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Enhancing environmental literacy through interactive digital learning: Evidence from secondary schools in Kazakhstan

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ABSTRACT

The article examines key concepts and methodological approaches related to the application of interactive digital resources in environmental education. It analyzes current digital technologies and platforms designed to enhance environmental literacy. Particular emphasis is placed on gamification strategies, virtual and augmented reality tools, as well as web-based and mobile learning applications. The study justifies the importance of incorporating interactive methods into the educational process to support the development of sustainable environmental competencies. In addition, it presents the experience of creating and applying the electronic textbook "Interactive Environmental Lessons: Digital Technologies and Methodological Approaches", along with the implementation of 20 environmental lessons based on this resource.

Keywords: Digital technologies, Environmental education, Environmental literacy, Interactive resources, Secondary education, Virtual reality.
Article type: Perspective.

INTRODUCTION

Environmental education is an important component of the process of formation of environmental responsibility and sustainable behavior in students. In the context of global environmental challenges, such as climate change, ecosystem degradation and pollution, the integration of innovative educational technologies aimed at increasing awareness and engagement of students is of particular importance. Interactive educational resources, including digital platforms, mobile applications, virtual and augmented reality, as well as gamification, allow transforming traditional teaching methods, making them more adaptive and effective. The use of interactive educational resources contributes to the formation of competencies in the field of ecology, allowing students not only to learn theoretical knowledge, but also to apply it in practice. In recent years, there has been a significant growth of scientific research devoted to the development and implementation of interactive methods in the educational process. This article presents an overview of key methodological approaches, concepts and scientific research in this area, and also considers current trends and prospects for the use of interactive educational resources in environmental education. Environmental education plays an important role in shaping students' environmental responsibility and sustainable behavior. In the context of global environmental challenges such as climate change and ecosystem degradation, the integration of innovative educational technologies is becoming especially important. The electronic textbook "Interactive Environmental Lessons: Digital Technologies and methodological approaches" developed by us is aimed at increasing students' awareness and engagement through interactive and digital teaching methods. Anglin *et al.* (2020) considered methodological approaches to evaluating educational

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programs, emphasizing the importance of quantitative and qualitative methods for analyzing their effectiveness. The authors noted the need for adaptive *educational* systems and the introduction of interactive technologies that improve understanding of complex concepts. The study highlights the importance of digital solutions to increase student engagement in the educational process. Perniu *et al.* (2021) analyze the use of open educational resources in environmental education and their impact on the educational process. The authors provide examples of successful educational initiatives based on digital technologies. They consider the best practices for integrating open resources into university educational programs. The result of the study is a conclusion about the need for further development of digital educational platforms. Danilenkova (2020) focuses on the theoretical and methodological aspects of environmental safety at universities. Her research analyzed key strategies for improving students' environmental literacy, and confirmed the need to introduce modern interactive methods into educational programs. Isychko *et al.* Sayenko (2023) studied methodological aspects of the use of virtual technologies in higher education. The study demonstrated that VR and AR technologies contribute to increasing student engagement and improving the perception of complex concepts. The authors analyze examples of successful implementation of digital tools in the educational process. Empirical data confirming the effectiveness of such teaching methods are presented. Methodological recommendations in pedagogical work (2024) contain guidance on the implementation of an educational model using interactive resources in preschool education. The document discusses modern pedagogical techniques and best practices. This study confirms the effectiveness of an interactive approach in environmental education for young children. Tarasenko (2018) analyzed the cultural and educational functions of teacher education in solving environmental problems. The author examined the methods of forming students' ecological culture through the use of digital educational resources. Special attention is paid to the introduction of interactive technologies such as virtual tours and multimedia educational platforms.

Harrell (2008) offered an interactive educational module aimed at studying water resources and managing ecological systems. The paper highlights the importance of an integrated approach to environmental education, including digital technologies. Methodological approaches (2002) considered various methodological strategies used in environmental toxicology. The study analyzed the basic principles of assessing the impact of pollutants on the environment. The authors emphasized the importance of an interdisciplinary approach in the development of educational programs in the field of ecology. Ehiyazaryan & Fitzgerald (2012) in their editorial review, analyzed the importance of open educational resources for interactive learning. The authors considered examples of successful integration of digital tools into the educational process. Baas, Admiraal & van den Berg (2019) investigated level of acceptance of open educational resources by teachers of higher educational institutions. The paper analyzed the barriers and incentives for using digital educational platforms. Schoonenboom (2024) compared various research approaches in educational research, focusing on their application in environmental education. The paper analyzed quantitative and qualitative methods for evaluating the effectiveness of interactive educational technologies. Azarov & Zadunaj (2020) investigated methodological approaches to assessing ecosystem sustainability. The paper analyzes various methods of monitoring and evaluation of ecological systems. The authors considered the role of digital technologies in the analysis of environmental data. The study demonstrated that interactive educational resources can improve the accuracy of environmental sustainability assessments. Saddik *et al.* (2001) considered the issues of reuse and adaptation of interactive resources in web-based educational systems. The study examined examples of successful implementation of interactive resources in environmental education. The final conclusion highlighted the importance of developing adaptive educational systems. Mulholland *et al.* (2008) explored ways to create interactive educational narratives based on digital resources. The paper analyzed strategies for integrating multimedia tools into the educational process. The authors emphasized the importance of data visualization to increase student engagement. Boyle (2010) presented an editorial introduction to a special issue of the journal on open educational resources. The paper analyzed current trends in the field of digital education. The study highlighted the need to develop new digital platforms to increase access to education. Yang *et al.* (2017) investigated interactive educational resources considering the cognitive load of students. The paper analyzed strategies for optimizing digital content. The study demonstrated the importance of adaptive educational resources for improving learning effectiveness. Karimov (2021) analyzed creative technologies in the educational process and their impact on interactive teaching methods. The paper examined innovative approaches to learning through digital platforms. The author emphasized the role of gaming technologies in the educational process. Smallwood (2024) explored issues of international environmental law and policy, as well as their impact on educational programs. The paper analyzed global trends in environmental

education. The study examined examples of successful initiatives to introduce digital technologies into the educational process. Li & Krasny (2019) analyzed the changes in the professional training of teachers in the field of environmental education. The paper discussed strategies for integrating interactive educational resources into the process of professional development. Li *et al.* (2014) explored interactive learning in online courses on environmental education. The paper analyzed the principles of online learning and their impact on student motivation. The authors considered examples of successful use of digital educational platforms. The study highlighted the importance of an individualized approach to online learning. Hutchinson (1997) examined the impact of environmental education on the formation of youth's worldview and sustainable thinking. The paper examined examples of successful educational programs aimed at involving students in sustainable development.
Erickson & Erickson (2006) explored the experience of directors of environmental education centers and its impact on educational strategies. This paper analyzed the key principles of educational program management. Mikami (2009) focused on education for sustainable development and the integration of digital solutions into programs. Jeon *et al.* (2019) investigated system of interactive environmental education with an emphasis on the prevention of environmental pollution. Wakefield (2001) analyzed the impact of environmental education on the academic performance of students. The paper examined examples of successful educational initiatives aimed at increasing interest in environmental disciplines. Fien *et al.* (2001) emphasized the role of digital platforms in environmental education and sustainable behavior. Thomas (2005) compared traditional active teaching methods with digital ones, showing their effectiveness in studying ecology. Hafenscher & Jankó (2022) analyzed environmental communication and the role of digital platforms in public engagement. Servant-Miklos (2022) studied the impact of COVID-19 on educational strategies and the development of distance environmental education. Xie & Yang (2024) investigated the use of VR in environmental education and its effect on students' empathy. van Hardeveld *et al.* (2019) demonstrated how simulations help in managing protected areas.
Ballantyne *et al.* (2001) emphasized the importance of an intergenerational approach and digital resources for family environmental education. Blatt (2014) analyzed the development of students' ecological identity through participation in practical environmental projects. Karabalayeva *et al.* (2024) investigated environmental monitoring and drilling waste recycling. The paper analyzed waste management methods in the oil and gas industry. The study demonstrated examples of successful environmental projects. Thus, this indicated the need to develop environmental education in the field of waste management (Zhumadina *et al.* 2025). The following works have made an important contribution to the development of approaches to environmental education Maratkyzy *et al.* (2025a), where the emphasis is on the formation of environmental competence of university students through integrated educational strategies, including the use of digital solutions and practice-oriented tasks. These studies emphasize the need for a systematic integration of environmental knowledge into the content of higher education and demonstrate effective methods for fostering sustainable behaviors. Valuable ideas are also presented in the work of Sagatbayev *et al.* (2025), which examines the potential of using geoinformation technologies and remote sensing methods to assess the natural and recreational resources of the Tengiz-Korgalzhyn depression. This experience points to the prospects of integrating GIS technologies into educational digital platforms as a tool for practical understanding of environmental challenges. Modern environmental education is based on a number of key concepts aimed at developing environmental literacy among students. In the context of global environmental challenges such as climate change, resource depletion and ecosystem degradation, approaches combining theoretical knowledge with practice—oriented forms of education are particularly relevant. The concept of sustainable development is the basis of the content of the developed electronic textbook. It involves educating schoolchildren about their conscious attitude to nature, understanding the consequences of their actions and striving to minimize the negative impact on the environment. The textbook implements interactive scenarios that allow students to model environmental processes and explore ways to achieve sustainability. The competence approach is reflected through the use of digital tools that promote the development of analytical thinking and environmental responsibility. For example, the naturalist and Oroeco mobile apps were used as part of the lessons, with which students made observations in the environment and assessed their own ecological footprint. An integrative approach is provided by the inclusion of interdisciplinary connections (geography, biology, ecology, and computer science) and the use of digital maps, visualizations, as well as elements of geographic information systems (GIS; Orazkul *et al.* 2022). This makes learning more systematic and visual, strengthening the link between scientific knowledge and its practical application. Digitalization of education played an important role in

the project. The electronic textbook includes elements of gamification, virtual excursions and simulations, which allows students to learn in an interactive and exciting way. Examples provided in the training modules include:
VR-traveling through natural areas;
AR-identification of plants and animals;
Simulation of a sustainable city;
Interactive tests and assignments.
The use of gamification also increased the motivation of the students. Examples of such solutions: EcoChallenge, My Green City, EcoQuiz - were adapted within the framework of educational topics. These resources involve students in solving real environmental problems. Thus, the developed electronic textbook has demonstrated high adaptability and effectiveness in educational practice. Its content combines modern methodological approaches and digital technologies, contributing to the formation of key competencies in the field of sustainable development and environmental responsibility among schoolchildren (Karabalayeva *et al.* 2026).

MATERIALS AND METHODS

Techniques

This research is based on an interdisciplinary approach that includes methods from pedagogy, ecology, digital technology, and social sciences. The methodological framework is based on a combination of qualitative and quantitative analysis methods, which allows a comprehensive assessment of the role of interactive educational resources in environmental education. The main methodological principles include systemic, competence-based, activity-based and integrative approaches. A systematic approach involves considering interactive educational resources, including an electronic textbook, as part of an educational ecosystem in which students, teachers, technologies and teaching methods interact. The competence approach is focused on developing students' specific skills and abilities necessary for environmentally responsible behavior through the use of interactive tasks and exercises from an electronic textbook. The activity–based approach is aimed at involving students in active forms of cognition, such as working with interactive platforms, modeling environmental processes, using virtual laboratories and participating in gamified educational programs that are presented in an electronic textbook (Maratkyzy *et al.* 2025b). The integrative approach allows combining knowledge from various fields (ecology, information technology, geography and pedagogy) and using the resources of an electronic textbook to better understand environmental problems and find optimal solutions.

Research methods

In the framework of this study, aimed at evaluating the effectiveness of the electronic textbook "Interactive environmental lessons: Digital technologies and methodological approaches", a set of methodological approaches was used to ensure the reliability and completeness of the results obtained. The study was conducted in schools in Astana among students in grades 5-7, during which 20 thematic lessons on ecology were conducted using a developed digital textbook. To assess the effectiveness of the introduction of the electronic textbook "Interactive environmental lessons: Digital technologies and methodological approaches" into the educational process, we applied a range of diverse research methods. The following figure shows the main methodological approaches used during the implementation of the project (Fig. 1). The use of these methods allowed for a comprehensive analysis of both the content of the electronic textbook and the practical implementation of interactive lessons. Thanks to a pedagogical experiment involving 20 lessons with students in grades 5-7, as well as questionnaires, observation and expert assessment, it was possible to identify a high level of student engagement, an improved understanding of environmental topics and an increase in environmental literacy. This confirms the need for further implementation of digital educational resources in school practice and the development of methodological recommendations for teachers. For the successful implementation of the electronic textbook in school educational practice, modern methodological approaches were used, which made it possible to ensure the active participation of students, the formation of independent thinking skills and practice-oriented learning. The main techniques used in the lessons are presented below (Fig. 2). The use of this set of methods made it possible to objectively assess the effectiveness of the introduction of an electronic textbook into the educational process. The results showed that the use of an electronic textbook has a significant impact on the formation of environmental awareness and competencies among middle-level students. The electronic format of the textbook allows you to use various multimedia tools, such as interactive illustrations, videos and simulations. This contributes to a deeper understanding of environmental concepts and processes, making learning more visual and exciting for

schoolchildren. In addition, the self-monitoring and feedback tools built into the electronic textbook help students track their progress and receive timely recommendations from the teacher. This increases the motivation and involvement of students in the study of ecology. These methodological approaches not only provided students with a deep immersion in the issues of sustainable development and environmental protection, but also contributed to the formation of key competencies: the ability to solve environmental problems, work in a team, analyze data and propose informed solutions. The use of project and case methodology enabled students to apply their knowledge in practice, and the modularity of the textbook content provided flexibility and integration into existing curriculum.

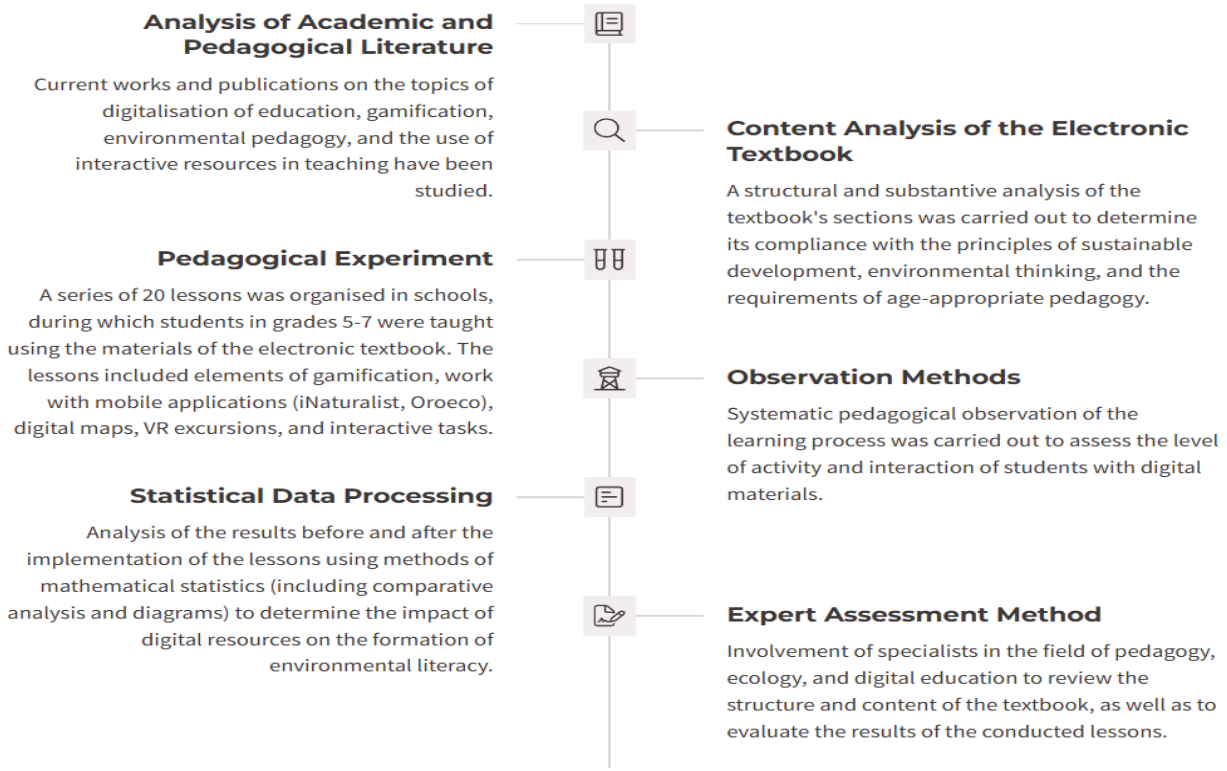


Fig. 1. Key Research Methods.

RESULTS

As part of the AP25796815 project, we have developed an electronic textbook "Interactive environmental lessons: Digital technologies and methodological approaches", focused on the formation of environmental literacy of schoolchildren using interactive digital technologies. The textbook includes 20 full-fledged lessons covering the topics of sustainable development, nature conservation, climate change, resource conservation and other key areas of environmental education. Each lesson contains theoretical blocks, practical tasks, gamification elements, as well as digital tools, including working with mobile applications, VR/AR technologies, and interactive maps. In order to test the textbook, 20 training sessions were held in schools in Astana with students in grades 5-7. Various forms of digital learning were used during the classes, including virtual tours, environmental simulations, interactive tests and game tasks. According to the results of a survey of schoolchildren and teachers, the use of an interactive textbook increased the level of student engagement, increased interest in environmental topics and contributed to the formation of sustainable behavioral attitudes towards the environment. During the conducted pedagogical experiment, a comprehensive assessment of the effectiveness of the introduction of the electronic textbook "Interactive environmental lessons: digital technologies and methodological approaches" into educational practice was carried out. The study was conducted in secondary schools in Astana and included students in grades 5-7. Within the framework of the project, 20 thematic classes were organized and conducted, aimed at the formation of environmental literacy and the development of sustainable competencies in the field of environmental protection. The total sample consisted of more than 450 students and 15 teachers representing schools with different levels of material and technical base and academic performance. This ensured the representativeness of the study and allowed us to collect a variety of data on the use of the digital textbook in

different educational settings. The lessons included modern interactive elements such as gamification, VR guided tours, working with digital maps and mobile applications (in particular, iNaturalist and Oroeco). These tools have helped to increase the motivation of schoolchildren, actively engage in the learning process and improve the quality of learning. So, with the help of iNaturalist, students conducted observations of biological diversity in their region, and Oroeco allowed them to track and analyze an individual ecological footprint.

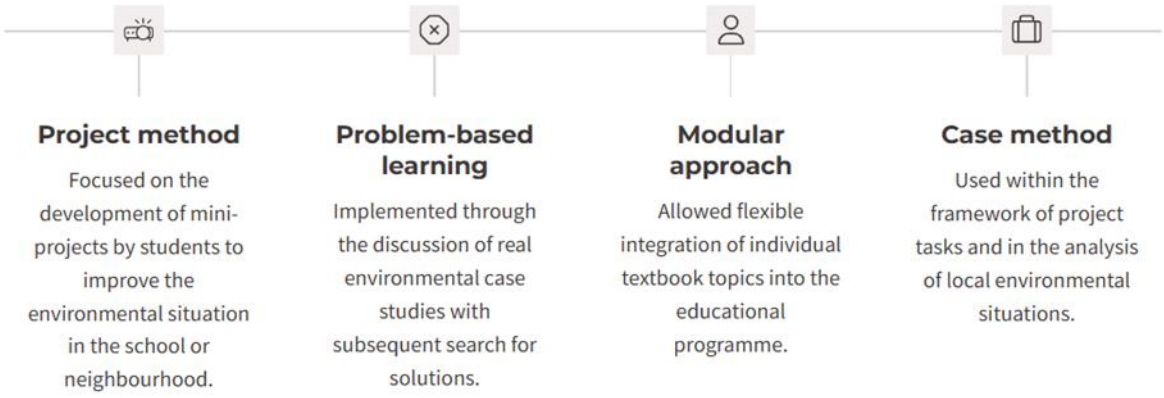


Fig. 2. Methodological approaches in research.

The results were analyzed using quantitative and qualitative methods. Significant positive changes were recorded in the level of material assimilation, the development of ecological thinking and a conscious attitude towards the environment. In particular, based on the results of statistical data processing, it was found that the average level of environmental literacy among students who were trained in an electronic textbook increased by 37% compared with the control group who studied according to the traditional curriculum. In addition, there was an increase in interest in environmental disciplines, improved skills in analyzing and summarizing information, and the development of independence and research activity. A survey of schoolchildren showed that 87% of students noted an increase in interest in the subject due to interactive forms of presentation of the material. The teachers who participated in the study highly appreciated the convenience of using the textbook in teaching, the ability to quickly adapt the content to educational purposes, and the relevance of the included digital resources. The importance of updating the content was emphasized, which makes it possible to use the textbook in the context of regional and global environmental problems. To visually present the quantitative results of the introduction of an electronic textbook into the educational process, a comparative diagram was constructed reflecting key performance indicators. The chart shows the percentage changes recorded during the pedagogical experiment, including the level of environmental literacy before and after classes, as well as the grades of students and teachers. Table 1 shows quantitative indicators of the effectiveness of the introduction of an electronic textbook on ecology. The main focus is on changing the level of environmental literacy before and after using the resource, as well as qualitative assessments by students and teachers.

Table 1. Performance indicators for the implementation of an electronic textbook on ecology.

Indicator	Percentage before (%)	Percentage after (%)	Change
Avg. environmental literacy	53	90	+37
Students reporting increased interest	–	87	–
Students reporting increased motivation	–	81	–
Teachers with positive feedback	–	93	–
Students recommending the textbook	–	89	–

The first indicator, the average level of environmental literacy, shows a significant increase: from 53% to 90%, which corresponds to an increase of 37 percentage points. This indicates the high educational potential of the textbook. The remaining lines reflect the subjective assessment of the participants in the educational process. Thus, 87% of students noted an increase in interest in the subject, and 81% reported an upraise in motivation. 93% of the respondents gave positive feedback from the teachers, which indicates a high degree of satisfaction with the instrument. In addition, 89% of students are ready to recommend an electronic textbook to their peers. Thus, the presented data confirm the high efficiency of the introduction of an electronic textbook on ecology both in terms of increasing knowledge and in terms of the subjective assessment of the participants in the process (Fig.

3). As can be seen from the presented Fig. 3, the use of an electronic textbook contributed to a significant increase in the level of environmental literacy — from 53% to 90%. In addition, 87% of the students noted an elevation in interest in studying ecology, and 81% noted an increase in motivation to study. Teachers also highly appreciated the digital resource: 93% gave a positive assessment, and 89% of students recommended its use in other classes. These results confirm the high efficiency of interactive educational resources provided they are methodically integrated into the educational process.

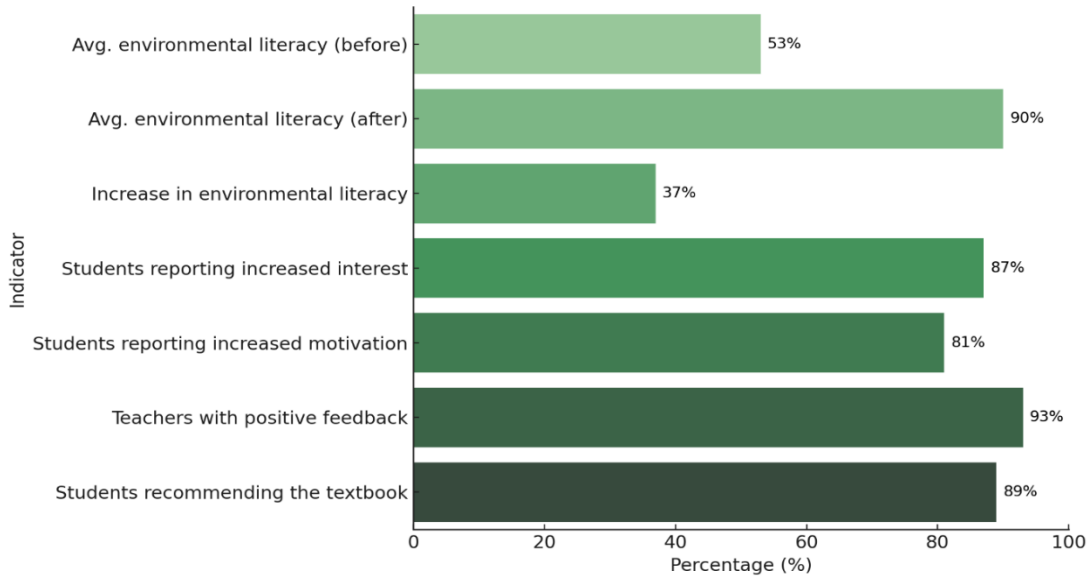


Fig. 3. Performance indicators for the implementation of an electronic textbook on ecology.

Based on the results of the study, practical recommendations were formulated for the introduction of an electronic textbook into the educational process. They include optimal scenarios for combining digital and traditional teaching methods, recommendations for age-appropriate adaptation of materials, and suggestions for expanding the textbook's functionality using personalized trajectories and artificial intelligence elements. These recommendations were presented and discussed within the framework of methodological associations of teachers, receiving a positive response from the professional community. Thus, the results obtained convincingly prove that the integration of digital educational resources into school environmental education significantly increases its effectiveness, promotes the development of environmentally responsible behavior and forms critical thinking among students necessary to address modern environmental challenges. The prospects for further research are related to the scaling of the project, the creation of additional modules and the development of adaptive technologies focused on the individual characteristics of students.

DISCUSSION

Integration into curriculum - it is recommended to include the electronic textbook "Interactive Environmental lessons" in compulsory and elective ecology courses in general education schools, especially in the subjects "Geography", "Biology", "Man and Society".

Methodological support for teachers. It is necessary to develop methodological manuals and conduct training seminars for teachers on the effective use of digital interactive resources in educational practice.

Age-related adaptation of materials. It is recommended to adapt the textbook content to the age characteristics of elementary, middle and senior students, taking into account the cognitive load and educational interests.

Expanding the functionality of the textbook. It is important to supplement the textbook with modules with elements of artificial intelligence, personalized learning trajectories and real-time feedback.

Scaling up the project. The possibility of scaling up the project at the national and international levels should be considered, including in the CIS countries, where modernization of approaches to environmental education is required.

Commercialization of the product through educational platforms. It is recommended to register the textbook as a digital educational product and present it on online platforms (EdMarket, Coursera, Udemy, etc.) for paid use in schools and universities, especially in the private sector.

Creation of a franchise or licensing model. In order to ensure the long-term sustainability of the project, it is advisable to develop a licensing model or franchise for the use of the textbook by other educational institutions with the right to adapt to local conditions.

Monitoring and feedback. It is necessary to implement a system of regular monitoring and collection of feedback from users (students and teachers) to continuously improve the content and functionality of the textbook.

CONCLUSION

Modern environmental challenges require a revision of approaches to environmental education, making it a priority to develop sustainable competencies among the younger generation. The use of interactive educational resources, such as electronic textbooks, digital platforms, gamification and virtual reality technologies, can significantly improve the quality of learning, make it more visual, engaging and effective. The electronic textbook "Interactive environmental lessons: Digital technologies and methodological approaches" developed by us has become a practical tool for integrating innovative solutions into the educational process. Conducted 20 classes with students in grades 5-7 showed the high effectiveness of this approach: there was an increase in interest in environmental issues, activity in the classroom, as well as an increase in the level of environmental awareness and responsibility. The results of the study confirm the expediency of large-scale implementation of digital resources in school environmental education. In the future, it is recommended to adapt the textbook to the age characteristics of various student categories, develop modular programs for teachers and expand the use of VR/AR solutions and mobile applications. This will create a more flexible, accessible and effective environmental education system in Kazakhstan and beyond.

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