Digitalization of Education for Sustainable Development: Using AI and VR to Build Environmental Awareness in Generation Alpha

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HOW TO CITE:

Inna Koreneva, Inna Shorobura, Karina Molozhon, Yuliia Kharchenko, Serhii Khrapatyi (2026). Digitalization of Education for Sustainable Development: Using AI and VR to Build Environmental Awareness in Generation Alpha. International Journal of Special Education, 41(6s), 258-273.

ABSTRACT:

The article examines the conceptual foundations and practical dimensions of the digitalization of education for sustainable development, with a focus on the integration of artificial intelligence and virtual reality technologies. It aims to generalize contemporary approaches to fostering environmental awareness among Generation Alpha, analyze the potential of artificial intelligence and virtual reality in school settings, and define the role of digital tools in promoting responsible environmental behavior. Special attention is given to the preparation of future biology teachers at pedagogical universities as a key condition for the effective implementation of innovative environmental education practices. The study is based on a qualitative methodological framework, including the analysis of scholarly literature on digital education, environmental education, and emerging technologies. Systemic, comparative, and interdisciplinary approaches are applied, alongside methods of generalization, systematization, structural and functional analysis, and pedagogical modeling. The findings indicate that artificial intelligence enables the personalization of learning, adapts educational content to individual needs, and supports the modeling

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and forecasting of environmental scenarios. Virtual reality enhances emotional engagement and deepens students' understanding of ecological issues. The combined use of artificial intelligence and virtual reality creates an interactive learning environment that supports knowledge acquisition and the development of environmentally responsible behavior, highlighting the need to modernize teacher education.

Keywords: biology teacher training, pedagogical university, digitalization of education, artificial intelligence, virtual reality.

1. Introduction

In today's conditions of global digitalization, education for sustainable development is gaining special importance as a tool for forming a responsible attitude towards the environment and preparing the younger generation to solve environmental problems. Information and communication technologies are increasingly being integrated into the educational process, covering almost all its components – from the organization of learning and assessment of results to the creation of a digital educational environment. At the same time, the rapid development of technologies opens up new opportunities for the modernization of environmental education and the search for effective means of forming students' environmental awareness.

The problem becomes particularly relevant in the context of the aggravation of global environmental challenges, including climate change, depletion of natural resources, environmental pollution and loss of biodiversity. Such processes require not only technological or economic solutions, but also the formation of a new type of thinking focused on the principles of sustainable development. In this context, school is considered an important space for educating an environmentally responsible individual, capable of realizing the relationship between human activity and the state of the environment.

A special role in the modern educational space is played by the Alpha generation – children and adolescents who grow up in an environment of constant digital interaction. They are characterized by a high level of digital competence, an orientation towards visual content, interactivity, rapid perception of information and the need for personalized learning. Traditional forms of environmental education often prove to be insufficiently effective for this age group, as they do not provide the appropriate level of engagement and do not allow to make environmental issues personally meaningful for students.

In this regard, the use of artificial intelligence and virtual reality technologies is of particular importance. Artificial intelligence provides the ability to adapt educational content to the individual needs of students, analyze their educational achievements, model environmental situations and predict the consequences of various scenarios of human interaction with nature. Virtual reality, in turn, allows you to create an immersive educational environment in which students can directly observe the consequences of environmental pollution, climate change, ecosystem degradation or participate in virtual environmental expeditions (Kruhlov et al., 2024).

The use of artificial intelligence (further – AI) and virtual reality (further – VR) in environmental education is seen not only as a technological innovation, but as a comprehensive pedagogical approach that combines tools of personalization, visualization, emotional engagement, and practical modeling. This approach promotes the transition from passive assimilation of information to active participation of students in the study of environmental problems, the formation of critical thinking skills, and decision-making in accordance with the principles of sustainable development (Makarenko et al., 2024).

At the same time, the effective implementation of digital technologies in school practice is impossible without proper training of pedagogical personnel. This is of particular importance for future biology teachers, who are leaders of environmental education and must possess not only professional knowledge, but also modern digital competencies. The training of such specialists at a pedagogical university should include mastering artificial intelligence technologies, virtual reality and methods of their use in the formation of students' environmental awareness.

Thus, the relevance of the study is due to the need for a comprehensive understanding of the possibilities of digitalization of education for sustainable development, determining the potential of AI and VR in forming the environmental consciousness of the Alpha generation, as well as substantiating the role of training future biology teachers in implementing innovative educational approaches.

2. Literature review

The issue of digitalization of education for sustainable development and the use of artificial intelligence and virtual reality technologies to form environmental awareness is the subject of active research in the fields of pedagogy, environmental education, information technology, psychology and educational management. In modern scientific literature, digitalization of education is considered as a complex process of transformation of the educational environment, combining technological, pedagogical and socio-cultural aspects and aimed at improving the quality of education and developing competencies necessary for sustainable development (Oliveira & De Souza, 2022; Zinchenko et al., 2023; Akour & Alenezi, 2022). Researchers emphasize that digital technologies are becoming an important tool for forming a new type of thinking focused on a responsible attitude towards the environment and awareness of global environmental challenges.

A significant number of scientific works are devoted to the study of education for sustainable development. The works of Pada et al. (2023), Yang et al. (2022), Rohman et al. (2024) emphasize that modern environmental education should be aimed not only at transferring knowledge about the state of the environment, but also at forming an environmental culture, values, and readiness for practical activities. Researchers note that the development of environmental awareness is one of the key prerequisites for achieving the Sustainable Development Goals, primarily in terms of ensuring responsible consumption, preserving ecosystems, and combating climate change.

A separate area of research is related to the use of artificial intelligence in education. An analysis of the works of Dieterle et al. (2024), Foltynek et al. (2023), Davis et al. (2024) shows that AI opens up wide opportunities for personalizing learning, adapting educational content to the individual needs of students, and automated assessment of results. The scientific literature emphasizes that artificial intelligence technologies are able to model complex ecological processes, predict the consequences of human activity, and develop students' systems thinking skills. At the same time, researchers draw attention to the risks of excessive technologization of education and the need to maintain a balance between digital tools and direct pedagogical interaction.

A significant layer of research is devoted to the use of virtual reality in the educational process. In the works of Lampropoulos and Kinshuk (2024), Ravichandran and Mahapatra (2023), Al-Ansi (2023) it is noted that VR technologies contribute to increasing motivation, involvement and emotional perception of educational material. The use of virtual reality is especially effective in environmental education, as it allows creating immersive environments in which students can observe the effects of environmental pollution, ecosystem degradation, climate change or participate in virtual environmental expeditions. It has been established that such an approach contributes to the development of empathy for nature and the formation of environmentally responsible behavior.

A separate area of scientific research concerns the characteristics of the Alpha generation as a target audience for modern education. The works of

Sarfraz et al. (2025), Spasova (2022), Fernando and Premadasa (2024) emphasize that representatives of the Alpha generation are distinguished by a high level of digital competence, an orientation towards interactivity, rapid perception of information and a need for individualized learning. Researchers emphasize that traditional teaching methods are increasingly less responsive to the needs of this generation, which necessitates the use of adaptive technologies, digital platforms and visual environments.

Considerable attention in the current literature is paid to the preparation of teachers for the use of digital technologies. The works of Timotheou et al. (2023), Schmitz et al. (2023), Bui (2022) address the issues of forming digital competence of future teachers, the ability to use AI and VR in the educational process, as well as the readiness to design innovative educational environments. Researchers emphasize that the preparation of future biology teachers should include not only the mastery of technical tools, but also the development of the ability to integrate them into the content of environmental education and education for sustainable development.

Within the framework of research on digital environmental education, a separate direction can be distinguished related to the combination of AI and VR technologies. The works of Hajj-Hassan et al. (2024), Brecka et al. (2022), Li et al. (2024) demonstrate that the integration of these technologies allows the creation of personalized immersive educational environments in which students can not only receive information, but also actively interact with it, analyze environmental situations and predict the consequences of their own decisions. At the same time, the authors note that the issue of the integrated pedagogical use of AI and VR to form environmental awareness in the Alpha generation remains underdeveloped.

Summarizing scientific developments, we can distinguish three main areas of research into the digitalization of education for sustainable development:

1. Technological – research into the possibilities of artificial intelligence and virtual reality for personalizing learning, modeling ecological processes, and creating an interactive educational environment (Lampropoulos, 2025; Pratama et al., 2023; Mohamed et al., 2025).
2. Pedagogical – analysis of the role of digital technologies in the formation of environmental awareness, environmental culture and competencies for sustainable development (Husamah et al., 2025; Kurniawan et al., 2025; Wang et al., 2024).
3. Pre-service – research on the preparation of future teachers, in particular biology teachers, for the use of AI and VR in school practice (Sokoliuk et al., 2022; Park et al., 2025; Potwora et al., 2024).

Thus, the analysis of scientific literature shows that, despite a significant amount of research, the problem of integrated use of artificial intelligence and virtual reality to form the ecological consciousness of the Alpha generation remains insufficiently studied. Special attention needs to be paid to the development of pedagogical models that will combine the technological capabilities of AI and VR with the tasks of education for sustainable development and the system of training future biology teachers at the pedagogical university.

3. Methodology

The study is based on the analysis of scientific, theoretical, methodological and analytical materials devoted to the digitalization of education for sustainable development, the use of artificial intelligence and virtual reality technologies in the educational process, as well as the formation of environmental awareness of the Alpha generation. The information base consisted of publications in professional scientific journals on pedagogy, environmental education, information technologies, psychology and educational management, materials of international scientific and practical conferences, reports of international organizations and strategic documents in the field of education for sustainable development and digital transformation of education.

The methodological basis of the study is a systems approach, which is used to consider the digitalization of education as a complex multi-level system that combines technological, pedagogical, psychological and social components. This allowed us to analyze the relationships between the level of development of digital technologies, the characteristics of the Alpha generation's learning, the use of AI and VR, and the formation of students' environmental awareness.

In order to study the structure and functioning of the digital educational environment, structural and functional analysis methods were used, which made it possible to identify its key elements: adaptive educational systems based on artificial intelligence, virtual learning environments, mechanisms for personalizing the educational process, interactive means of forming an ecological culture and training pedagogical personnel. The comparative method was used to compare international experience in using AI and VR in the field of environmental education, which allowed us to identify common trends and features of different models of digitalization of education.

To generalize theoretical provisions and practical experience, the method of content analysis of scientific publications, analytical reports and educational programs dedicated to sustainable development, environmental education and digital technologies was used. This provided an opportunity to systematize approaches to the use of artificial intelligence and virtual reality, as well as to determine their potential in shaping environmentally responsible behavior of students.

At the stage of conceptual understanding of the results, the pedagogical modeling method was applied, aimed at developing a generalized model of integrating AI and VR into the process of forming the ecological consciousness of the Alpha generation. The model involves the interaction of such components as diagnostics of the level of ecological competence, personalization of educational content, immersive interaction in a virtual environment, and evaluation of results using artificial intelligence tools.

Additionally, the analogy method was used to determine the possibilities of adapting international experience to the conditions of training future biology teachers at a pedagogical university. This made it possible to outline promising directions for the modernization of educational programs, in particular by including disciplines and modules related to digital technologies, environmental education, and education for sustainable development.

The study also applied the historical-logical method, which allowed us to trace the evolution of approaches to environmental education - from traditional models of knowledge transfer to modern interactive concepts focused on the use of digital technologies and the active participation of students in solving environmental problems. To form conclusions, methods of analysis, synthesis, generalization and secondary analysis of scientific sources were used.

Thus, the methodological structure of the study combines systemic, comparative, content-analytical, and conceptual-model approaches, which provides a comprehensive study of the digitalization of education for sustainable development, determining the potential of AI and VR in forming the environmental consciousness of the Alpha generation, and substantiating the directions of training future biology teachers to use modern digital technologies.

4. Results

Generation Alpha encompasses children born after 2010, who have been growing up in a digital environment from an early age and have constant access to mobile devices, online services, interactive content, and social platforms. Unlike previous generations, today's students do not perceive digital technologies as an additional learning tool, but consider them as a natural part of everyday life and communication. In the context of digitalization of education, the Alpha generation acts as a new type of subject of the educational process, which is characterized by a high speed of information acquisition, the need for interactivity, personalization, and emotional involvement. Such students more easily assimilate educational material

through visual images, simulations, video fragments, augmented and virtual reality than through traditional textual explanations or reproductive forms of learning.

To determine the impact of the characteristics of the Alpha generation on the educational process, it is advisable to summarize their main characteristics and possible pedagogical consequences (Table 1).

Table 1. Characteristics of the Alpha generation and their impact on the organization of environmental education

Characteristic trait of the Alpha generation	Manifestation in the educational process	Impact on the formation of environmental awareness	Required pedagogical approaches
High level of digital competence	Active use of gadgets, digital platforms, multimedia resources	Facilitates access to environmental information, but increases the risk of superficial perception	Using interactive platforms, AI and VR
Focus on visual content	Better perception of videos, infographics, 3D models	Increases emotional awareness of environmental issues	Use of virtual tours, simulations, digital maps
The need for personalization	Desire to work at your own pace and on your own individual trajectory	Promotes a more conscious assimilation of environmental knowledge	Adaptive educational systems based on AI
Rapid attention switching	Difficulty concentrating on one activity for a long time	Makes it difficult to perceive complex ecological processes	Using short interactive modules and variable work formats
The desire for active interaction	The need not only to observe, but also to act	Forms readiness for environmentally responsible behavior	Using project activities, VR cases, game scenarios
High level of emotional sensitivity	Strong response to visual and story stimuli	Deepens the experience of environmental problems and promotes empathy for nature	Creating emotionally rich digital content

Source: systematized by the author

The above characteristics indicate that the Alpha generation needs to transition from a traditional learning model to a flexible digital environment in which environmental information is presented in a visual, interactive, and personally meaningful form.

One of the key features of modern students is the specific nature of the perception of information about the environment and ecological problems. Most global challenges – climate change, depletion of natural resources, pollution of the atmosphere or oceans – are remote in time and space. Because of this, they are often not perceived by students as an immediate threat or problem that concerns their personal lives.

Traditional presentation of environmental information in the form of text, statistics or theoretical explanations does not always provide the proper level of understanding and emotional engagement. For the Alpha generation, forms of work that allow them to "see" the consequences of environmental processes and feel their own involvement in them are much more effective.

Modern students better perceive environmental information if the information:

– has a visual representation;

– related to real or simulated life situations;

– provides for the possibility of interaction and decision-making;

– has an emotional and personal nature.

That is why the use of artificial intelligence and virtual reality technologies is particularly effective. For example, a student can observe in a virtual environment how the state of a river changes depending on the level of its pollution or how the area of forests is reduced due to deforestation. Such digital scenarios allow not only to master the educational material, but also to understand the cause-and-effect relationships between human activity and the state of the environment. In addition, modern students tend to trust information that is presented in a dynamic and interactive form. However, this at the same time creates the risk of uncritical perception of digital content. In this regard, an important component of environmental education is the formation of skills for critical analysis of information, the ability to check sources, assess the reliability of facts and distinguish scientifically based environmental data from manipulative messages.

In the context of digitalization of education, the combination of cognitive and emotional components of learning becomes especially important. If a student not only receives information about a problem, but also experiences it through a virtual experience, this significantly increases the likelihood of forming environmentally responsible behavior.

In the context of sustainable development, important educational needs of the Alpha generation include the need for:

– cooperation, communication and collective problem-solving;

– practical activities and modeling of real situations;

– fast and personalized feedback;

– connection of educational material with everyday life;

– visualization of complex ecological processes.

Of particular importance is the need to move from a knowledge model of environmental education to a competency model. For the Alpha generation, it is not enough to just know the causes of environmental problems; it is important to teach students to analyze the situation, predict the consequences, evaluate alternative options for action and make decisions in accordance with the principles of sustainable development. In this context, organizing learning based on cases, projects and digital simulations is effective. For example, students may be asked to model the development of a city under various environmental scenarios: increasing the number of green areas, using alternative energy sources, reducing waste or introducing a waste sorting system. Such tasks contribute to the formation of systems thinking and understanding the relationship between environmental, social and economic factors.

Another important educational need is the creation of a safe and motivating digital environment. For the Alpha generation, it is important that learning is not perceived as coercion or mechanical assimilation of information. The educational process should be built on the principles of partnership, active interaction and support for student initiative.

Thus, the characteristics of the Alpha generation determine the need to rethink the content and forms of environmental education. The formation of environmental awareness of modern students is possible only if digital technologies, a personalized approach, emotional involvement and practical orientation of learning are combined. These characteristics should be taken into account when developing modern models of using AI and VR in the education system for sustainable development.

The modern digitalization of education creates new opportunities for shaping the environmental consciousness of students, in particular representatives of the Alpha generation. Unlike traditional learning, where all students work with the same materials and tasks, AI-based systems can take into account:

– the student's level of environmental knowledge;

– the pace of learning the material;

– preferred type of information perception;

– interests and motivation;
– previous learning outcomes.

This ensures that the student receives the content and learning format that best suits their needs. For example, a student with a high level of preparation may receive more complex tasks on climate change analysis, while for a student with a lower level of preparation, the system offers visualized explanations, interactive exercises, and step-by-step prompts.

In addition to personalization, AI opens up wide possibilities for modeling environmental situations. Using artificial intelligence algorithms, it is possible to create dynamic scenarios in which the student observes the consequences of his own decisions. For example, the system can simulate:

– change in air quality depending on the amount of transport;
– reduction of forest area due to deforestation;
– level of water pollution;
– the impact of waste on the environment;
– city development under different resource consumption models.

In the process of interacting with such models, the student not only receives information, but also learns to predict the results of his own activities, evaluate alternative solutions, and establish cause-and-effect relationships (Figure 1).

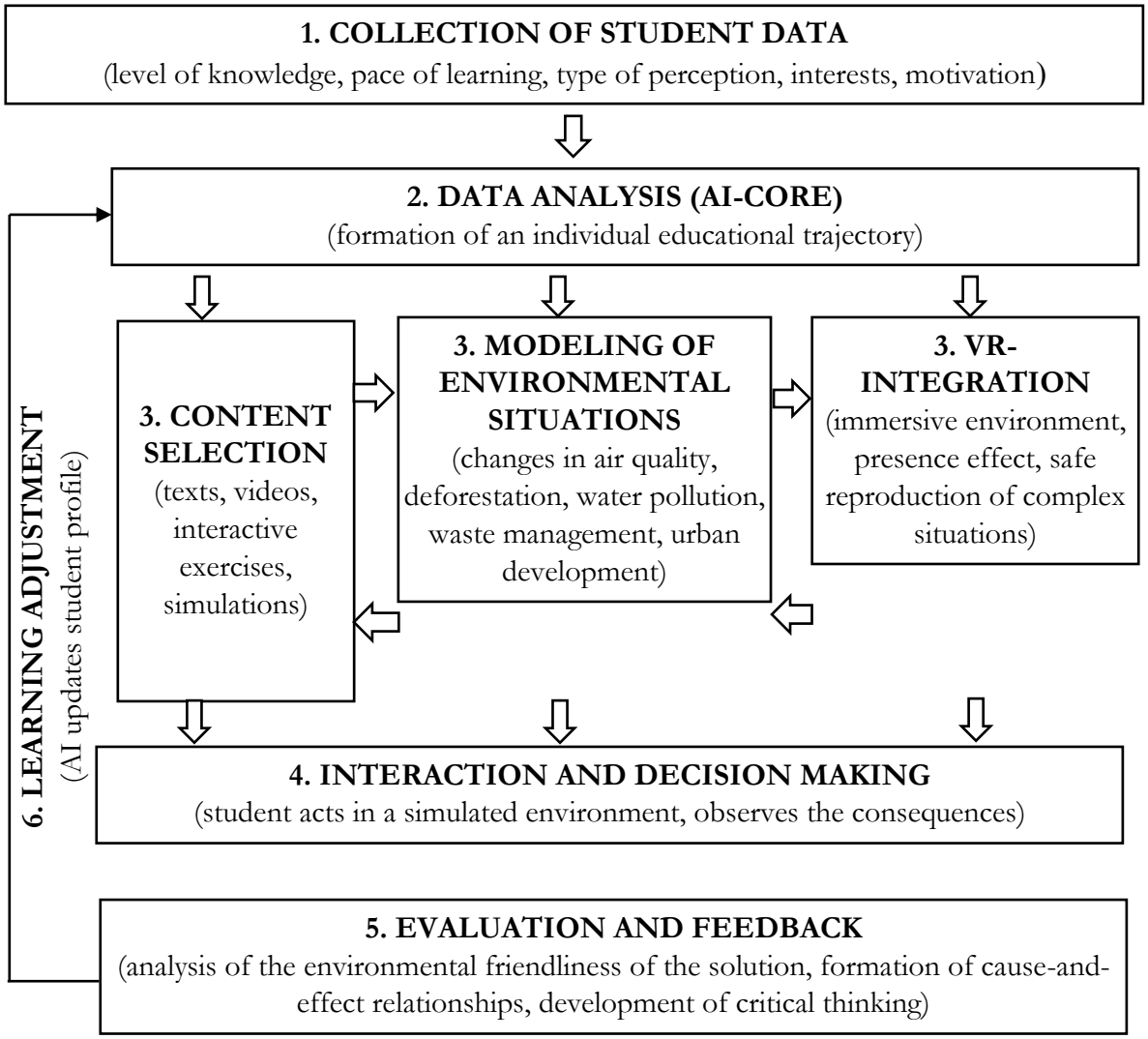

Figure 1. The mechanism of using AI to form environmental awareness among students
Source: developed by the author

The use of AI also contributes to the formation of critical thinking skills. Students can work with large volumes of environmental information, compare different sources, determine the reliability of data and analyze alternative points of view. Thus, artificial intelligence becomes not only a technical tool, but also a means of developing a responsible attitude towards the environment.

Virtual reality is one of the most effective technologies for environmental education, as it allows you to create an immersive environment in which the student not only observes, but also directly experiences a certain environmental situation. Unlike conventional images or videos, VR provides the effect of presence, which significantly enhances emotional involvement and contributes to a deeper awareness of environmental problems.

In a virtual environment, a student can: "visit" a polluted river or landfill, observe the effects of deforestation, see climate change in different regions, explore the ecosystem of the ocean or forest, and model human behavior in an environmental crisis.

A feature of VR is the ability to safely recreate situations that are impossible or difficult to demonstrate in real life. For example, students can observe how rising temperatures affect glaciers, how air pollution spreads in a city, or how certain plant and animal species disappear.

The immersive environment contributes not only to the acquisition of knowledge, but also to the formation of an emotional and value-based attitude towards nature. Experiencing an ecological situation in VR, the student begins to better realize personal responsibility for the state of the environment. It is the emotional impact that is one of the main advantages of VR compared to traditional teaching methods.

Using VR in education also allows for the implementation of the activity-based approach. The student can perform specific actions in a virtual environment: sort waste, clean a reservoir, plan an environmentally friendly city, choose energy sources, or make decisions about the use of natural resources. After that, the system demonstrates the results and consequences of the choices made.

Although AI and VR technologies share a common goal – improving the effectiveness of environmental education – their functional capabilities and pedagogical impact differ. AI is focused mainly on individualizing the learning process, analyzing learning outcomes, and intelligent modeling of environmental situations. VR, on the other hand, is aimed at creating an emotionally rich environment in which the student experiences direct interaction with an environmental problem.

To determine the advantages and limitations of both technologies, it is advisable to compare them (Table 2).

Table 2. Comparative characteristics of the capabilities of AI and VR in the formation of students' environmental culture

Comparison criterion	AI technologies	VR technologies
Main function	Learning personalization and intelligence analysis	Creating an immersive learning environment
Type of influence on the student	Cognitive, analytical	Emotional, visual and practical
Environmental information submission form	Adaptive texts, tests, simulations, recommendations	Virtual spaces, 3D scenarios, interactive interaction
Level of individualization	High, taking into account the personal characteristics of the student	Average, same scenario for a group or individual student

Formation of cause-and-effect relationships	Through data analysis and modeling	Through direct observation and experience
Impact on motivation	Increases interest through personalization	Increases interest through the presence effect
Impact on emotional attitude towards nature	Moderate	High
Developing critical thinking	High	Average
Formation of practical environmental behavior	Through analysis of solutions and recommendations	By performing actions in a virtual environment
Technical requirements	Requires software and network access	Requires special VR equipment
Main limitations	The risk of excessive automation and dependence on algorithms	High cost of equipment and complexity of implementation

Source: developed by the author

Comparative analysis shows that AI and VR are not mutually exclusive technologies. On the contrary, the greatest efficiency can be achieved through their integrated use. AI provides adaptation of the educational process and selection of optimal content, and VR provides emotional experience and practical assimilation of environmental knowledge.

As a result, not only a system of environmental knowledge is formed, but also an ecological culture, which includes a responsible attitude towards the environment, readiness for environmentally appropriate behavior, and awareness of one's own role in ensuring sustainable development.

The training of students of pedagogical universities to use AI and VR should be consistent, systematic and integrated into the content of professional education. It is advisable to carry it out in stages, which ensures a gradual transition from awareness of the potential of digital technologies to their professionally appropriate application in pedagogical activities. The structure of the training distinguishes three main stages: motivational and orientational, practical and technological and professional and creative (Table 3).

The motivational and orientation stage involves familiarizing students with the possibilities of AI and VR in biological and environmental education, analyzing current trends in digitalization, and studying examples of the use of innovative technologies in school practice. The main tasks of this stage are to form positive motivation for the use of digital technologies, to realize the importance of AI and VR for sustainable development education, and to develop interest in digital innovations in future professional activities.

The practical and technological stage is aimed at students acquiring practical skills in working with digital tools. Future teachers learn to use artificial intelligence services, create educational tasks, adapt material to students' needs, work with VR environments, and design lesson fragments. The content of this stage includes mastering AI-based platforms, using virtual laboratories and VR excursions, developing interactive cases on environmental topics, creating digital teaching materials, and modeling biology lessons using AI and VR.

The professional-creative stage is associated with the independent design of their own pedagogical activities by students. Future teachers develop original lessons, educational projects and scenarios for using AI and VR, test them during pedagogical practice and evaluate the results obtained. Of particular importance at this stage are the integration of digital technologies into professional activities, the formation of the ability to pedagogical design, the development of creativity and innovative thinking, as well as reflection on the effectiveness of the technologies used.

A generalized description of the stages of preparation, their content, and expected results is presented in Table 3.

Table 3. Stages of training future biology teachers to use AI and VR

Preparation stage	Main content	Expected result
Motivational and orientational	Familiarization with the capabilities of AI and VR, formation of positive motivation for the use of digital technologies	Awareness of the importance of digital technologies and a positive attitude towards their use
Practical and technological	Mastering digital tools, creating learning materials, using virtual labs, and modeling lessons	Developed practical skills in applying AI and VR in the educational process
Professionally creative	Development of own educational projects, their testing and pedagogical reflection	Readiness for independent and professionally appropriate use of technologies in pedagogical activities

Source: developed by the author

The sequential completion of these stages ensures the gradual formation of the digital competence of the future biology teacher and his readiness to use AI and VR in professional activities.

To ensure effective training of future biology teachers, it is advisable to use a generalized model of digital technology integration, which combines the goal, content, methods, means and learning outcomes. Such a model is focused on forming the readiness of future teachers to use AI and VR in the process of environmental education and the implementation of sustainable development ideas.

The structure of the model includes five interconnected blocks: target, content, technological, activity and performance. Their relationship and sequence of implementation are shown in Figure 2.

The target block defines the strategic goal of training, its tasks and expected results. It orients the educational process towards the formation of digital competence, ecological thinking and readiness for innovative activity.

The content block covers disciplines, topics, and learning modules in which students master AI and VR technologies. These include digital technologies in education, fundamentals of artificial intelligence, VR in natural sciences, environmental education methodology, and education for sustainable development.

The technological block includes forms, methods, and means of learning: lectures, trainings, practical classes, project activities, digital laboratories, VR simulations, and AI services for analyzing and personalizing learning.

The activity block involves active participation of students in the development and implementation of their own educational products. Future teachers create interactive lessons, virtual excursions, environmental cases, digital educational materials and test them.

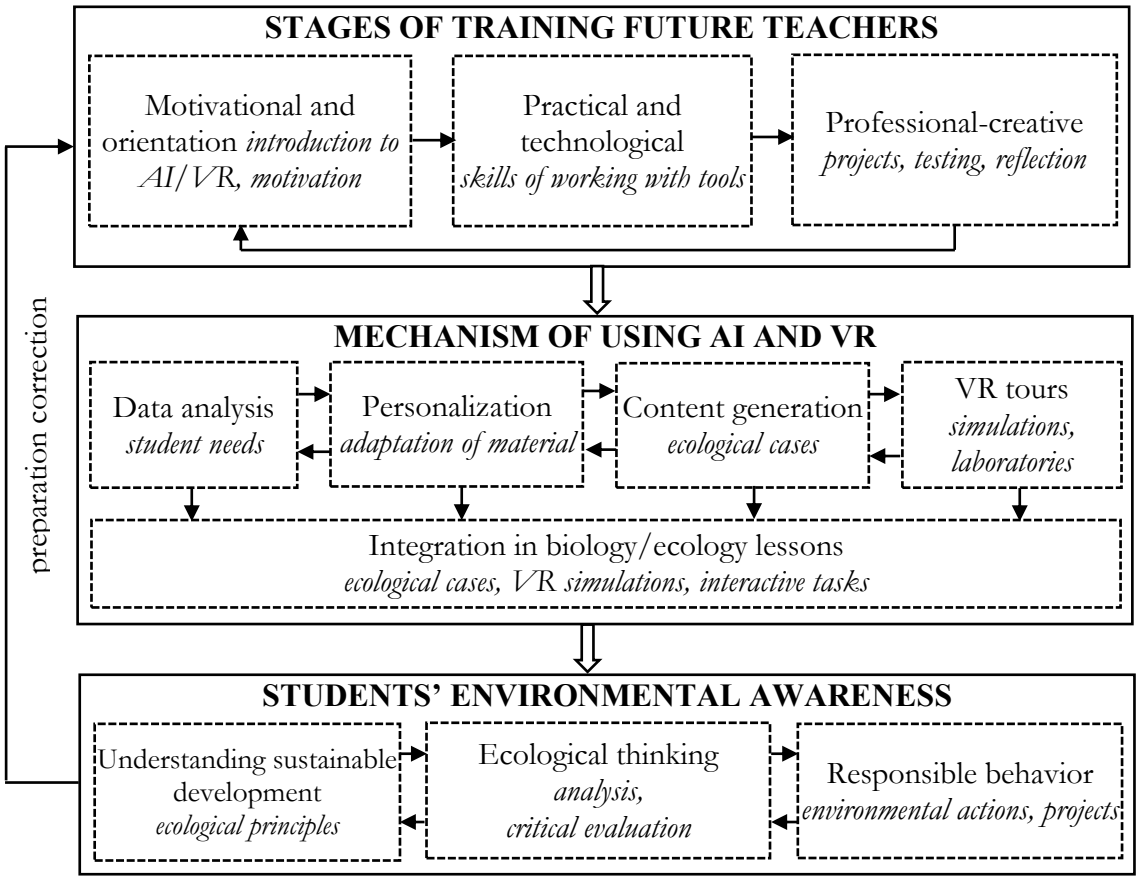

Figure 2. Generalized model of integrating AI and VR into the professional training of future biology teachers

Source: developed by the author

The outcome block reflects the level of digital competence and readiness of the future teacher for professional activity. Its indicators are the ability to use AI and VR in teaching, the ability to integrate digital technologies into the content of biology lessons, the readiness to form students' environmental awareness, as well as the ability for pedagogical reflection and self-development.

Therefore, the presented model provides a logical connection between the goal, content, and results of professional training and creates conditions for the comprehensive use of digital technologies in the training of future biology teachers.

5. Discussion

The results of the study are consistent with modern scientific approaches to the use of AI and VR in education for sustainable development, according to which digital technologies are considered not only as an auxiliary tool for learning, but as a factor in the transformation of the educational environment. In contrast to traditional approaches that focus mainly on the transfer of knowledge, this work substantiates the need for the integrated use of AI and VR to form the cognitive, emotional and behavioral components of the environmental consciousness of the Alpha generation. This approach corresponds to modern concepts of education for sustainable development, which emphasize the need to combine knowledge, values and practical activities.

The results presented in Table 3 and Figure 2 confirm the thesis about the system-forming role of digital technologies in the training of future biology teachers. Unlike a number of studies where the use of AI and VR is considered episodically or as a separate element of professional training, this work proves the need for their integration into a holistic model of the educational process. This allows us to consider AI and VR not only as innovative teaching tools, but also as the basis for the formation of a

new digital competence of a teacher. At the same time, it is worth noting that the practical implementation of the proposed model may be complicated by the insufficient level of technical support of educational institutions and the uneven level of digital training of teachers.

The issue of the relationship between AI and environmental education deserves special attention. The results obtained confirm the conclusions of other authors regarding the significant potential of artificial intelligence for personalizing learning and adapting content to the individual needs of students, but complement them with an emphasis on the development of systemic environmental thinking. It was found that AI can be used not only for the automated selection of educational materials, but also for modeling environmental scenarios, predicting the consequences of human activity and analyzing alternative ways to solve environmental problems. This opens a new direction for further research related to the use of AI to form students' skills in environmental forecasting and decision-making.

In the context of the use of VR, the results of the study confirm the provisions of modern literature on its significant impact on the emotional and value component of learning. However, unlike most scientific works, where virtual reality is considered mainly as a means of increasing motivation or visualizing complex processes, this study substantiates its role as a tool for forming environmental awareness. This is reflected in Table 3 and Fig. 3.1, which shows that VR provides not only the acquisition of knowledge, but also the formation of a personal attitude to environmental problems through the effect of presence and emotional experience.

A special contribution of the study is the emphasis on the integrated use of AI and VR. The results obtained expand existing approaches, which mostly analyze these technologies separately, and emphasize their complementary nature. In particular, it is proven that AI has a greater impact on the cognitive component of environmental awareness, while VR has a greater impact on the emotional-value component. Their combination allows you to create an educational environment in which students not only gain knowledge about the environment, but also learn to assess the consequences of their own actions, make responsible decisions and apply the principles of sustainable development in practical activities.

The question of the ratio of technological and pedagogical factors in the process of digitalization of environmental education remains debatable. On the one hand, the results of the study confirm the need to introduce modern digital technologies in the training of future biology teachers. On the other hand, it has been proven that even the most modern AI and VR tools do not provide the expected result without proper pedagogical support. The formation of environmental awareness involves not only the assimilation of information, but also the development of values, critical thinking and the ability to reflect. This indicates the feasibility of the transition from a technocentric to a human-oriented approach in the organization of digital learning.

In addition, the results of the study indicate the need to strengthen the institutional component of future teacher training. Despite the growing interest in AI and VR in teacher education, their practical implementation often faces problems of resource provision, insufficient number of relevant curricula and limited readiness of teachers to work with new technologies. In this context, it is important to create specialized courses, improve the content of pedagogical practice and develop partnerships between educational institutions, scientific institutions and technology companies.

At the same time, certain limitations of the study should be taken into account. In particular, it is based mainly on a theoretical analysis of modern scientific sources and a generalization of existing pedagogical experience, which limits the possibility of empirical verification of the results obtained. Further research should be directed at experimentally studying the effectiveness of using AI and VR in forming the ecological consciousness of the Alpha generation, as well as at developing criteria and indicators for assessing the level of digital competence of future biology teachers.

Thus, the results of the study confirm the need to rethink approaches to the professional training of future biology teachers and substantiate the feasibility of comprehensive integration of AI and VR into the education system for sustainable development. Of particular importance is the combination of cognitive, emotional and activity components of learning, which opens up new prospects for both the development of pedagogical theory and the modernization of modern educational practice.

6. Conclusion

The study substantiates that the use of AI and VR is an important condition for the modernization of education for sustainable development and the formation of environmental awareness of the Alpha generation. It has been established that the modern digital educational environment should be considered not only as a set of technical means, but as an integrated system that combines cognitive, emotional-value and activity components of learning.

It is proven that AI and VR have a system-forming nature in the process of training future biology teachers and ensure the coordinated formation of digital competence, ecological thinking and readiness for professional activity. Generalization of the stages of training future biology teachers to use AI and VR (Table 3) and their integration into a generalized model of professional training (Figure 2) allowed us to establish that the effectiveness of training depends on the combination of motivational-value, practical-technological and professional-creative components.

It was found that AI most effectively affects the cognitive component of environmental awareness, providing personalization of learning, adaptation of content to the individual needs of students, modeling of environmental situations and forecasting the consequences of human activity. It was found that the use of AI contributes to the development of systems thinking, critical analysis and the ability of students to make informed decisions regarding environmental problems.

It is substantiated that VR is an important tool for the formation of the emotional and value component of environmental awareness. The results presented in Table 3 and Fig. 3.1 confirm that the use of virtual reality contributes to the creation of the effect of presence, emotional experience of environmental situations and the formation of a personal attitude to environmental problems. This provides increased motivation for learning, the development of empathy and readiness for environmentally responsible behavior.

The feasibility of integrated use of AI and VR in the system of professional training of future biology teachers has been proven. It has been established that the combination of the capabilities of artificial intelligence and virtual reality creates a synergistic effect that ensures the simultaneous development of knowledge, values, and practical skills. This approach allows students to form not only environmental awareness, but also the ability to apply the principles of sustainable development in real life situations.

The practical significance of the results obtained lies in the possibility of their use in the modernization of the content of pedagogical education, the development of training courses using AI and VR, the improvement of training programs for future biology teachers and the organization of the educational process in secondary education institutions. The proposed model can be adapted for implementation in the system of professional training of teachers of various specialties related to environmental and natural education.

At the same time, it has been established that the effectiveness of AI and VR implementation depends on the level of technical support of educational institutions, the readiness of teachers to use digital technologies, and the availability of appropriate methodological support. This necessitates the creation of specialized educational programs, the development of digital competence of teachers, and ensuring equal access to modern technologies.

Thus, AI and VR are important factors in the transformation of modern education for sustainable development, and their integration into the professional training of future biology teachers creates the prerequisites for forming the environmental awareness of the Alpha generation, developing digital competence, and increasing the effectiveness of environmental education.

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