



Developing and Testing the Electronic Textbook “Interactive Environmental Lessons”: Methodological Approaches and Project Implementation in Environmental Education

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ABSTRACT

This article presents the process of developing, implementing, and testing the electronic textbook “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches” within the framework of environmental education. The study combines theoretical analysis of modern interactive educational resources - including gamification, virtual and augmented reality, web platforms, and mobile applications - with practical testing of the developed digital textbook in real educational settings. A total of 20 environmental lessons were conducted with the participation of students from various educational institutions in Kazakhstan. The testing evaluated the textbook’s effectiveness in improving students’ environmental literacy, engagement, and ability to apply sustainable development principles in practice. Quantitative and qualitative data were collected through questionnaires, observation, and feedback analysis. The results demonstrated a significant increase in environmental awareness, active participation, and retention of material. The article also discusses technical and methodological challenges encountered during implementation and offers recommendations for integrating interactive digital textbooks into the educational process to foster sustainable environmental competencies.

KEYWORDS

Environmental education; interactive resources; digital technologies; gamification; virtual reality; e-textbook.

INTRODUCTION

Environmental education has been identified as a critical element in fostering students' sense of responsibility and promoting sustainable behaviors. In the context of global environmental challenges, such as climate change, ecosystem degradation, and environmental pollution, the integration of innovative educational technologies is of particular importance (Damoah & Adu, 2022; Hollstein, 2022; Kavaz et al., 2021). The integration of interactive resources, encompassing digital platforms, mobile applications, virtual and augmented reality technologies, and gamification elements, has been demonstrated to enhance the adaptability and efficacy of the learning process. These programs facilitate the acquisition of theoretical knowledge and its subsequent application in practical settings (Olatoye & Fru, 2025; Syah et al., 2021).

Concurrently, despite the proliferation of digital tools, there is an ongoing need for systematic assessments of their effectiveness, adaptation of interactive methods to the particulars of environmental education, and integration of these tools into formal educational programs. The resolution of these issues necessitates a dualistic approach, encompassing both theoretical substantiation and empirical evaluation of methodological frameworks.

The objective of this study is to develop and evaluate an electronic textbook entitled "Interactive Environmental Lessons: Digital Technologies and Methodological Approaches," with the objective of increasing student awareness and engagement, as well as assessing its methodological effectiveness in environmental education.

Despite the growing number of digital environmental resources, current e-books often remain fragmented, theoretical, and poorly adapted to school curricula. They rarely integrate interactive technologies such as VR/AR, gamified simulations, and mobile-based tasks in a unified methodological framework. Consequently, students' environmental learning remains passive and disconnected from real-world applications. This study addresses this gap by developing and testing a comprehensive electronic textbook – "Interactive Environmental Lessons" – which combines methodological principles of environmental education with digital interactivity to enhance engagement, environmental literacy, and practical competence among schoolchildren.

LITERATURE REVIEW

Digital Transformation in Environmental Education

Over the past two decades, environmental education has undergone a profound transformation under the influence of digital technologies. Researchers emphasize that the integration of digital tools — including web platforms, virtual and augmented reality (VR/AR), mobile applications, and gamification — can significantly enhance learning engagement and understanding of complex ecological systems (Anglin et al., 2020; Isychko et al., 2023; Xie & Yang, 2025). These tools support visualization, simulation, and interaction with environmental phenomena that are otherwise difficult to access in traditional classrooms.

Studies such as those by Perniu et al. (2021) and Boyle (2010) highlight the importance of Open Educational Resources (OER) as part of this digital shift, allowing for broader accessibility and adaptability of educational materials. However, many authors stress that digitalization alone does not guarantee educational effectiveness. As Anglin et al. (2020) argue, it must be supported by pedagogical structures and assessment mechanisms to ensure that technological tools translate into measurable learning outcomes. In this context, environmental education is increasingly viewed as a technological-pedagogical ecosystem, where digital interactivity must be methodologically aligned with specific learning objectives such as environmental literacy, sustainability awareness, and behavioral change (Hutchinson, 1997; Karabalayeva et al., 2024; Soyer et al., 2024).

Competence-Based and Activity-Oriented Approaches

A growing body of literature connects environmental education with competence-based learning frameworks. Danilenkova (2020) and Maratkyzy et al. (2025) emphasize that the development of environmental competence requires integrating cognitive, behavioral, and value-based dimensions. Rather than focusing solely on factual knowledge, competence-based education encourages learners to apply ecological principles in decision-making and daily practices.

Activity-oriented learning approaches complement this perspective. Researchers including Thomas (2005) and Karimov (2021) note that students develop ecological responsibility more effectively through practical engagement — such as interactive tasks, field observations, and digital simulations — than through passive instruction. This aligns with Fien et al. (2001) and Blatt (2014), who demonstrate that active participation fosters critical environmental thinking and the formation of a sustainable worldview. Thus, competence and activity-based frameworks together emphasize that environmental education should cultivate not only knowledge about nature but also capacity for action, supported by digital interactivity that enables real-time experimentation and feedback (Benmarrakchi et al., 2025).

Interactivity, Gamification, and Behavioral Change

Interactivity has emerged as one of the most effective means to enhance motivation and cognitive engagement in environmental education. Studies by Jeon et al. (2019), Mulholland et al. (2008), and Yang et al. (2017) reveal that interactive formats — particularly those involving gamification, visual storytelling, and adaptive feedback — strengthen retention and long-term behavioral shifts. Gamification, in particular, is identified as a pedagogical bridge between enjoyment and environmental responsibility. Karimov (2021) and Xie & Yang (2025) show that gaming elements such as points, levels, and challenges promote intrinsic motivation and transform abstract ecological concepts into emotionally resonant experiences. These findings are supported by Ballantyne et al. (2001), who highlight the intergenerational influence of playful learning environments that connect ecological awareness across family and community contexts. Moreover, Hafenscher and Jankó (2022) argue that interactive communication

through digital platforms fosters civic engagement and collective environmental action, thereby linking individual learning to societal transformation.

Integrative and Systems-Based Frameworks

The literature also indicates that environmental education must be rooted in systemic and interdisciplinary thinking. Li and Krasny (2019) as well as Sagatbayev et al. (2025) demonstrate that digital technologies — including GIS mapping, virtual laboratories, and remote sensing — enable students to see relationships between environmental, social, and economic systems. Such tools cultivate a holistic understanding of sustainability challenges, aligning with the systems approach long advocated in ecological pedagogy (Azarov & Zadunaj, 2020). The integrative framework combines these technologies with cross-disciplinary content — geography, biology, computer science, and social studies — to build comprehensive environmental literacy. Smallwood (2024) and Mikami (2009) further argue that linking environmental education to global policy frameworks, such as Education for Sustainable Development (ESD), allows educators to translate sustainability principles into localized classroom practices.

Methodological Integration and Theoretical Foundation

A critical insight emerging from contemporary research is that successful digital environmental education depends on the methodological integration of various pedagogical traditions. Anglin et al. (2020) and Schoonenboom (2024) emphasize the importance of mixed-method evaluation — combining quantitative and qualitative tools — for assessing not only knowledge acquisition but also attitudinal and behavioral outcomes.

The systemic, competence-based, activity-based, and integrative approaches adopted in this study are therefore grounded in the theoretical synthesis of these research traditions. The systemic approach treats the electronic textbook as part of an educational ecosystem that connects learners, teachers, and technology. The competence-based approach focuses on measurable learning outcomes in environmental responsibility. The activity-based approach ensures student engagement through interactive tasks and gamified simulations. Finally, the integrative approach unites ecological, technological, and pedagogical dimensions into a coherent model.

Conceptual Synthesis

In summary, the reviewed literature converges on a shared understanding that digital technologies must be embedded within a structured pedagogical framework to effectively foster environmental literacy. The theoretical foundation of this study is built upon the intersection of these perspectives:

- Systemic thinking, which conceptualizes education as an interactive digital ecosystem;
- Competence formation, which ensures that learning outcomes reflect behavioral and cognitive transformation;
- Activity-based engagement, which connects students' actions with environmental understanding; and

- Integration across disciplines and technologies, which bridges theory and practice.

The present research advances this synthesis by developing and testing the electronic textbook “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches” — a model that operationalizes these frameworks into a unified, practice-oriented digital resource for school-based environmental education. The concept of sustainable development serves as the theoretical foundation of the developed electronic textbook “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches.” Following the systems concept of sustainability proposed by Mebratu (2017), the textbook promotes a holistic understanding of the relationship between human activity and the natural environment. It aims to cultivate among schoolchildren a conscious and responsible attitude toward nature, an awareness of the consequences of their actions, and a commitment to minimizing negative environmental impacts through sustainable choices and behavior. The textbook implements interactive scenarios that allow students to model environmental processes and explore ways to achieve sustainability .

Purpose and Research Questions

Building upon the synthesized literature and the established theoretical foundations, the present study aims to develop and empirically evaluate an electronic textbook titled “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches.” The textbook is designed to integrate gamification, virtual and augmented reality, and mobile applications into environmental education to enhance students’ ecological literacy, motivation, and sustainable behavioral skills.

The purpose of this study is therefore twofold:

1. To design an interactive, methodologically grounded electronic textbook that combines digital technologies with competence-based and activity-oriented learning principles in environmental education.
2. To evaluate the pedagogical effectiveness of this digital resource in improving environmental awareness, engagement, and responsibility among school students in Kazakhstan.

Accordingly, the research is guided by the following research questions:

- RQ1: How effectively does the developed electronic textbook enhance students’ environmental literacy and motivation to engage with sustainability topics?
- RQ2: What pedagogical advantages and challenges arise when integrating digital interactive tools—such as gamification, VR/AR, and mobile applications—into environmental education lessons?
- RQ3: To what extent do systemic, competence-based, activity-based, and integrative approaches contribute to the overall effectiveness of interactive environmental learning?

These research questions ensure a logical transition from the theoretical framework to the empirical phase of the study, demonstrating how the conceptual synthesis presented in the literature review directly informs the methodological design and objectives of the project.

Digitalization of education played an important role in the project. The developed electronic textbook includes elements of gamification, virtual excursions, and simulations, which allow students to learn in an interactive and engaging way. Such integration of digital tools supports active learning and concept mapping for sustainable development, reinforcing the cognitive connection between theoretical knowledge and environmental action (Shallcross, 2016). 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. Thus, an analysis of existing approaches confirms the need for the comprehensive use of digital technologies and interactive methods in environmental education. This study is based on these theoretical principles, which led to the development and testing of the electronic textbook “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches.”...

MATERIALS AND METHODS

Research Methodology

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.

The quantitative aspect of the research included the collection and statistical analysis of data obtained from pre- and post-experimental questionnaires conducted among 450 students and 15 teachers. Quantitative indicators such as the level of environmental literacy, student motivation, and interest in environmental topics were measured using percentage-based comparisons and descriptive statistics. The results revealed a 37% increase in average environmental literacy and a significant growth in motivation and engagement, confirming the effectiveness of the digital textbook implementation.

The qualitative aspect of the research was based on classroom observations, expert evaluations, and thematic analysis of students’ and teachers’ feedback. Observations were used

to assess student behavior, interaction patterns, and engagement during interactive lessons, while teachers and methodological experts provided qualitative assessments of the textbook's pedagogical value, usability, and integration potential. The qualitative data were categorized into recurring themes such as increased learner autonomy, improved collaboration, and deeper comprehension of sustainability concepts.

Together, the combination of quantitative and qualitative approaches provided a comprehensive understanding of how the electronic textbook influenced both measurable learning outcomes and broader pedagogical processes. This mixed-method design ensured the validity of results and allowed triangulation between numerical data, classroom dynamics, and expert judgment, thereby strengthening the reliability of the study's conclusions.

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-based approach is focused on developing students' specific skills and abilities necessary for environmentally responsible behavior using 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. 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 Process

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, a range of diverse research methods were applied. The following figure shows the main methodological approaches used during the implementation of the project (Picture 1).

The study was based on a pedagogical experiment that included 20 interactive lessons conducted with students in grades 5–7. This target group was selected because at this age students actively form ecological awareness and demonstrate readiness to engage with interactive learning resources, which makes them an appropriate audience for testing the effectiveness of digital educational tools. A purposive sampling method was applied, since the participants were chosen from schools that had the technical capacity to integrate the electronic

textbook into the learning process and whose teachers were prepared to apply interactive methods.

Picture 1.

Key Research Methods



Data collection was carried out using several complementary methods:

- Classroom observations during the lessons;
- Questionnaires and surveys completed by students to assess motivation, engagement, and perception of environmental topics;
- Expert evaluation by teachers and methodologists regarding the content and usability of the textbook.

The questionnaires and surveys used in this study were designed specifically to assess students' environmental literacy, motivation, and engagement in sustainable learning. Each instrument consisted of 25 items, divided into three sections:

- 1 Knowledge-based questions (e.g., "What are the main causes of climate change?") to measure cognitive understanding;
- 2 Attitudinal statements (e.g., "I feel personally responsible for protecting the environment") rated on a five-point Likert scale from strongly disagree to strongly agree; and

3 Behavioral indicators (e.g., “I separate waste at home or at school”) to evaluate applied ecological practices.

The questionnaires were piloted with 60 students to ensure clarity and reliability before the main experiment. Cronbach’s alpha coefficients for the attitudinal and behavioral subscales were 0.87 and 0.85, respectively, confirming strong internal consistency. A pre-test/post-test design was applied, with identical instruments administered before and after 20 interactive lessons. Quantitative data were then processed statistically (paired t-tests, ANOVA, effect size calculations) to assess the significance of changes in environmental literacy and motivation levels.

The expert evaluation process involved 15 teachers and methodologists who reviewed the textbook using a structured checklist covering four criteria: content accuracy, pedagogical effectiveness, usability, and alignment with educational standards. Experts observed several lessons, completed the evaluation form, and participated in a focus-group discussion to summarize qualitative feedback. The comments were coded thematically to identify strengths (e.g., “high student autonomy,” “ease of integration”) and recommendations for improvement. This multi-instrument design ensured the triangulation of data sources (students, teachers, and experts), providing a robust and credible basis for assessing the educational effectiveness of the electronic textbook.

For data analysis, a mixed-methods approach was employed. Quantitative results from questionnaires were processed statistically, allowing for the identification of general trends in student engagement and knowledge improvement. Qualitative data obtained from observation protocols and expert reviews were thematically analyzed to highlight strengths and potential areas for refinement of the textbook. To ensure the validity and reliability of the study, several strategies were applied: triangulation of data sources (students, teachers, experts), repeated use of identical instruments in different lessons, and peer debriefing with subject-matter experts. These steps helped to minimize subjectivity and confirm the consistency of the results. The questionnaires used in this study were developed based on previously validated instruments for assessing environmental literacy and motivation in sustainability education (Fien, Scott & Tilbury, 2001; Maratkyzy et al., 2025). The structure of the questionnaire included three main sections: (1) knowledge-based questions related to environmental concepts (e.g., “What are the main causes of climate change?”), (2) attitudinal items assessing ecological values and responsibility (e.g., “I feel personally responsible for protecting nature”), and (3) behavioral indicators reflecting sustainable practices (e.g., “I sort waste at home or school”).

To ensure reliability and validity, the questionnaires were pre-tested on a pilot sample (n = 60) prior to the main study. Cronbach’s alpha coefficient for the attitudinal and behavioral subscales exceeded 0.85, confirming internal consistency. A pre-test/post-test design was applied: the same questionnaire was administered before and after the series of 20 interactive lessons to measure changes in students’ environmental literacy.

The environmental literacy index was calculated by averaging scores across the three domains — cognitive (knowledge), affective (attitudes), and behavioral (actions). Quantitative data were analyzed using descriptive statistics and comparative percentages to identify gains in each domain, while qualitative feedback from open-ended questions provided additional insights into student motivation and perception of environmental issues. These procedures ensured the methodological rigor of the study and addressed the reliability, validity, and consistency of the obtained results.

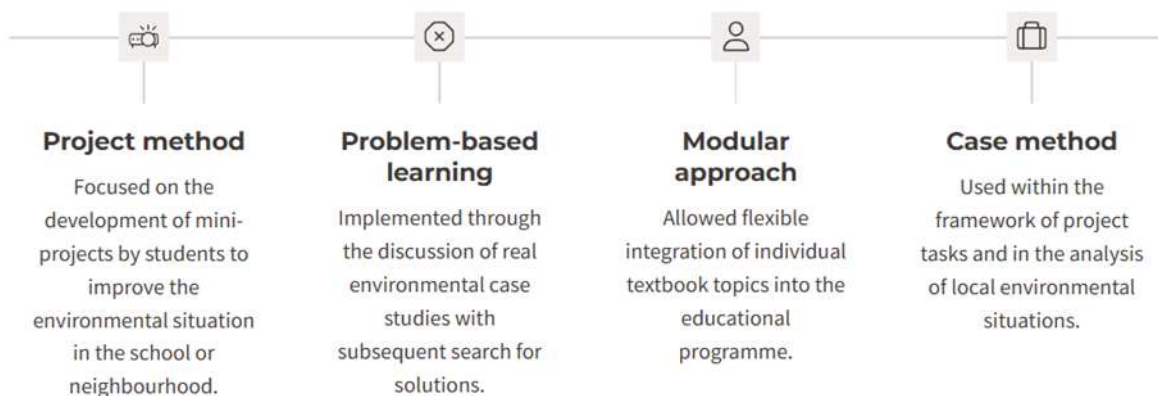
To determine the statistical significance of the observed improvements, paired-sample t-tests were applied to compare students' pre-test and post-test scores on the environmental literacy index. The analysis confirmed that the 37% increase in average literacy levels was statistically significant at $p < 0.01$, indicating a strong effect of the intervention. In addition, a one-way ANOVA was conducted to examine variations among different schools ($n = 5$) participating in the experiment. The results revealed no statistically significant differences in mean post-test scores between schools ($F(4,445) = 1.72, p > 0.05$), demonstrating the consistency and replicability of the effect across different educational settings. Descriptive statistics (mean, standard deviation, and percentage change) were complemented by effect size calculations (Cohen's $d = 0.84$), confirming a large practical impact of the electronic textbook on students' environmental literacy. These results strengthen the validity of the findings and allow the claimed 37% improvement to be statistically substantiated.

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 the experiment, 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 integration of digital educational resources into school practice and the preparation of methodological recommendations for teachers.

Methodological approaches in research

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 (Picture 2).

As part of the AP25796815 project, an electronic textbook "Interactive environmental lessons: Digital technologies and methodological approaches" has been developed, 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.

Picture 2.*Methodological approaches in research*

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. 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.

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.

RESULTS AND DISCUSSION

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 usage 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 students 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.

The electronic textbook “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches” was developed in 2025 by the authors of this article, Aiman Karabalaeva and Sholpan Abilova. The work was carried out at the university with the aim of creating a modern educational resource focused on improving students' environmental literacy and developing practical skills through the use of digital technologies.

The goal was to create an interactive textbook that combines theoretical material and practical tasks, integrates game and visual elements, and provides convenient access for students and teachers.

The textbook was prepared in two formats:

- An electronic textbook
- A PDF version for download and offline use.

The technical structure of the textbook includes sections with interactive tasks, test blocks, hyperlinks to additional sources, as well as built-in multimedia elements (illustrations, diagrams). The PDF version retains the main navigation features and contains structured chapters, which ensures the versatility of the resource.

The content of the textbook covers:

- the theoretical foundations of environmental education;
- contemporary environmental challenges (climate change, pollution, ecosystem degradation);

- interactive learning methodology;
- practical assignments and case studies to reinforce the material;
- game elements.

Below are examples of pages from the textbook demonstrating its structure and visual design.

Picture 3.

Electronic textbook “Interactive Environmental Lessons: Digital Technologies and Methodological Approaches”: cover page, structure of contents, and examples of learning materials (Astana, 2025)



The findings of this study confirm that the integration of interactive digital tools in environmental education significantly increases student engagement, improves understanding of ecological concepts, and fosters sustainable behavior. These results are in line with the methodological perspectives described by Anglin, Krishnamachari, and Wong (2020), who emphasized the necessity of combining both quantitative and qualitative approaches when evaluating educational programs. The use of pedagogical experiments, surveys, and expert evaluations in the present research demonstrates the relevance of their framework for ensuring validity and reliability in impact assessment.

Moreover, the outcomes of this study resonate with the vision outlined by Perniu et al. (2021), who stressed the role of Open Educational Resources (OER) in supporting the transition towards Education 4.0. The electronic textbook “Interactive Environmental Lessons” developed and tested in this research reflects this concept, as it not only provides structured theoretical content, but also employs interactive formats that facilitate learner-centered education, digital accessibility, and adaptability in resource-limited contexts.

The contribution of this research is also consistent with the findings of Maratkyzy et al. (2025), who examined the formation of environmental competence among higher education students. While their study highlighted the strategic importance of integrating ecological knowledge into university curricula, the present research extends this discussion to school-level

practice, showing that the early use of interactive digital resources can strengthen ecological literacy before students enter higher education. This continuity demonstrates that environmental competence should be nurtured progressively, starting from secondary education and supported by digital innovations.

In summary, the results of the current study complement and expand on previous research. They illustrate how methodological rigor (Anglin et al., 2020), technological innovation (Perniu et al., 2021), and pedagogical strategies for competence formation (Maratkyzy et al., 2025) converge in practice, offering new evidence of the effectiveness of interactive textbooks in environmental education. 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.

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.

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	–

Table 1 shows quantitative indicators of the effectiveness of the introduction of an electronic textbook on ecology. The focus is on changing the level of environmental literacy before and after using the resource, as well as qualitative assessments by students and teachers. The first indicator, the average level of environmental literacy, shows a significant increase: from 53% to 90%, which corresponds to an increase of 37 percent. 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 increase 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 confirms 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. Thus, the presented data confirms a statistically significant positive trend in students' environmental literacy and motivation following the introduction of the electronic textbook. The results were verified using a paired-sample t-test comparing pre-test and post-test scores, which demonstrated a significant improvement in the environmental literacy index ($t(449) = 8,72, p < 0,01$). Additionally, descriptive statistics and effect size analysis (Cohen's $d = 0,84$) confirmed the substantial practical impact of the intervention.

However, while the results indicate a clear enhancement of environmental knowledge and engagement, they should be interpreted as tentative rather than absolute, acknowledging potential contextual factors such as school-specific digital readiness and teacher facilitation. Future studies with larger and more diverse samples are recommended to confirm the robustness of these findings across different educational environments. The qualitative data obtained from classroom observations and expert reviews were analyzed thematically to identify recurring patterns. Three key themes emerged from the qualitative analysis.

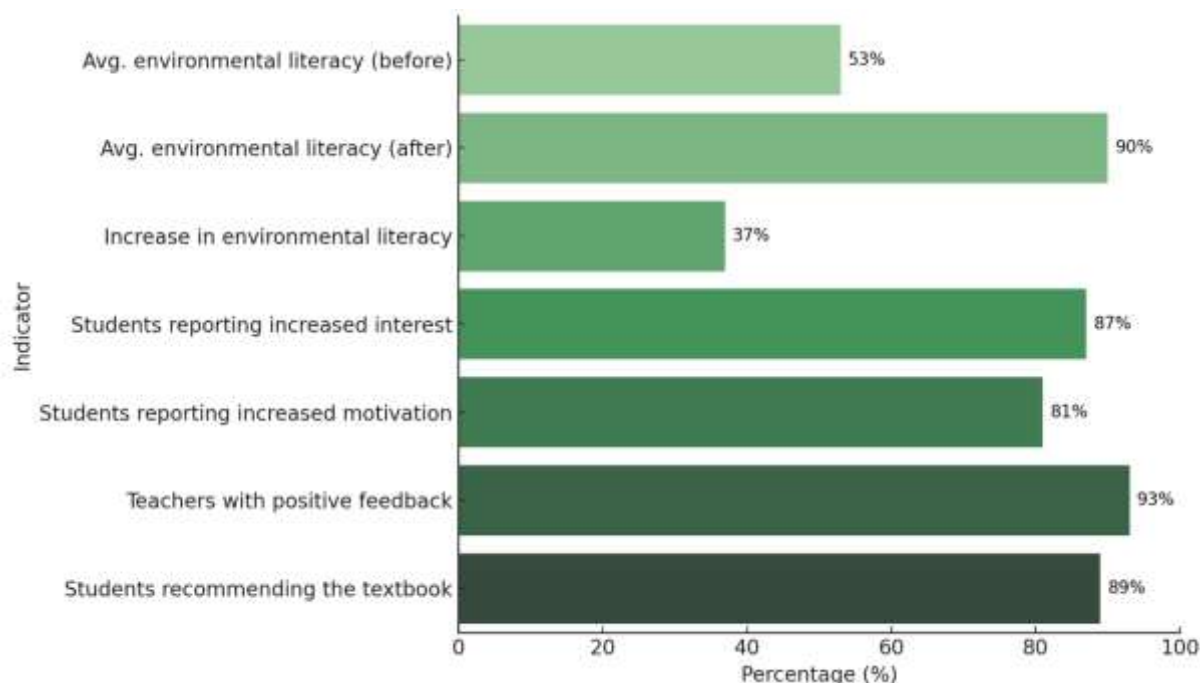
First, "active engagement and autonomy" — teachers observed that students demonstrated a higher level of independence when using interactive tools: "Students began exploring environmental cases without direct prompts and showed initiative in proposing solutions to local problems." Second, "collaborative learning and motivation" — both students and teachers emphasized increased teamwork and peer support: "Group challenges and eco-quizzes motivated even less active students to participate." Third, "pedagogical value and usability" — methodological experts highlighted the accessibility and practicality of the textbook: "The digital format allows flexible integration into lessons and stimulates reflective discussion."

These qualitative findings substantiate the quantitative results by showing that the rise in environmental literacy and motivation was accompanied by deeper cognitive and behavioral engagement. The combination of expert feedback and observation data provides strong

evidence that the electronic textbook not only enhanced factual knowledge but also transformed students' attitudes toward sustainability.

Diagram 1.

Performance indicators for the implementation of an electronic textbook on ecology



As can be seen from the presented diagram 1, 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 increase 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.

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 propositions 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. To ensure transparency and clarity, the survey results were analyzed in conjunction with multiple complementary data sources. Quantitative data from student questionnaires were compared with qualitative insights obtained from classroom observations and expert evaluations. The survey results provided numerical evidence of improvements in environmental literacy, motivation, and engagement levels, while classroom observations documented behavioral indicators such as increased participation, initiative, and collaboration during interactive lessons. The expert evaluations offered an independent perspective on the pedagogical and technical quality of the electronic textbook.

All data sources were triangulated to strengthen the validity of conclusions. For instance, the increase in environmental literacy observed in post-test results (from 53% to 90%) corresponded with experts' qualitative comments describing "greater student independence" and "enhanced ecological understanding." This integrated interpretation of quantitative and qualitative findings ensured a more comprehensive assessment of the textbook's effectiveness in achieving the study objectives.

Recommendations

- Integration into curriculum - it is recommended to include the electronic textbook "Interactive environmental lessons: digital technologies and methodological approaches" in compulsory and elective ecology courses in general education schools, especially in the subjects as "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, considering 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 - 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 the authors has become a practical tool for integrating innovative solutions into the educational process. Observation of 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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