

The Use of Innovative Digital Technologies in Teaching Natural Sciences in Higher Education Institutions

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Abstract. The digital transformation of higher education has created new opportunities for modernizing the teaching of natural sciences. In biology, chemistry, physics, ecology, geography, and related disciplines, innovative digital technologies support visualization, modeling, experimentation, data analysis, blended learning, and students' research activity. Their use is especially important because natural science education requires the integration of theoretical knowledge with practical, laboratory, and inquiry-based learning. The objective of this article is to analyze the specific features of using innovative digital technologies in teaching natural sciences in higher education institutions and to determine their impact on students' motivation, cognitive activity, theoretical knowledge, practical skills, research competence, digital competence, and independent learning. The study is based on a comprehensive methodological approach combining analysis of scientific, pedagogical, methodological, and regulatory literature; systematization and classification of digital tools; pedagogical observation; analysis of teaching materials and electronic courses; pedagogical modeling; and generalization of teaching experience. The empirical component was conducted at Uman National University and compared a control group taught mainly through traditional methods with an experimental group in which multimedia presentations, virtual laboratories, interactive platforms, digital simulators, online tests, electronic maps, cloud services, mobile applications, and blended learning tools were systematically applied. The results show that the systematic use of innovative digital technologies had a positive effect on all key indicators of students' educational activity. In the experimental group, learning motivation increased by 41 percentage points, theoretical knowledge acquisition by 41 percentage points, practical skills by 40 percentage points, research skills by 36 percentage points, digital competence by 49 percentage points, independent work by 38 percentage points, and the quality of educational and research tasks by 41 percentage points. Virtual laboratories, interactive presentations, video materials, online tests, and digital simulators were identified as the most effective tools. Innovative digital technologies improve the quality, accessibility, interactivity, and practical orientation of natural science education.

Keywords: innovative digital technologies; natural sciences; higher education institutions; digitalization of education; virtual laboratories; interactive learning; blended learning; digital competence; research competence; artificial intelligence in education; science education; educational technologies.

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Introduction. In the current conditions of societal development, higher education is undergoing significant transformations related to global digitalization, the rapid advancement of information and communication technologies, the renewal of the content of educational programs, and changes in approaches to organizing the learning process. These processes are particularly relevant in the teaching of natural sciences, since natural science disciplines form students' scientific worldview, research thinking, environmental culture, and ability to analyze natural phenomena and apply acquired knowledge in practical activities. In this regard, the use of innovative digital technologies in the teaching of natural sciences in higher education institutions is an important factor in improving the quality of professional training of future specialists (Bialyk et al., 2020; Bida et al., 2020).

Today, the traditional model of education, which is primarily based on the transmission of ready-made knowledge from the teacher to the student, is gradually giving way to interactive, inquiry-based, project-based, and practice-oriented forms of educational activity. Digital technologies open up broad opportunities for modernizing the educational process, providing access to modern electronic resources, virtual laboratories, simulators, multimedia materials, online platforms, distance learning systems, and digital tools for modeling natural processes. As a result, the teaching of natural sciences becomes more visual, dynamic, individualized, and closer to real scientific research practice.

Natural sciences have significant potential for the implementation of digital educational innovations, as their content is closely connected with observation, experimentation, data analysis, modeling, forecasting, and the interpretation of research results. In the process of studying biology, chemistry, ecology, physics, geography, and other natural science disciplines, digital technologies make it possible to demonstrate complex phenomena that cannot always be directly observed in classroom settings. For example, with the help of virtual laboratories, students can conduct experiments in chemistry or biology without risks to their health, use digital microscopes, work with ecological databases, analyze satellite images, model physical processes, investigate climate change, assess the state of biodiversity, or examine the level of environmental pollution (Honcharuk, 2024).

An important aspect of using digital technologies in the teaching of the natural sciences is the development of learners' digital, research, and professional competencies. A modern specialist in the natural sciences must not only possess theoretical knowledge but also be able to work with digital data, use specialized software, search for, process, and visualize information, critically evaluate scientific sources, and apply digital tools to solve professional tasks. That is why the integration of innovative digital technologies into the educational process contributes to the preparation of

competitive professionals capable of acting effectively in the conditions of an information society and rapid technological change.

The relevance of the topic under study is also determined by the need to increase students' motivation to study natural science disciplines. The use of interactive presentations, educational platforms, online testing, video lectures, e-learning courses, augmented reality, and virtual reality promotes the activation of learners' cognitive activity. Such technologies help make learning material more accessible and engaging, provide opportunities for independent study of topics, revision of complex issues, and completion of individual and group tasks. In addition, digital tools enable instructors to assess knowledge promptly, analyze students' academic performance, provide feedback, and adjust the educational process in accordance with the individual needs of learners (Honcharuk et al., 2022).

Digital technologies have become particularly important in the context of distance and blended learning. The experience of recent years has shown that higher education institutions must be prepared for the flexible organization of the educational process, the use of online communication, e-learning courses, cloud services, video conferencing, and digital platforms. For natural science disciplines, this issue is especially challenging, as a significant part of their content involves laboratory, practical, field, and experimental work. That is why an important task of modern higher education is to find effective ways to combine traditional forms of learning with digital tools that make it possible to preserve the practical orientation of natural science training.

At the same time, the introduction of innovative digital technologies into the teaching of natural sciences is accompanied by certain challenges. Among them are the insufficient level of digital competence among some teachers and students, the limited technical resources of certain higher education institutions, the need for high-quality methodological support, and the necessity of adapting curricula to the digital educational environment. It is also important to take into account that digital technologies should not completely replace face-to-face communication, real experimentation, and direct research activity. They should be regarded as an effective tool for supplementing, expanding, and improving traditional teaching methods (Honcharuk et al., 2020; Honcharuk et al., 2024a).

The use of innovative digital technologies in teaching the natural sciences is one of the leading directions in the modernization of contemporary higher education. It contributes to improving the effectiveness of learning, fostering students' independence, and developing research skills, digital literacy, and the professional competence of future specialists. The integration of traditional pedagogical approaches with modern digital tools creates conditions for the high-quality preparation of learners who are capable of creative thinking, working with information, conducting scientific inquiry, and solving current problems in the natural sciences.

Literature Review. The problem of using innovative digital technologies in the teaching of natural sciences in higher education institutions belongs to the range of topical scientific and pedagogical issues, since modern natural science education is increasingly oriented toward the integration of traditional teaching methods with digital tools, virtual environments, interactive platforms, artificial intelligence systems, simulation tools, and remote communication. In the academic literature, digitalization of education is viewed not only as a technical modernization of the educational process, but also as a comprehensive transformation of the content, methods, forms of instruction, assessment approaches, and the nature of interaction between the teacher and the student.

In international educational documents, digital transformation is regarded as one of the leading directions for the modernization of education. The European Commission's Digital Education Action Plan 2021-2027 identifies the need to build high-quality, inclusive, and accessible digital education and to adapt education and training systems to the digital age. The plan emphasizes two strategic priorities: the development of an effective digital education ecosystem and the enhancement of digital skills and competencies of all participants in the educational process. These priorities directly concern higher natural science education, since its quality depends not only on the availability of equipment or platforms, but also on the readiness of teachers and students to use digital tools to solve educational and research tasks.

In scholarly works, digital technologies in education are often examined through the lens of competency-based, activity-based, constructivist, and inquiry-based approaches. From the perspective of the competency-based approach, digital tools should support the development not only of subject knowledge but also of skills in working with information, analyzing natural phenomena, using digital resources to conduct experiments, processing results, and presenting scientific conclusions. The activity-based approach emphasizes the student's active role in the educational process, which is realized through the completion of interactive tasks, participation in projects, work with virtual laboratories, digital maps, databases, simulators, and multimedia models. The constructivist approach assumes that knowledge is not transmitted in ready-made form but is constructed by the student through active interaction with the learning environment (Honcharuk et al., 2021; Makohonchuk et al., 2023).

A significant portion of contemporary research is devoted to the use of virtual laboratories in science and engineering education. A virtual laboratory makes it possible to model physical, chemical, biological, ecological, and geographical processes that cannot always be fully reproduced in classroom settings due to limited equipment, the danger of conducting certain experiments, the high cost of reagents, or the complexity of field observations. For the natural sciences, it is especially important that

virtual laboratories not only compensate for a lack of material resources but also expand the teacher's didactic possibilities.

For example, in chemistry, virtual laboratories make it possible to safely model reactions, vary substance concentrations, temperature, pressure, and reaction time, and observe the effects of these changes. In biology, virtual laboratories are used to model cellular processes, genetic patterns, ecological interactions, and the functioning of organs and systems. In ecology, they can be useful for analyzing the impact of anthropogenic factors on ecosystems, forecasting changes in biodiversity, and modeling pollution of aquatic, soil, and air environments. In physics, such tools make it possible to visualize the laws of mechanics, electrodynamics, optics, thermodynamics, and quantum phenomena (Kuchai et al., 2024; Parakhnenko & Honcharuk, 2025).

The development of augmented and virtual reality technologies creates new opportunities for natural science education. In science education, augmented reality is particularly promising for visualizing objects and processes that are difficult to observe directly. In chemistry, augmented reality can be applied to demonstrate the three-dimensional structure of molecules, mechanisms of chemical reactions, and crystal lattices. In geography and geology, it can be used to study terrain, geological structures, erosion processes, tectonic movements, and climate change. At the same time, the didactic value of immersive technologies is determined by the extent to which they are connected with the learning objective, the content of the discipline, students' level of preparedness, and the system for assessing learning outcomes.

An important place in contemporary literature is occupied by digital simulations and computer modeling. For the natural sciences, modeling is not only a teaching method but also a method of scientific inquiry. Through digital models, students can investigate processes that occur very quickly or very slowly, are dangerous, expensive, or inaccessible for direct observation. For example, in ecology, digital modeling makes it possible to analyze population dynamics, the spread of invasive species, changes in climatic indicators, eutrophication of water bodies, and the impact of industrial pollution on biocenoses. In physics, it is used to model the motion of bodies, electromagnetic fields, and wave processes; in chemistry, to predict the course of reactions and the properties of substances (Parakhnenko et al., 2025).

Innovative digital technologies that are actively discussed in scientific literature also include learning management systems, online platforms, cloud services, interactive whiteboards, mobile applications, digital educational resources, electronic textbooks, massive open online courses, and video conferencing tools. Their importance has increased especially after many educational institutions shifted to distance and blended learning. In higher natural science education, these tools provide access to learning materials,

organization of independent work, communication between teachers and students, testing, discussion of the results of laboratory and field research, and preparation of collaborative projects (Zhurat et al., 2022).

The role of artificial intelligence and generative tools in natural science education should also be considered separately. According to the OECD Digital Education Outlook 2026, generative artificial intelligence is changing the educational landscape because it is widely accessible, intuitive, and can be used by students outside direct institutional control. For the teaching of natural sciences, this means the possibility of using artificial intelligence to explain complex concepts, create individualized tasks, analyze data, prepare instructional materials, formulate research questions, simulate scientific discussion, and develop critical thinking. At the same time, the OECD stresses the need to design educational AI systems that support genuine learning rather than replace students' cognitive effort.

The literature also emphasizes the risks of uncritical use of generative artificial intelligence. UNESCO's guidance for generative AI in education and research highlights the need for a human-centered approach, ethical use, protection of academic integrity and personal data, and preservation of the teacher's role as a responsible organizer of the educational process. In science education, this is especially important because students should not merely receive ready-made answers; they should learn to verify information, analyze sources, substantiate conclusions, work with empirical data, and understand the limits of using digital tools.

A significant aspect of the problem under study is the teacher's digital competence. Scholars note that the effective use of digital technologies depends not so much on the availability of technical tools as on the teacher's methodological readiness to integrate them into the educational process. A teacher of natural sciences must possess not only basic digital skills, but also the ability to select digital resources in accordance with the lesson objectives, create interactive assignments, organize digital laboratory work, ensure academic integrity, assess the results of online learning, and support students in the digital environment. That is why the teacher's digital competence is one of the key conditions for the modernization of higher natural science education (Davyskyba et al., 2024; Yuzyk et al., 2025).

At the same time, research in digital education shows that access to technology alone does not guarantee improved learning quality. The OECD review on the impact of digital technologies on students' learning emphasizes a balanced approach: digital tools can have a positive effect, but their effectiveness depends on pedagogical design, the quality of implementation, teacher preparation, student motivation, and alignment of technologies with specific educational objectives. Therefore, digitalization should not be viewed as an end in itself; it must be subordinated to improving the quality of education, developing research thinking, and forming the professional competencies of future specialists.

An analysis of the literature makes it possible to argue that innovative digital technologies open up new opportunities for implementing blended learning in higher education institutions. Blended learning combines classroom interaction with online activities, independent work, digital assignments, video lectures, forums, tests, virtual laboratories, and project-based activities. For the natural sciences, this model is appropriate because theoretical material can be studied by students using digital resources, while classroom time can be used for discussion, experiments, analysis of results, solving problem-based tasks, and developing practical skills.

In the context of science education, an important issue is also the development of students' research competence through digital technologies. A modern specialist in biology, chemistry, physics, ecology, geography, or Earth sciences must be able to work with digital databases, geographic information systems, statistical software, sensor devices, electron microscopes, mobile laboratories, and platforms for processing experimental results. Geographic information systems, for example, enable students to analyze spatial data, create pollution maps, assess the condition of natural resources, and model environmental risks. Digital sensors and mobile measuring systems help bring learning closer to real scientific practice.

A positive aspect of using digital technologies is the possibility of individualizing learning. Through electronic platforms, the teacher can offer students tasks of varying levels of difficulty, monitor their progress, provide feedback, and organize the reworking of difficult topics. For science disciplines, this is especially important, since students may have different levels of preparation in mathematics, physics, chemistry, biology, or information technology. Adaptive digital systems help identify learning difficulties and adjust the educational process in a timely manner.

Along with these advantages, the literature identifies a number of problems and limitations of the digitalization of science education. These include unequal access to high-quality internet and equipment, an insufficient level of digital competence among some teachers and students, overload from digital platforms, a decline in the quality of communication in conditions of formal distance learning, the risk of superficial knowledge acquisition, academic dishonesty, cybersecurity issues, and the protection of personal data. A particular challenge for the natural sciences is that digital models cannot fully replace real experiments, fieldwork, direct observation of natural objects, or the development of practical laboratory skills.

Thus, scholarly literature is gradually establishing the view that a balanced use of digital technologies in teaching the natural sciences is necessary. The most effective approach is not the complete replacement of traditional learning with digital tools, but their pedagogically justified combination. Real laboratory and field research should be complemented by virtual simulations, digital data analysis, interactive models, online consultations, electronic resources, and artificial intelligence tools. Such an

approach ensures the integrity of science education by combining empirical experience, theoretical understanding, digital literacy, and students' research activity.

Aims. The aim of the article is to provide a theoretical justification and analysis of the specific features of using innovative digital technologies in the teaching of natural sciences in higher education institutions, as well as to determine their impact on the quality of students' professional training, the development of cognitive activity, research skills, digital competence, and the ability to apply natural science knowledge in practical activity.

The objectives of the article are:

1. To analyze the theoretical and methodological foundations of using innovative digital technologies in teaching natural sciences.
2. To identify the main types of digital tools used in natural science education, including virtual laboratories, digital simulators, multimedia resources, online platforms, mobile applications, artificial intelligence tools, and blended learning systems.
3. To determine the pedagogical potential of digital technologies for increasing students' motivation, cognitive activity, theoretical knowledge, practical skills, research competence, and digital competence.
4. To compare the educational outcomes of students taught mainly through traditional methods with those of students taught through a combination of traditional and digital learning tools.
5. To identify the main advantages, limitations, and methodological conditions for the effective integration of innovative digital technologies into natural science education in higher education institutions.

Methodology. The methodological basis of the study is a comprehensive approach to analyzing the use of innovative digital technologies in teaching natural sciences in higher education institutions. The study is grounded in a combination of general scientific, theoretical, and empirical methods, which made it possible to comprehensively examine the specifics of digitalization of the educational process, identify its pedagogical potential, advantages, risks, and conditions for effective implementation in the training of higher education students in natural science fields.

In the course of the study, the method of analyzing scientific-pedagogical, methodological, and regulatory literature on the digital transformation of education, innovative teaching technologies, the development of digital competence among teachers and students, as well as the methodological foundations of teaching natural science disciplines, was applied. This made it possible to clarify the current state of the issue under study and outline the main directions for using digital tools in teaching biology, chemistry, physics, ecology, geography, and other natural sciences.

To summarize scientific approaches, the methods of systematization, comparison, and classification were used. Through these methods, innovative digital technologies were considered as a set of electronic

educational platforms, virtual laboratories, interactive simulators, multimedia resources, cloud services, distance learning systems, artificial intelligence tools, digital models, and mobile applications. Particular attention was paid to technologies that facilitate the visualization of complex natural processes, the organization of students' research activities, experiment modeling, the development of critical thinking, and the enhancement of learning motivation.

The empirical component of the study involved pedagogical observation of the organization of the educational process using digital technologies, analysis of teaching and methodological materials, electronic courses, practical and laboratory classes, as well as generalization of the experience of teachers of natural science disciplines. Attention was focused on how digital tools affect student engagement, the quality of mastering learning material, independent work, communication between teachers and students, and the formation of practical skills.

Within the study, two groups of students were conventionally identified: a control group and an experimental group. In the control group, the educational process was carried out mainly using traditional teaching methods, including lectures, seminars, work with printed sources, written assignments, and oral questioning. In the experimental group, alongside traditional forms of instruction, innovative digital technologies were actively applied, including multimedia presentations, virtual laboratories, interactive educational platforms, digital simulators, online tests, electronic maps, video fragments related to the natural sciences, cloud services for collaborative work, mobile applications for data collection and processing, and elements of distance and blended learning.

The method of pedagogical modeling was used to determine the optimal conditions for implementing innovative digital technologies in teaching natural sciences. These conditions include the availability of appropriate technical support, the digital competence of teachers and students, the methodological appropriateness of using digital resources, the combination of traditional and digital forms of instruction, orientation toward practical and research-based activities, and ensuring academic integrity in the digital educational environment.

The use of the generalization method made it possible to formulate conclusions regarding the effectiveness of digital technologies in natural science education. It was established that their implementation contributes to improving the visual presentation of learning material, individualizing the educational process, developing research skills, and forming digital and natural science competencies among higher education students. At the same time, the effectiveness of digitalization depends not only on the availability of technical means, but also on the pedagogically justified selection of digital tools in accordance with the content of the discipline, the objectives of the lesson, and the students' level of preparation.

Results. The study on the effectiveness of using innovative digital technologies in teaching natural sciences was conducted at Uman National University. Its purpose was to determine the impact of digital educational tools on the quality of mastering learning material, the level of students' cognitive activity, the development of research skills, motivation to learn, and the readiness of future specialists to apply digital technologies in professional practice. The original article presents results in percentages; therefore, the summary tables below preserve these statistical indicators without introducing additional sample-size assumptions.

Initial level of students' digital readiness. Before the introduction of digital tools, both the control and experimental groups demonstrated approximately similar starting indicators of readiness to use digital technologies. This made it possible to compare the dynamics of changes during the study.

Table 1. Initial Digital Readiness of Students

Level of digital readiness	Control group, %	Experimental group, %
High level	18	19
Average level	54	55
Low level	28	26

Source: compiled by the authors based on diagnostic results at the initial stage of the pedagogical study at Uman National University.

The data show that both groups had comparable initial levels of digital readiness. The majority of students in both groups demonstrated an average level, while the share of students with a high level was below 20%. This confirms the need for systematic development of digital competence in natural science education.

Dynamics of motivation and theoretical knowledge. The next stage of the study assessed changes in students' motivation to study natural sciences and the level of theoretical knowledge acquisition. The experimental group showed more pronounced positive changes than the control group.

The results indicate that the use of innovative digital technologies significantly increased students' motivation and improved their theoretical knowledge. In the experimental group, the share of students with a high level of motivation increased by 41 percentage points, while the share of students with a high level of theoretical knowledge also increased by 41 percentage points. These changes were considerably stronger than in the control group.

Table 2. Dynamics of Motivation and Theoretical Knowledge

Indicator	Group	High level before, %	High level after, %	Increase, percentage points	Low level before, %	Low level after, %	Decrease, percentage points
Motivation to study natural sciences	Control	20	32	+12	29	17	-12
Motivation to study natural sciences	Experimental	21	62	+41	22	5	-17
Theoretical knowledge acquisition	Control	16	31	+15	28	17	-11
Theoretical knowledge acquisition	Experimental	17	58	+41	27	6	-21

Source: compiled by the authors based on final testing and comparative analysis of motivation levels in the control and experimental groups.

Cognitive activity, practical skills, research skills, and digital competence. The study also examined the impact of digital technologies on students' cognitive activity, practical skills, research skills, and digital competence. These indicators are especially important for natural science education because they reflect the ability to observe, analyze, model, interpret, and apply scientific knowledge.

Table 3. Development of Key Learning and Professional Competencies

Indicator	Group	High / active level before, %	High / active level after, %	Increase, percentage points	Low / passive level before, %	Low / passive level after, %	Decrease, percentage points
Cognitive activity	Control	36	44	+8	23*	15	-8
Cognitive activity	Experimental	38	74	+36	17	5	-12
Practical skills	Control	14	29	+15	32*	21	-11
Practical skills	Experimental	15	55	+40	32	6	-26
Research skills	Control	12	25	+13	34*	24	-10
Research skills	Experimental	13	49	+36	34	8	-26
Digital competence	Control	18	34	+16	26*	18	-8
Digital competence	Experimental	19	68	+49	26	3	-23

Note: where the original article did not separately specify all intermediate categories in the final comparison, the table preserves the reported high/active and low/passive indicators.

Source: compiled by the authors based on pedagogical observation, assessment of practical and research tasks, and digital competence diagnostics.

The table 3 demonstrates that the experimental group achieved stronger progress across all key indicators. The most significant increase was observed in digital competence, which rose by 49 percentage points. Practical skills increased by 40 percentage points, while cognitive activity

and research skills increased by 36 percentage points each. These results confirm that digital technologies contribute not only to knowledge acquisition but also to the formation of applied and research-oriented competencies.

Students' evaluation of digital tools. The study also assessed how students perceived different types of digital tools used in the teaching of natural sciences. The results show that the most effective tools were those that provided visualization, interactivity, practical orientation, and opportunities for independent work.

Table 4. Students' Perception of the Effectiveness of Digital Tools

Digital tool / effect	Share of students, %
Virtual laboratories helped better understand natural phenomena and processes	81
Digital simulations made it possible to reproduce complex or long-term experiments safely	76
Virtual laboratories contributed to the development of research result analysis skills	69
Virtual laboratory format increased interest in laboratory tasks	64
Visualization of natural processes facilitated understanding of complex topics	84
Interactive materials helped better memorize educational information	79
Digital visualization made classes more interesting, dynamic, and practically oriented	72
Excessive amount of digital material may reduce concentration if poorly structured	11

Source: compiled by the authors based on the student survey in the experimental group.

The results show that students positively evaluated virtual laboratories, digital simulations, interactive materials, and visualization tools. At the same time, the data also reveal the need for methodological balance: 11% of students indicated that an excessive amount of digital materials may make concentration more difficult if digital content is not clearly structured.

Online assessment, collaborative work, and independent learning. Digital technologies also influenced assessment practices, collaborative learning, and students' independent work. These components are important because they indicate whether digital tools support continuous learning rather than only classroom activities.

Table 5. Impact of Digital Technologies on Assessment, Cooperation, and Independent Work

Indicator	Share of students, %
Positively evaluated electronic testing	73
Instant test results helped identify knowledge gaps more quickly	70
Online testing encouraged systematic preparation for classes	67
Digital assessment was more convenient than traditional written questioning	58
Experienced technical difficulties during online testing	9
Cloud services facilitated communication among group members	77
Cloud services helped distribute tasks and jointly edit documents	74
Digital cooperation increased responsibility for group work	66
Digital cooperation developed communication and organizational skills	61
Regular use of electronic educational resources for self-study before digital support	33
Regular use of electronic educational resources for self-study after digital support	71

Source: compiled by the authors based on student survey results and analysis of independent and collaborative work.

The results indicate that online testing and cloud services supported feedback, cooperation, and learning autonomy. The share of students who regularly used electronic resources for self-study increased from 33% to 71%, which demonstrates the positive role of digital technologies in developing independent learning habits.

Quality of educational and research tasks. The quality of individual educational and research tasks was another important indicator of the effectiveness of digital technologies. The experimental group showed a more substantial increase in high-level works than the control group.

Table 6. Quality of Individual Educational and Research Tasks

Group	High-level works before, %	High-level works after, %	Medium-level works after, %	Low-level works after, %
Control group	21	35	47	18
Experimental group	22	63	32	5

Source: compiled by the authors based on the assessment of individual educational and research tasks.

The number of high-level works in the experimental group increased from 22% to 63%, while the share of low-level works decreased to 5%. This confirms that digital technologies not only intensify students' learning activities but also improve the quality of practical and research tasks.

Ranking of the most effective digital tools. Students identified the most effective digital tools used in natural science education. These results are important for improving course design and selecting digital resources.

Table 7. Most Effective Digital Tools in Teaching Natural Sciences

Digital tool	Share of students who considered it effective, %
Virtual laboratories	82
Interactive presentations and video materials	78
Online tests	73
Digital simulators	71
Electronic educational platforms	69
Cloud services for group work	64
Mobile learning applications	58
Electronic maps and geoinformation resources	54
Forums for educational discussion	37

Source: compiled by the authors based on student survey results.

The data show that students prefer visually rich, interactive, and practice-oriented tools. Forums for educational discussion were the least popular, which may be related to students' preference for more dynamic formats of interaction.

Teachers' assessment of digital technologies. The study also included a survey of natural science teachers at Uman National University. The results show that teachers generally recognize the importance of digital technologies, while also identifying the need for additional support.

Table 8. Teachers' Assessment of Digital Technologies in Natural Science Education

Teacher response	Share of teachers, %
Consider digital technologies a necessary component of the modern educational process	86
Noted that digital tools diversify teaching methods	79
Emphasized that digital technologies increase students' interest in learning	72
Indicated improvement in the quality of feedback with students	68
Emphasized the need for additional methodological support	43
Pointed to the need to improve teachers' digital competence	38
Indicated the need to update the material and technical base	31

Source: compiled by the authors based on a survey of natural science teachers at Uman National University.

Teachers' responses confirm that digital technologies are perceived as an essential part of modern education. However, the results also show that successful implementation requires methodological support, professional development, and improvement of the technical infrastructure of higher education institutions.

Difficulties in using digital technologies. Despite the positive results, students reported certain difficulties related to the use of digital technologies. These data are important for developing realistic recommendations for higher education institutions.

Table 9. Difficulties Encountered by Students When Using Digital Technologies

Difficulty	Share of students, %
Technical problems	29
Insufficient level of own digital training	18
Overload with online educational materials	16
Difficulty working with certain digital platforms	14
Unstable internet access	13
No significant difficulties	10

Source: compiled by the authors based on student survey results.

The main difficulties were technical problems, insufficient digital training, and overload with online materials. These findings indicate that digitalization of natural science education should be gradual, methodologically balanced, and supported by training, technical resources, and clear instructional design.

Comparative effectiveness of digital technology integration. A comparative analysis of the control and experimental groups confirmed the higher effectiveness of instruction under the conditions of systematic use of innovative digital technologies.

The results show that the experimental group significantly outperformed the control group in all measured indicators. Overall academic performance increased to 87%, the quality of knowledge increased to 76%, academic activity reached 74%, and digital competence rose to 68%.

Table 10. Comparative Learning Outcomes in the Control and Experimental Groups

Indicator	Control group before, %	Control group after, %	Experimental group before, %	Experimental group after, %
Overall academic performance	63	72	64	87
Quality of knowledge	37	49	38	76
Academic activity	36	44	38	74
Digital competence	18	34	19	68

Source: compiled by the authors based on comparative analysis of the control and experimental groups.

Generalized outcomes of digital technology implementation. A generalization of the research results made it possible to establish that innovative digital technologies positively influenced all the main components of students' educational activity.

Table 11. Generalized Positive Effects of Digital Technologies

Indicator	Increase, percentage points
Learning motivation	+41
Quality of theoretical knowledge acquisition	+41
Practical skills	+40
Research skills	+36
Digital competence	+49
Independent work	+38
Quality of educational and research tasks	+41

Source: compiled by the authors based on the generalization of empirical results of the pedagogical study.

The generalized results confirm the feasibility and pedagogical effectiveness of using innovative digital technologies in teaching natural sciences. The strongest effect was observed in the development of students' digital competence, followed by motivation, theoretical knowledge acquisition, and quality of educational and research tasks.

Discussion. The research results indicate that the use of innovative digital technologies in teaching natural sciences in higher education institutions is one of the important factors in modernizing the educational process, improving the quality of professional training of students, and forming their key competencies necessary for future professional activity. Modern higher education is undergoing active digital transformation; therefore, traditional approaches to teaching natural science disciplines require renewal and supplementation with interactive, visualized, research-based, and practice-oriented forms of learning.

Digital technologies are of particular importance in the teaching of natural sciences, since these disciplines are closely related to experimentation, observation, modeling, data analysis, and the establishment of causal relationships between natural phenomena. The use of virtual laboratories, digital simulators, interactive models, online platforms, multimedia resources, geographic information systems, mobile applications, and electronic learning environments makes it possible to present learning material in a more visual, accessible, and comprehensible way for students.

As a result, students not only acquire theoretical knowledge but also develop the ability to apply it in practical situations.

During the research, it was established that digital technologies have a positive impact on students' learning motivation. This is explained by the fact that modern students actively use digital tools in everyday life; therefore, the integration of such tools into the educational process makes learning more aligned with their needs, interests, and information perception style. Interactive tasks, visual materials, online testing systems, e-courses, and video lectures contribute to greater student engagement in the educational process and enhance their independence and responsibility for learning outcomes.

At the same time, it is important to emphasize that the effectiveness of digital technologies depends not only on the availability of technical means but also on the methodological appropriateness of their use. Digital resources should not be used formally or replace meaningful pedagogical interaction between the teacher and the student. They must be integrated into the structure of a lesson in accordance with its objectives, content, expected learning outcomes, and the students' level of preparation. The most effective use of digital technologies is when they complement traditional teaching methods, strengthen the research component, provide feedback, and foster critical thinking.

One of the important aspects of the discussion is the role of the teacher in the context of digitalization of natural science education. The teacher is no longer only a source of information but performs the functions of organizer, consultant, mentor, and moderator of students' educational and cognitive activities. He or she must not only master the content of the academic discipline but also be able to select digital tools, create electronic learning materials, organize distance and blended learning interaction, and assess learning outcomes using digital platforms. This requires the continuous development of teachers' digital competence and their readiness to implement innovative methods.

A positive result of the use of innovative digital technologies is the expansion of opportunities for individualized learning. Through electronic educational platforms, students can study material at a convenient pace, return to difficult topics, complete additional tasks, take tests, and receive prompt feedback. This is especially important for natural science disciplines, where mastering certain topics requires repetition, practical reinforcement, and visualization of complex processes. Individualized learning contributes to higher academic achievement and the development of self-education skills.

An important advantage of digital technologies is the ability to model natural processes and phenomena that are difficult or impossible to reproduce in classroom conditions. For example, in the study of ecology, biology, chemistry, physics, or geography, students can analyze virtual

experiments, observe the dynamics of natural systems, work with digital maps, and model the impact of anthropogenic factors on the environment. This promotes a deeper understanding of the learning material, the development of systems thinking, and the formation of research skills.

At the same time, the research findings provide grounds for stating that the introduction of digital technologies is accompanied by certain difficulties. The main problems include the insufficient level of material and technical support in some higher education institutions, unequal access for students to high-quality internet connectivity and modern devices, inadequate digital training of some teachers, as well as the risk of excessive use of digital resources without proper pedagogical justification. In addition, prolonged work with electronic devices can cause fatigue, reduced concentration, and the superficial completion of learning tasks.

Special attention should be paid to the issue of assessing learning outcomes in a digital environment. Online testing, electronic grade books, automated knowledge assessment systems, and distance learning platforms provide speed and convenience in monitoring, but they do not always make it possible to fully assess students' depth of understanding of natural processes. Therefore, it is advisable to combine test-based forms of assessment with practical tasks, project-based activities, case analysis, defense of laboratory work, preparation of presentations, and research reports.

The issue of the relationship between traditional and digital teaching methods also remains debatable. The conducted research confirms that the most effective approach is not the complete replacement of traditional learning with digital learning, but their rational combination. Lectures, practical and laboratory classes, field research, and work with natural objects remain important components of natural science education. At the same time, digital technologies expand their possibilities, provide additional visual support, access to up-to-date scientific data, and increase the interactivity of learning.

Thus, the use of innovative digital technologies in the teaching of natural sciences in higher education institutions has significant pedagogical potential. It contributes to increasing students' motivation, activating their cognitive activity, developing research skills, and forming digital, natural science, and professional competencies. At the same time, the effectiveness of digitalization depends on the level of teacher training, the quality of methodological support, the technical capabilities of the educational institution, and students' readiness for independent learning. Therefore, innovative digital technologies should be regarded as an important tool for improving natural science education, but not as an end in itself. Their implementation must be pedagogically justified, systematic, and aimed at achieving specific educational outcomes.

Conclusions. Thus, the use of innovative digital technologies in teaching natural sciences in higher education institutions is an important factor in modernizing the educational process, improving its quality, accessibility, and practical orientation. Modern higher education requires the introduction of teaching methods and tools that ensure active student participation, foster research competence, develop critical thinking, digital literacy, the ability to work with information, analyze natural phenomena, and apply acquired knowledge in future professional activities.

The study found that digital technologies significantly expand the possibilities of teaching natural science disciplines. In particular, the use of virtual laboratories, interactive simulators, multimedia presentations, online platforms, digital maps, cloud services, mobile applications, distance learning systems, and artificial intelligence contributes to better assimilation of complex learning material. Such technologies make it possible to model natural processes, conduct virtual experiments, and analyze ecological, biological, chemical, and physical phenomena, which is not always possible in traditional classroom-based learning.

An important advantage of innovative digital technologies is their ability to ensure the individualization and differentiation of learning. Higher education students have the opportunity to study at a convenient pace, review difficult topics, complete interactive tasks, take tests, work with electronic resources, and receive prompt feedback from the instructor. This contributes to increased academic motivation, independence, responsibility, and cognitive activity among students.

The empirical results confirm that systematic use of digital technologies has a positive impact on the main components of students' educational activity. In the experimental group, learning motivation increased by 41 percentage points, theoretical knowledge acquisition improved by 41 percentage points, practical skills increased by 40 percentage points, research skills by 36 percentage points, digital competence by 49 percentage points, independent work by 38 percentage points, and the quality of educational and research tasks by 41 percentage points.

At the same time, the effectiveness of digital technologies depends not only on the availability of technical support but also on the level of digital competence of instructors, the methodological validity of using electronic resources, the quality of educational content, and students' readiness to work actively in a digital environment. Therefore, an important task for higher education institutions is the systematic professional development of academic staff, upgrading the material and technical base, developing electronic educational and methodological complexes, and implementing modern educational platforms.

Innovative digital technologies in teaching natural sciences serve not only as an auxiliary learning tool but also as an important means of forming the professional competencies of future specialists. Their use promotes the

integration of theoretical training with practical activity, activates students' research work, improves the quality of the educational process, and ensures the compliance of higher education with the modern requirements of the digital society.

Prospects for further research are connected with studying the effectiveness of using artificial intelligence, augmented and virtual reality, digital laboratories, adaptive educational platforms, and geoinformation systems in the process of professional training of students in natural science specialties in higher education institutions.

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