative learning during the professional training of future teachers positively impacts task efficiency, motivation levels, and encourages active engagement both in and outside the classroom.

Among the most productive cooperative learning methods are: «think-pair-share», «say and switch»», «round table», «three-step interview», «learning together», discussion, didactic games, simulation, and project-based learning. Through these methods, students collaboratively develop and present research projects or create new didactic materials. By participating in cooperative projects using these methods, students develop their own thinking strategies while learning to collaborate with other participants in STEM projects. This interaction fosters the formation of integrated competencies and the ability to solve complex, combined tasks, as mutual support becomes the foundation for personal growth.

Researcher D. Elkins identifies several types of social skills that can be developed through cooperative learning:

1. *Social relationship skills* – Skills that help build interpersonal relationships, such as introducing oneself, apologizing, or asking for help.
2. *Peer-related social skills* – Skills involving interaction with teammates to achieve common goals.
3. *Person-oriented behavior* – Through this, learners evaluate social situations, learn emotional regulation, and understand their own feelings.
4. Communication skills – These include active listening, turn-taking, and providing feedback (Barna, 2017).

When organizing cooperative activities, it's best to use active learning methods and various creative exercises that promote social skill development, cognitive engagement, creativity, and independence.

Future teachers of natural sciences must possess not only theoretical knowledge but also well-developed practical skills for organizing practice-oriented education and conducting laboratory work. This includes working with technical devices, functional models, and software tools.

Solid theoretical knowledge and well-formed professional competencies enable the implementation of integrated laboratory work in physics, chemistry, biology, and geography. Such integration helps students grasp the core of interdisciplinary educational content, understand the processes they will later teach, and better absorb the methodological principles of STEM technologies. Using digital tools and virtual or simulated laboratories allows for the execution of experiments that are difficult to perform in real settings (simulating chemical reactions or modeling natural landforms).

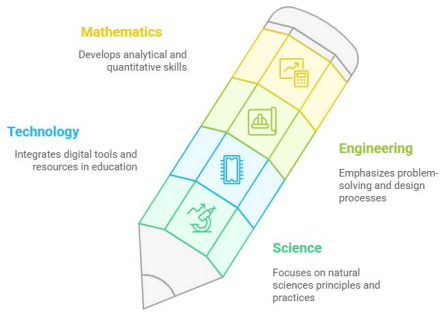

Fig. 3. Enhancing Teacher Training with STEM

One of the key aspects of preparing future science teachers is the development of skills for independent work and critical thinking. To achieve these goals, it is necessary to use methods such as the case method, real-world case studies, and practical examples. These enable students to apply scientific knowledge to real-life situations.

Organizing independent research projects, where students can conduct their investigations in various types of laboratories using digital tools, facilitates the mastery of new strategies for structuring the educational process and building effective mechanisms for acquiring practical competencies.

Integration of STEM Learning into the Curriculum. To effectively implement STEM technologies in the training of future natural science teachers, it is necessary to revise the structure of educational curricula. These curricula should include not only scientific disciplines but also courses that incorporate technical and engineering aspects (Fig.3).

This may include: specialized courses in programming and robotics; modules focused on modeling technologies and 3D design; courses in data processing and analysis (statistics, the use of modeling and visualization software); practical and laboratory sessions that provide opportunities to apply STEM technologies in solving real educational tasks.

CONCLUSIONS AND PROSPECTS OF FURTHER RESEARCH

To work effectively with STEM technologies, teachers must possess proficiency in modern information and communication technologies (ICT), which support the integration of educational materials and enhance the learning process through the use of software for modeling scientific phenomena (e.g., mathematical models, virtual laboratories). They also need a foundational knowledge of programming, which enables them to incorporate coding into educational processes (e.g., through simple modeling programs or working with sensors and data-collecting devices), as well as the ability to use platforms for online learning and conducting remote lessons.

Future scientific research should focus on exploring the potential of STEM technologies in the professional training of future teachers of natural science disciplines.

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