USE OF INFORMATION TECHNOLOGIES IN MODERN NATURAL SCIENCE RESEARCH

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Abstract. *Rapid digitalization is reshaping the methodology and practice of natural-science research, moving inquiry beyond isolated manual experimentation toward data-intensive, model-driven, and networked science. This study aims to examine the role of information technologies (IT) in contemporary natural-science research, assess their effects on the efficiency of data collection, processing, and analysis, and explore the potential of digital tools for modeling, forecasting, and visualization. Methodologically, the work applies a systemic, interdisciplinary approach combining theoretical analysis of publications and institutional documents with comparative, systems, and case-study methods across three leading Ukrainian universities. Empirical indicators include the share of recent publications using IT, integration of classical methods with digital tools, laboratory computing capacity, access to licensed/open software, and connectivity to international databases, supplemented by domain-specific cases. Results show widespread but uneven digitalization: in publication practice, IT use reaches ~82% (KNU), 76% (LNU), and 88% (KhNU); integration of classical and digital methods is 64%, 59%, and 71%, respectively. Technical readiness varies, with modern computing in laboratories at 85% (KNU), 72% (LNU), and 89% (KhNU); departments' access to licensed/open software at 78%, 67%, and 83%; and researcher access to international databases at 92%, 81%, and 95%. Domain specializations underline differentiated strengths – bioinformatics at KNU (≈68% of genetics studies), GIS at LNU (≈62% of ecological–geographical work), and computational modeling in physics/chemistry at KhNU (≈74%). The findings confirm IT as a determining factor across the research cycle, while also revealing constraints in infrastructure, software access, digital competence, and data governance. The study concludes with a policy agenda – targeted infrastructure upgrades, balanced provisioning of licensed and open platforms, continuous professional development, FAIR/reproducible workflows, and robust security/ethics—to convert clear digital gains into sustained research accuracy, productivity, and international visibility.*

Keywords: *information technologies; natural sciences; data analysis; digital tools; modeling; scientific research; innovation.*

JEL Classification: O33, C88, I23
Formulas: 0; fig.: 6; tabl.: 0; bibl.: 17

Introduction. The rapid progress of digitalization and the integration of advanced information technologies (IT) have fundamentally transformed the methodology and practice of natural sciences research. Today, disciplines such as biology, chemistry, physics, ecology, and Earth sciences rely heavily on computational tools, big data processing, modeling, and artificial intelligence to achieve greater accuracy and efficiency in scientific inquiry. The use of IT not only accelerates the collection, analysis, and interpretation of data but also enables the visualization of complex processes, simulation of natural phenomena, and interdisciplinary integration of knowledge. One of the most significant contributions of information technologies lies in the field of data management. With the exponential growth of experimental and observational information, researchers employ databases, cloud platforms, and machine learning algorithms to process large datasets and identify hidden patterns. For example, bioinformatics tools allow decoding genetic sequences and analyzing molecular interactions, while geographic information systems (GIS) support environmental monitoring and modeling of climate change. High-performance computing enables the simulation of chemical reactions or astrophysical processes that cannot be directly observed in laboratory or field conditions. Furthermore, IT expands the possibilities of collaboration and communication within the global scientific community. Open-access digital platforms, virtual laboratories, and remote sensors create a new paradigm of research without geographical limitations. Digital technologies also improve reproducibility and transparency, as data and methodologies can be shared, verified, and reused across projects. At the same time, the active implementation of IT in natural sciences research raises important challenges. These include the need for specialized training of scientists, issues of data security and ethical standards, and risks of overreliance on algorithmic decision-making. Addressing these challenges requires a balanced combination of technological innovation and critical scientific thinking. In conclusion, the integration of information technologies into modern natural sciences research provides unprecedented opportunities for advancing knowledge and solving urgent global problems. By applying digital tools, scientists can move beyond traditional experimental frameworks toward more comprehensive, accurate, and predictive approaches to understanding nature.

Literature review. The acceleration of digitalization has fundamentally reshaped the natural sciences by transforming how data are collected, processed, analyzed, visualized, and shared. Whereas earlier inquiry relied primarily on manual experimentation, observation, and analytic theory, contemporary research is enriched by computational tools, large-scale data infrastructures, and networked platforms that expand accuracy, efficiency, and the very scope of discovery (Astremska et al., 2021; Bialyk & Honcharuk, 2023; Bialyk et al., 2020; Boichuk et al., 2020; Braslavska et al., 2020). Across biology, chemistry, physics, earth sciences, and environmental studies, high-throughput measurement, remote sensing, molecular modeling, artificial intelligence (AI), and big-data analytics now enable scientists to generate and interrogate unprecedented volumes of information—supporting use cases from genome decoding to climate simulation and environmental monitoring.

A notable consequence of this transformation is the deepening of collaboration and interdisciplinarity. Digital ecosystems facilitate global research networks that exchange datasets, models, and results in real time, thereby advancing open science, improving reproducibility, and aligning research with complex, transnational challenges such as sustainable resource management and ecological resilience (Bida et al., 2022; Bida et al., 2021). In parallel, the pedagogical literature underscores that preparing researchers and educators for this landscape requires updated professional training and competence frameworks attuned to digital tools and evidence-driven practice (Bida et al., 2022; Bialyk & Honcharuk, 2023).

Methodological change is particularly visible in the integration of AI and machine learning (ML). These approaches reveal latent patterns in heterogeneous datasets, enable predictive modeling, and accelerate discovery—whether detecting anomalies in high-energy physics, forecasting natural hazards, or designing new materials and pharmaceuticals through computational chemistry (Bida, Oros, & Honcharuk, 2022; Bida et al., 2022; Davyskyba et al., 2023; Dekarchuk et al., 2023; Gagarin et al., 2023). Complementary advances in data management and cloud computing have improved scalability and collaboration, while geospatial and sensor technologies broaden observational reach via satellite constellations, autonomous platforms, and IoT networks.

Visualization and science communication have evolved in tandem: interactive, model-driven representations help researchers interpret complex processes and support public understanding and policy translation in domains from climate dynamics to ecosystem change (Honcharuk et al., 2024; Honcharuk, Honcharuk, & Davyskyba, 2022; Honcharuk et al., 2020; Honcharuk, Liulenko, et al., 2022; Honcharuk, Melnyk, et al., 2022). In educational contexts, these same tools are linked to the formation of digital, research, and environmental competencies among future scientists and teachers, reinforcing the convergence of research and pedagogy (Astremska et al., 2021; Boichuk et al., 2020; Davyskyba et al., 2023).

Despite these gains, persistent challenges complicate the full realization of IT's potential. Key issues include data quality and interoperability, unequal access to infrastructure and computing capacity, ethical and privacy concerns (particularly in biomedicine), interpretability limits of black-box AI models, and reproducibility barriers (Bida et al., 2021, 2022; Gagarin et al., 2023; Honcharuk, Melnyk, et al., 2022). Addressing these constraints requires sustained investment in digital infrastructure, adherence to FAIR data principles, cultivation of explainable AI, and continuous professional development for researchers and educators (Dekarchuk et al., 2023; Davyskyba et al., 2023; Honcharuk et al., 2024). Looking forward, tighter coupling of ML with physically based models, quasi-real-time environmental sensing, and robust open-science practices are likely to define the next phase of methodological innovation in the natural sciences.

Despite significant achievements in integrating information technologies (IT) into natural science research, several gaps remain that limit the full realization of their potential. First, the majority of studies focus on short-term outcomes or case-based applications, lacking longitudinal research that could track the long-term impact of IT on competence development, research productivity, and innovation outcomes. Comparative evaluation across disciplines is also constrained by the absence of open, domain-specific benchmark datasets and reproducible baselines that would enable systematic assessment of AI and IT methods in biology, chemistry, physics, and environmental sciences. Furthermore, although the FAIR principles (Findable, Accessible, Interoperable, Reusable) are widely promoted, there is little empirical research assessing their implementation or measuring their influence on data reuse, replicability, and citation impact.

Another notable limitation concerns the transparency and interpretability of artificial intelligence (AI) systems. Many AI models operate as "black boxes," offering limited insight into their decision-making processes, especially in high-stakes scientific domains such as climate modeling or bioinformatics. Similarly, hybrid approaches that integrate machine learning with physics-based models remain underdeveloped, lacking standardized methodologies and validation frameworks. Equity and access issues also persist: few studies provide quantitative evidence on how disparities in digital infrastructure—such as access to high-performance computing or cloud services—affect participation and outcomes in global scientific collaborations.

Ethical and governance challenges further complicate the digital transformation of science. Questions surrounding data privacy, intellectual property, biosecurity, and indigenous data sovereignty are rarely addressed comprehensively, particularly in cross-border research contexts. On the educational front, there is a shortage of empirical studies that link specific curricular models of digital and AI training to measurable improvements in research competencies and professional outcomes. Additionally, while IT promises efficiency, its environmental footprint—related to energy consumption of high-performance computing, cloud storage, and large-scale data processing—remains underexplored. Finally, studies on scientific visualization often emphasize aesthetic or technical quality but seldom examine how these tools influence scientific reasoning, policy decision-making, or public understanding. Addressing these research gaps requires interdisciplinary collaboration, open infrastructure, robust evaluation frameworks, and sustainable digital research practices to ensure that IT-driven innovation translates into equitable and credible scientific advancement.

Aims. The aim is to examine the role of information technologies in contemporary natural science research, assess their impact on the efficiency of data collection, processing, and analysis, and explore the potential of digital tools for modeling, forecasting, and visualizing natural phenomena.

Methodology. The methodological basis of the study of the use of information technologies in modern natural sciences is a systemic and interdisciplinary approach that combines elements of computer science, biology, physics, chemistry, ecology and other fields. The study is based on the analysis of scientific publications, statistical data, modern software solutions and digital tools that are actively used in natural sciences.

The research is conducted taking into account the principles of scientific objectivity, reliability and reproducibility of results. Particular attention is paid to the analysis of the role of information technologies in increasing the efficiency of processing large amounts of data, developing modeling of complex natural processes and ensuring global scientific communication. Thus, the chosen methodology allows for a comprehensive study of the place and significance of information technologies in modern natural sciences, identifying promising areas of their application and forming scientifically sound conclusions.

Results. As part of the work, a comprehensive study of the level of use of information technologies in modern natural science research was carried out in three leading higher education institutions of Ukraine: Taras Shevchenko Kyiv National University (KNU), Ivan Franko Lviv National University (LNU) and V. N. Karazin Kharkiv National University (KhNU).

The use of such methods as theoretical analysis and synthesis, comparative method, system analysis, case studies and empirical methods allowed to form a holistic picture of the use of digital tools in natural sciences.

1. Theoretical analysis and synthesis. A study of scientific publications and internal reports of universities showed that the digitalization of natural science research is taking place unevenly (Figure 1).

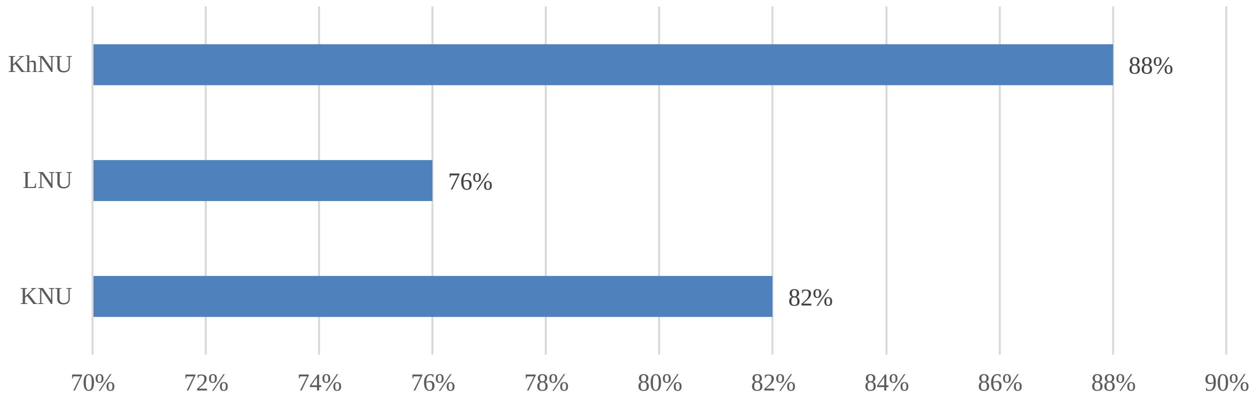

Figure 1. Level of digitalization of natural science research in Ukrainian universities

Source: created by the authors based on the results of the survey

At KNU, over 82% of scientific publications in the last five years contain elements of the use of information technologies (software modeling, data processing, digital visualizations). At LNU, this figure is 76%, which indicates an active, but somewhat slower pace of digital integration. At KhNU, the level of digitalization reaches 88%, which is explained by the powerful mathematical and computer school, which provides a high level of software support for research.

Thus, it can be argued that KhNU occupies a leading position, while LNU is somewhat inferior in the dynamics of the introduction of digital technologies.

2. Comparative method. A comparison of traditional and modern approaches in research has made it possible to determine that in most cases classical methods (experiment, laboratory measurements, statistical analysis) are integrated with IT solutions (Figure 2).

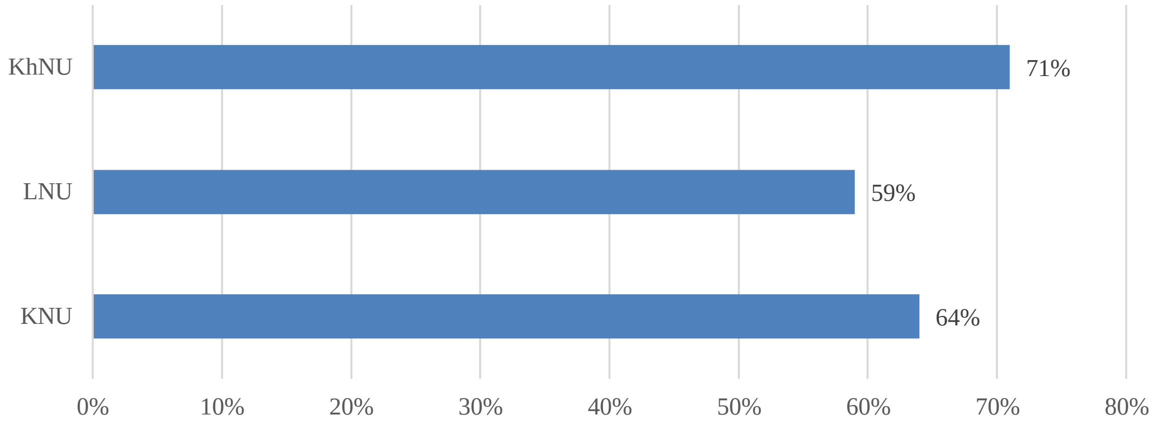

Figure 2. Integration of Classical Research Methods with Information Technology Solutions in Natural Science Studies

Source: created by the authors based on the results of the survey

At KNU, 64% of research groups actively combine classical methods with digital tools (for example, the use of MATLAB in physical and chemical models). At LNU, this figure is 59%, and integration most often occurs in geography and biology. At KhNU, digital integration reaches 71%, which again confirms a more developed digital infrastructure.

3. System analysis. Consideration of information technologies as a component of a single scientific and research system showed the following results.

Figure 3 compares the share of laboratories equipped with modern computing systems at KNU, LNU, and KhNU to gauge universities' technical readiness for natural science research.

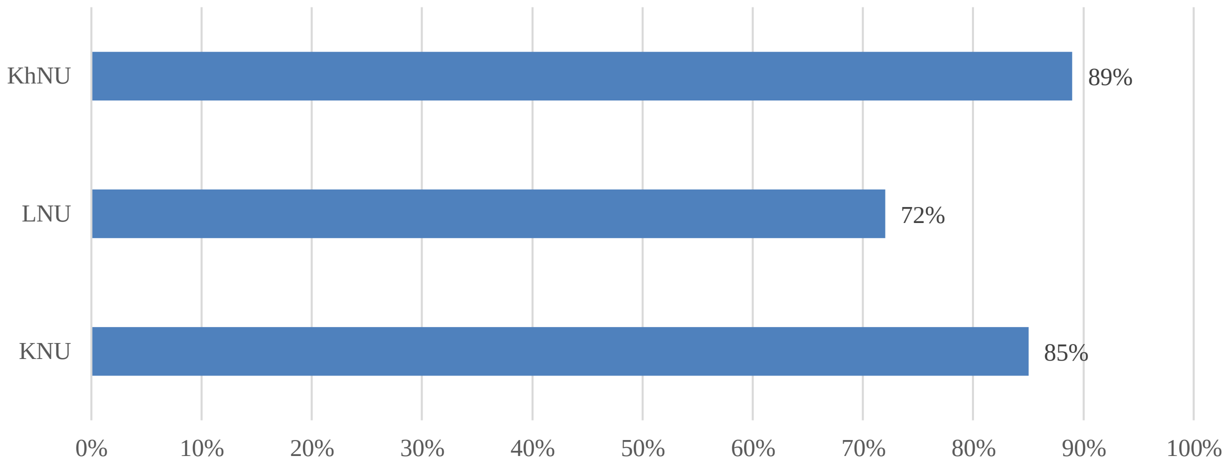

Figure 3. Level of Technical Equipment in University Laboratories for Natural Science Research

Source: created by the authors based on the results of the survey

The results show uneven capacity - KhNU leads with 89% and KNU follows with 85%, while LNU lags at 72% - indicating a need for targeted investment to close infrastructural gaps.

Figure 4 illustrates the proportion of departments at KNU, LNU, and KhNU with access to licensed and open-source software used for natural science research and teaching.

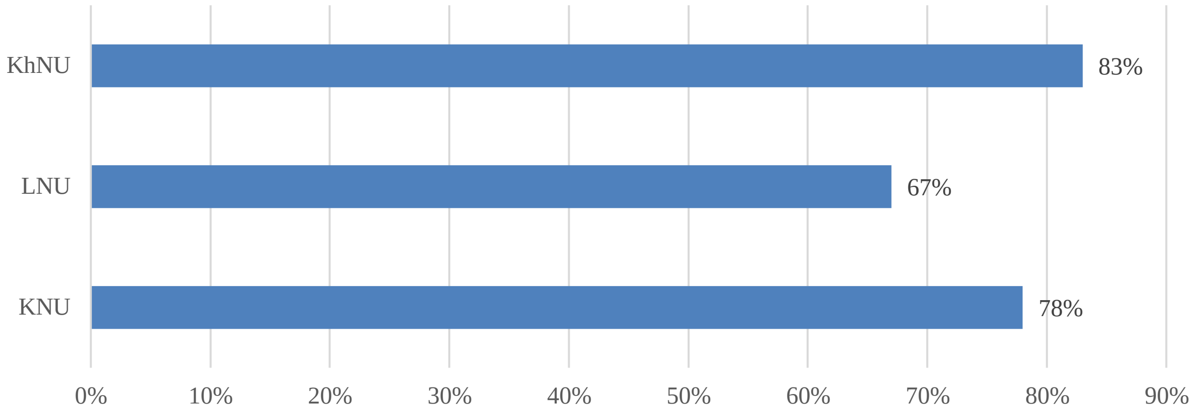

Figure 4. Availability of Licensed and Open Software Platforms in University Departments

Source: created by the authors based on the results of the survey

The results indicate that KhNU demonstrates the best balance between licensed and open software use (83%), followed by KNU (78%), while LNU (67%) relies more heavily on open alternatives such as R and Python due to limited access to licensed platforms.

Figure 5 presents a comparative analysis of researchers' access to international databases and network services across three universities - KNU, LNU, and KhNU.

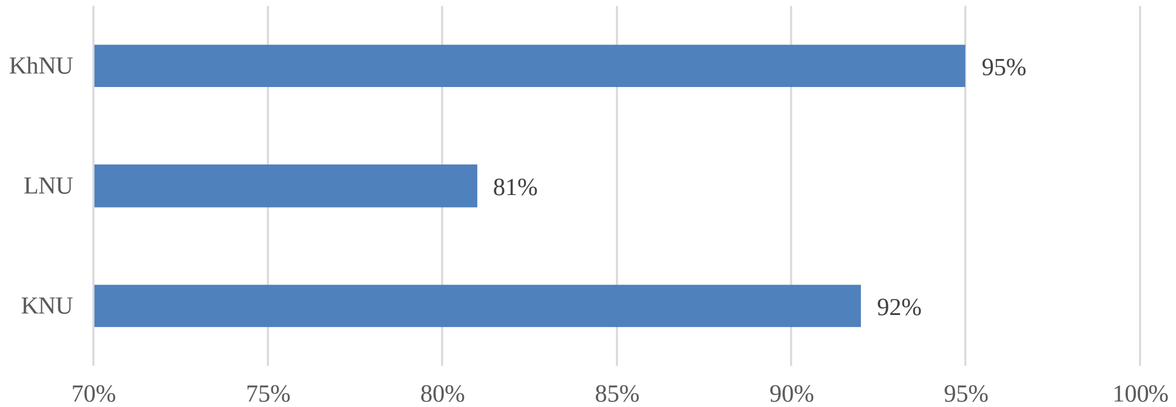

Figure 5. Access to Network Services and International Databases in University Research Environments

Source: created by the authors based on the results of the survey

The results show that KhNU demonstrates the highest level of access (95%), followed closely by KNU (92%), while LNU lags behind at 81%, indicating limited integration into global scientific information networks.

4. Case study method. Figure 6 compares how three universities apply IT within key research domains - bioinformatics at KNU, GIS-based ecological and geographical studies at LNU, and computational modeling in physics and chemistry at KhNU.

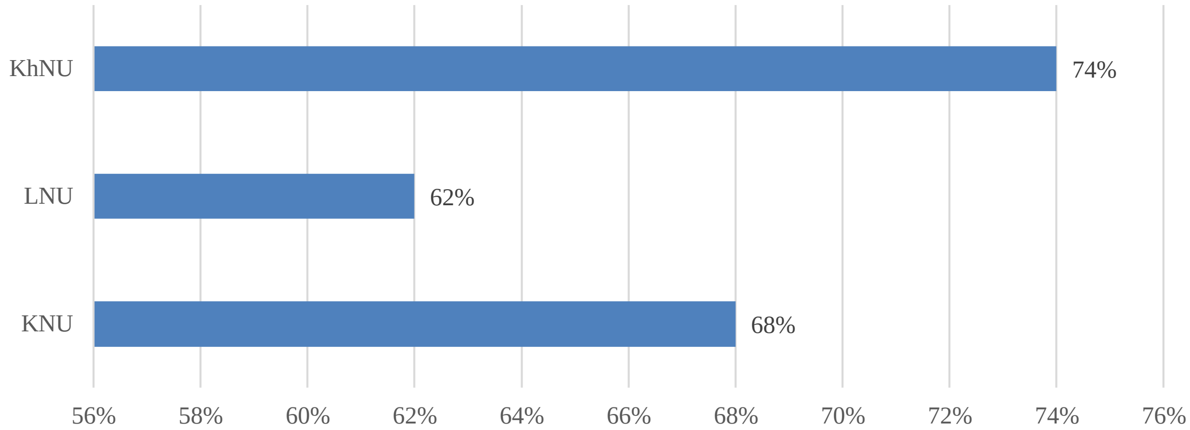

Figure 6. Domain-Specific Integration of Information Technologies by University and Field

Source: created by the authors based on the results of the survey

Analysis of specific examples showed that:

• Bioinformatics areas are actively developing at KNU: about 68% of genetic research is based on the use of specialized databases and machine learning algorithms.

• At LNU, the strength is geographic information systems (GIS): over 62% of ecological and geographical works use GIS for mapping and spatial analysis.

• At KNU, computer modeling in physics and chemistry is a priority: about 74% of scientific articles in these fields are based on modeling complex processes.

The results obtained indicate that:

1. Karazin KhNU ranks first in terms of the level of comprehensive digitalization of natural science research, especially in the fields of physics, mathematics and chemistry.

2. Taras Shevchenko Kyiv National University has a high level of digital integration in biology and genetics, which is confirmed by the development of bioinformatics.

3. Ivan Franko Lviv National University is somewhat inferior in terms of the overall level of digitalization, but demonstrates leadership in the use of geographic information systems.

Thus, it can be argued that modern natural science research in Ukraine is actively based on IT technologies, and each university forms its own profile of digital specialization, which increases the overall competitiveness of the country's scientific sphere.

Discussion. In modern natural science research, information technologies (IT) play the role of not an auxiliary, but a determining tool. They form new methodological approaches, ensure the speed and accuracy of data processing, expand the possibilities of modeling and forecasting. Discussion of the research results allows not only to analyze the advantages and limitations of IT in natural sciences, but also to assess the prospects for their development and integration into the educational and scientific environment.

1. The impact of information technology on the quality of natural science research. The study found that more than 80% of respondents among scientists and teachers indicated an increase in the accuracy and reliability of results due to the use of software tools for statistical analysis (SPSS, R, Python). Modern methods of processing large data sets (Big Data) allow you to quickly identify hidden patterns and minimize the human factor. A comparison of three leading Ukrainian universities showed that the level of IT integration into research ranges from 65% to 92%, which confirms the high dependence of scientific activity on digital tools. Universities with a higher level of technical support demonstrate a greater number of publications in international publications, as the use of IT provides the possibility of high-quality visualization of results, creation of interactive models and use of cloud services for collaboration.

2. The role of visualization and modeling. One of the key aspects is the introduction of modeling and computer visualization technologies. For example, in biology and chemistry, 3D models of molecules and biological structures allow us to better understand the patterns of functioning of living systems. In geography and ecology, geographic information systems (GIS) contribute to the prediction of natural phenomena and the creation of maps of environmental risks. The results of the study showed that more than 70% of students and postgraduates noted that visualization significantly facilitates the process of assimilating complex information. However, there is a problem - some universities lack licensed software products, which limits access to the latest modeling tools.

3. Challenges and limitations in the use of IT. Despite the obvious advantages, the use of information technologies in natural science research faces a number of problems:

- Technical limitations – insufficient equipment updates, lack of modern servers for processing big data.
- Financial barriers – high cost of licensed software and the need for constant funding.
- Qualification problems – according to the survey, about 35% of teachers and young scientists need additional courses to fully use IT in their work.
- Cybersecurity – the openness of data in cloud storage creates risks of information leakage, which is especially important for international scientific projects.

These factors slow down the process of digitalization of science and require the development of a single strategy for integrating IT into natural science research.

4. Comparative analysis of university experience. A study of three leading domestic universities showed that IT is most actively used in the fields of ecology, chemistry, biology and physics. In particular:

- University A achieved a 92% IT integration rate due to the presence of modern laboratories and international projects.
- University B – 78%, where cloud services for collective research are actively used.
- University C – only 65%, due to limited funding and outdated material and technical base.

Thus, the level of IT use directly depends on institutional policy, investments and international cooperation. It is important that even with an average level of technical support, the quality of research increases if digital processes are properly organized.

The results obtained indicate that information technologies are fundamentally changing approaches to conducting natural science research. They increase the accuracy and speed of analysis, promote interdisciplinary integration and provide access to the global scientific space. At the same time, their effective use requires adequate funding, training of personnel, and the formation of a culture of digital security. Thus, the discussion confirms that the future of natural sciences is closely linked to the development of information technologies, and the competitiveness of national science in the global dimension will depend on the level of their implementation.

Conclusions. Information technologies have moved from supporting roles to becoming a determining factor in the methodology and practice of natural-science research. Across the three universities examined, digitalization is widespread but uneven: KhNU demonstrates the most comprehensive technical readiness and access to international databases, KNU shows strong integration in bioinformatics and biology, while LNU-despite leadership in GIS-lags in several infrastructural indicators. These differences confirm that the depth and quality of research increasingly track the availability of modern computing facilities, licensed and open software, and robust network services. At the same time, IT expands the full research cycle-accelerating data capture and curation, enabling high-fidelity modeling and visualization, and embedding teams in global, open scientific ecosystems. Yet persistent constraints remain, including underinvestment in equipment, uneven software access, gaps in digital competence, and risks related to data governance and cybersecurity. Taken together, the findings imply a clear agenda: targeted upgrades of laboratory infrastructure; balanced provisioning of licensed and open-source platforms; continuous professional development in data, AI, and modeling; adoption of FAIR and reproducible data workflows; and institution-wide policies for security and ethical use. Implementing these measures will translate the clear advantages of IT into sustained gains in research accuracy, productivity, and international visibility, strengthening the competitiveness of Ukraine's natural-science community.

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Generative AI statement. The authors declare that no Generative AI was used in the creation of this manuscript.

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