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DIGITAL TECHNOLOGIES IN EDUCATION AS A TOOL FOR ENVIRONMENTAL SAFETY: ANALYSIS OF INNOVATIVE APPROACHES AND RISKS

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This article presents a comprehensive analysis of the role of digital technologies in education as a tool for ensuring environmental security. Emphasis is placed on innovative digital methods and tools that enhance ecological awareness and promote sustainable development practices. The study highlights key digital technologies currently applied in environmental education, including virtual laboratories, interactive AR/VR simulations, mobile applications, and gamified learning platforms. Special attention is given to the comparative assessment of digitalization levels in secondary schools and higher education institutions, revealing a significant gap in the integration of environmental topics between these educational stages. Additionally, the paper identifies critical risks associated with digitalization in education, such as digital inequality, inadequate digital competencies among educators, and the potential environmental harm caused by the production and disposal of digital devices. Based on the analysis, practical recommendations are provided to facilitate effective implementation of digital technologies in educational processes, including the development of specialized interactive courses, continuous professional development for teachers, creation of unified digital educational platforms, and the encouragement of practical ecological projects. The findings underscore the necessity of systematic and balanced integration of digital solutions into ecological education programs, aiming not only to enhance students' ecological awareness but also to address global ecological challenges through informed and responsible behavior. Moreover, the article emphasizes the need for inclusive policy frameworks that support equitable access to environmental education in the digital age, ensuring long-term environmental resilience and awareness.

Keywords: *digital technologies, environmental education, security, digitalization of education, virtual reality.*

Problem Statement. The digitalization of education is considered one of the key directions in modernizing the educational process in the context of the information society. However, global digital transformation inevitably affects the environmental sphere, generating both potential for reducing resource consumption and new threats to the environment. Despite positive effects such as reduced paper use, lower transportation costs, and decreased energy consumption for maintaining physical infrastructure, digital educational solutions are accompanied by an increase in electronic waste (e-waste), high energy consumption, and limited possibilities for equipment reuse.

In the context of environmental safety, the issue lies not only in minimizing the harmful impact of digital tools but also in leveraging them to promote environmental awareness and develop sustainability competencies. Digital simulations, virtual laboratories, AR models, and interactive educational platforms have the potential to shape environmentally oriented thinking and responsible behavior among learners. At the same time, there is a lack of systematic understanding in academic and educational discourse regarding which digital tools effectively support environmental education, how efficient they are, and what ecological risks accompany their implementation.

Therefore, a comprehensive study of the interrelation between digital technologies in education and environmental safety becomes highly relevant — both from the perspective of reducing environmental harm and fostering environmental consciousness through the use of modern digital tools.

Analysis of Recent Studies and Publications. The publication by M. S. Horobei [1] highlights the potential of digital technologies as a tool for ensuring environmental safety in the educational environment. The author focuses on the integration of distance learning platforms, mobile applications, and augmented and virtual reality technologies into the development of students' environmental thinking. The article emphasizes the importance of overcoming digital inequality, particularly by improving teachers' digital competencies, which is a prerequisite for effective digitalization of environmental education.

The practical dimension of using digital tools in school environmental education is explored in the study by P. Brečka, M. Valentová, and I. Tureková [2]. Within the framework of a case study on the implementation of digital learning materials in Smart Notebook in primary schools in Slovakia, increased student interest in environmental topics was observed. However, the study also revealed a low level of methodological preparedness among teachers to implement innovative digital resources in the learning process.

A systematic review of current research, presented in the work of M. Hajj-Hassan, R. Chaker, and A. Söderqvist [3], analyzes digital technologies used in environmental education — including gamified mobile applications, online platforms, interactive simulations, and AR/VR environments. The authors emphasize the potential of these tools to foster environmental awareness, while also noting the need to adapt educational content to the age and sociocultural characteristics of target audiences, as well as the need to improve the digital literacy of educators.

Thus, the analysis of scientific sources indicates the growing role of digital technologies as a means of transforming the environmental education space, which requires a comprehensive combination of technological, methodological, and behavioral approaches in the process of their implementation.

Purpose of the Article. The aim of this study is a comprehensive investigation of the potential of digital technologies in the educational process as a tool for enhancing environmental safety. The research focuses on the analysis of innovative digital approaches to fostering environmental awareness, identifying key risks associated with the digitalization of the educational environment, and justifying strategies for the effective

integration of digital tools into the education system to achieve the goals of sustainable development.

Main Research Findings. Digital technologies are becoming an increasingly significant tool in ensuring environmental safety, particularly in the field of education, where they not only support the learning process but also foster environmentally oriented thinking. Their integration into learning platforms, educational policies, and practical initiatives opens new avenues for implementing the concept of sustainable development through education.

One of the key directions involves the introduction of virtual laboratories, mobile applications, and augmented and virtual reality (AR/VR) platforms that simulate real ecological scenarios (such as air pollution or acid rain), allowing students to better understand ecosystem interconnections. As demonstrated by the study of Hajj-Hassan, Chaker, and Söderqvist (2024) [3], the most effective tools in environmental education are those that enable interactive modeling of ecological processes. These include scenarios related to circular resource use, environmental pollution, soil degradation, and more. This approach contributes not only to a deeper understanding of cause-and-effect relationships in natural systems but also to the development of critical thinking and environmental responsibility among learners.

However, along with the potential of educational digitalization for environmental security, certain risks emerge. One of the most significant is digital inequality. According to UNESCO (2023) [5], about 35% of schools worldwide lack stable internet access, hindering equal access to digital environmental tools. Additionally, the low level of digital competence among educators, particularly in Ukraine, leads to inefficient use of available resources. According to a 2022 national survey [5], only 14.6% of Ukrainian teachers assessed their skills in creating interactive content as sufficient.

Another important aspect is the environmental cost of digital technologies themselves. Servers, data centers, and gadget production exert considerable pressure on the environment. For instance, each online search query results in a CO_2 emission, and manufacturing one tablet requires around 70 kg of resources, many of which are toxic or non-renewable.

In the context of global environmental challenges and rapid digitalization of education, there is a growing need for synergy between technological tools and ecological awareness. However, despite the high level of technological equipment in educational institutions and the active implementation of digital solutions in the learning process, the integration of environmental topics remains fragmented. To identify the imbalance between the level of digitalization and the environmental content of educational materials, key indicators were analyzed — the results are presented in the diagram (Fig. 1).

The diagram illustrates a high level of technical equipment in Ukrainian schools (99.8%) and active use of digital technologies by teachers (79%). Despite this, the level of integration of environmental topics into digital educational content remains relatively low (35%), highlighting a significant potential for development in this area.

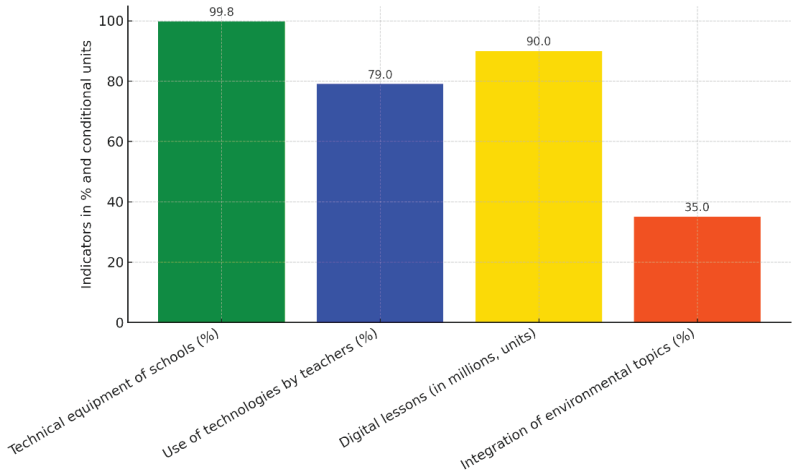

Fig. 1. Correlation between the level of digitalization in the educational process and the integration of environmental safety into educational content.

The strong digital infrastructure and educators' digital competencies create favorable conditions for incorporating environmental safety into the educational process. Digital platforms enable interactive modeling of environmental scenarios (pollution, resource crises, climate change), which contributes to fostering environmentally responsible behavior among students.

However, the low level of environmental integration points to the need for a systemic approach, including the development of specialized digital programs, educational modules, and interactive simulators aimed specifically at increasing environmental awareness and responsibility among the younger generation.

Table

Balance of Advantages and Risks of Digital Technologies in Environmental Education

Advantages of Digitalization	Risks of Digitalization
Interactive learning	Digital inequality
Improvement of environmental literacy	Insufficient digital competence of educators
Formation of environmental responsibility	High implementation costs
Adaptive and personalized learning	Environmental damage from digital devices
Accessibility of data for analysis	Information overload

In the process of researching the role of digital technologies in ensuring environmental safety, an important aspect is the analysis of the level of environmental education at different stages of learning. In particular, it is worth comparing how effectively environmental competencies are developed in general secondary education institutions (schools) and in higher education institutions (HEIs). Figure 2 presents comparative

data based on three criteria: the integration of digital tools into teaching environmental topics, the level of environmental awareness, and the practical involvement of learners in environmental initiatives. This allows for the identification of strengths and weaknesses of each educational level in the context of sustainable development.

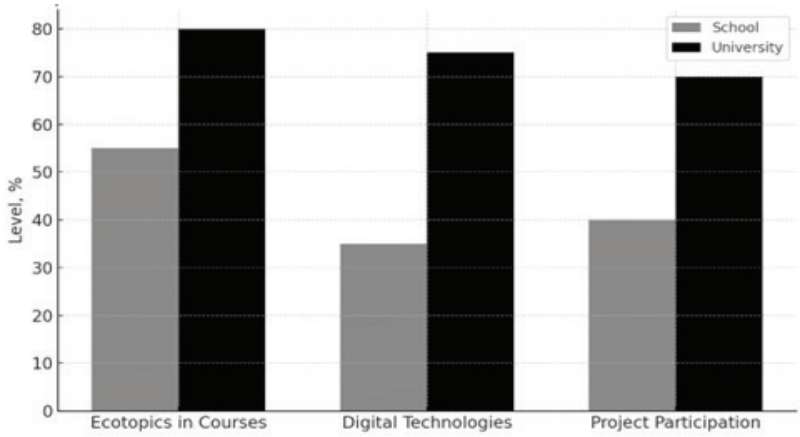

Fig. 2. Comparison of the level of environmental education in general secondary education institutions (schools) and higher education institutions (HEIs) based on three criteria

Comparative analysis of environmental education in schools and higher education institutions reveals a significant difference in approaches to fostering environmental awareness. While schools address basic environmental topics within general courses, the integration of digital technologies remains limited. In contrast, higher education institutions often include environmental topics as separate disciplines supported by specialized digital content (such as virtual labs, simulations, and educational platforms). HEIs also more actively involve students in environmental projects, fostering practical eco-competence. This gap highlights the need for the systematic implementation of digital tools in primary and secondary environmental education to ensure a consistent development of environmental culture from early schooling to professional formation.

To implement digital technologies in environmental education effectively, it is advisable to develop specialized interactive courses and modules using AR/VR simulations to deepen the understanding of ecological issues and foster appropriate awareness. Regular upskilling of teachers' digital competencies through training and workshops focused on modern digital tools is crucial. The creation of unified educational platforms with interactive environmental tasks and virtual laboratories accessible at various educational levels appears promising. Moreover, integrating practical ecological projects using digital technologies can enable students to work with real data and solve local environmental issues. Special attention should be paid to overcoming digital inequality by ensuring equitable provision of technical equipment to educational institutions, especially in rural areas, to guarantee equal access to quality digital environmental resources.

Conclusions. The study identifies digital technologies with the highest potential for fostering environmental safety through educational practices. It analyzes innovative

digital approaches in the learning process, particularly interactive modules, mobile applications, and augmented and virtual reality (AR/VR) platforms. The key risks of educational digitalization are characterized, including digital inequality, insufficient teacher preparedness, and the environmental impact of digital technologies themselves. The level of environmental topic integration is found to be higher in higher education institutions than in schools. Recommendations are formulated to strengthen the environmental component in digital educational programs. The research results contribute to substantiating effective strategies for integrating digital tools to develop environmental awareness and achieve the goals of sustainable development through education.

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ЦИФРОВІ ТЕХНОЛОГІЇ В ОСВІТІ ЯК ІНСТРУМЕНТ ЕКОЛОГІЧНОЇ БЕЗПЕКИ: АНАЛІЗ ІННОВАЦІЙНИХ ПІДХОДІВ ТА РИЗИКІВ

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У статті представлено комплексний аналіз ролі цифрових технологій в освіті як інструменту забезпечення екологічної безпеки. Акцент зроблено на інноваційних цифрових методах і засобах, які сприяють підвищенню екологічної обізнаності та впровадженню практик сталого розвитку. У дослідженні висвітлено основні цифрові технології, які наразі застосовуються в екологічній освіті, зокрема віртуальні лабораторії, інтерактивні AR/VR симуляції, мобільні додатки та гейміфіковані освітні платформи. Особливу увагу приділено порівняльній оцінці рівнів цифровізації у закладах загальної середньої освіти та закладах вищої освіти, що виявило значний розрив в інтеграції екологічної тематики між цими освітніми рівнями. Крім того, у роботі окреслено основні ризики, пов'язані з цифровізацією освіти, зокрема цифрову нерівність, недостатню цифрову компетентність педагогів та потенційну шкоду для довкілля, спричинену виробництвом і утилізацією цифрових пристроїв. На основі проведеного аналізу запропоновано практичні рекомендації для ефективного впровадження цифрових технологій в освітні процеси, включаючи розробку спеціалізованих інтерактивних курсів, постійне підвищення кваліфікації педагогів, створення єдиних цифрових освітніх платформ та заохочення до участі в практичних екологічних проєктах. Отримані результати підкреслюють необхідність системної й збалансованої інтеграції цифрових рішень у програми екологічної освіти з метою не лише розвитку екологічної свідомості здобувачів освіти, а й вирішення глобальних екологічних проблем шляхом відповідальної поведінки. Окрім цього, у статті наголошено на потребі формування інклюзивної освітньої політики, яка б забезпечила рівний доступ до екологічної освіти в умовах цифрової трансформації, сприяючи довгостроковій екологічній стійкості та усвідомленості.

Ключові слова: *цифрові технології, екологічна освіта, екологічна безпека, цифровізація освіти, сталий розвиток, цифрова нерівність, віртуальна реальність, цифрові компетентності.*

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