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Integration of Digital Educational Resources and Scientific Research Activities in Higher Natural Science Education

Abstract

Introduction. The article presents the experience of integrating digital educational resources and research activities into the teaching of the elective course Ecophysiology. The study aimed to assess the effectiveness of digital learning materials and research-oriented practical tasks in developing students' research competencies. *Materials and Methods.* The experiment involved second-year students of the chemistry-biology program at the Kazakh National Women's Teacher Training University. During the study, students in the experimental groups used digital tools, including the Miro platform, to complete interactive assignments, analyze laboratory data, and present research results, whereas the control group worked through traditional methods. *Results:* The results demonstrated that the integration of digital and research components increased students' learning motivation, strengthened their research and analytical skills, and improved the quality of practical task performance. The use of digital platforms promoted collaboration, visualization of results, and critical discussion. The findings confirm that the integration of digital educational resources into ecophysiology teaching is an effective approach for enhancing scientific thinking and student engagement in higher education. *Scientific novelty.* A special learning tool has been written and tested to integrate knowledge, science, and digital resources in the digital age. The effectiveness of research-based tasks as a means of integrating tasks into the learning tool has been demonstrated. *Practical significance.* Interactive tasks prepared in the Ecophysiology textbook can be used in environmental education to achieve the expected results within the framework of this course in the learning process and to integrate students' motivation and psychological state in the communication environment and research-oriented educational activities with a digital system.

Keywords: education, digital resource, ecophysiology, academic research, AKKU-36, stress factors.

Introduction. In the era of educational digitalization, interest in the application of digital educational resources in the teaching of natural science disciplines is growing. This practical component is particularly important for courses such as Ecophysiology, where conducting experiments, making observations, analyzing data, and developing scientific thinking are essential. This course was reviewed in advance by both students and employers before being included in the educational program. A manual was developed for the course, featuring tasks on platforms focused on integrating digital educational resources and enhancing research activities (Baitasheva & Zhamanbayeva, 2023).

The Ecophysiology course requires an integrated, hands-on approach. It is impossible to master it without connecting laboratory work and assignments to the environment, observing, under laboratory conditions, the mechanisms by which organisms are affected, analyzing them, and understanding their significance. One effective approach we propose is the use of interactive tasks aimed at integrating research and digital resources. In this regard, we developed a teaching and methodological guide for the ecophysiology course that includes theoretical material, practical assignments, and links to digital educational resources. The use of these materials enabled students to complete tasks interactively, develop independent learning skills, analyze information, and apply their theoretical knowledge in practice.

The goal of the research is to assess the effectiveness of integrated digital training materials developed for the “Ecophysiology” elective, focusing on the development of students’ research skills. Utilizing digital platforms for scientific research enhances learning engagement, boosts student motivation, and fosters critical thinking and research abilities (Baitasheva & Zhamanbayeva, 2023). The study aimed to evaluate the effectiveness of the developed teaching aid for teaching the ecophysiology course and to analyze the impact of practical assignments posted on digital platforms on students’ learning. At present, issues related to the digitalization of education and the integration of science and education are widely studied in pedagogical research.

The authors’ bibliometric analysis of research on integrating information and communication technologies (ICT) into environmental education showed growing interest in digital pedagogy, mobile learning, virtual laboratories, and environmental simulation (Darwis et al., 2025). Husamah et al. (2025b) show that digital educational technologies, including artificial intelligence, visualization systems, and interactive platforms, enable students to develop system-based ecological thinking and research competencies. Attention is given to an interdisciplinary approach and ecological literacy. Studies show that the role of interactive technologies in teaching environmental protection subjects is increasing. Interactive platforms help students develop systems-based ecological thinking and research competencies, with particular emphasis on an interdisciplinary approach and ecological literacy (Husamah et al., 2025a, 2025b).

The integration of assignments and digital platforms has shown positive results in fostering students’ critical thinking, teamwork, and independent research skills, especially in the teaching of environmental and biological subjects (Abildinova et al., 2024). Samitra & Winarni (2025) developed a mobile learning platform to prepare future teachers. The results showed that mobile learning enhances students’ environmental thinking, scientific literacy, and research skills. The use of digital resources also increased motivation to study subjects related to environmental protection (Samitra & Winarni, 2025). Some studies place special emphasis on fostering inquiry-based learning in digital educational environments (Sáez-López et al., 2023). AI technologies in environmental and biological disciplines enable the modeling of physiological processes, the analysis of environmental data, and the personalization of learning (Zawacki-Richter et al., 2019).

Research suggests that integrating digital tools into subject teaching can improve students’ understanding of abstract concepts and increase engagement, particularly through virtual labs and immersive environments (Mello et al., 2019). Educational resources are presented as digital tools. The basic principles, concepts, methodologies, and the effective and safe use of these resources are considered in the context of electronic educational resources (EER). These are categorized in the following order: information and educational resources, digital educational resources, educational multimedia, cyber-EER, educational cyber systems, multimedia hypertext textbooks (Hu et al., 2022). This paper examines the influence of digital resources on the scientific literacy of students in Natural Science fields and discusses related opportunities in Ecophysiology. Scientists have comprehensively reviewed types of digital educational resources, usage methods, and the obstacles and specific features affecting their adoption in teachers’ professional work. They conducted a thorough evaluation of electronic textbooks in educational settings and emphasized their relevance (Makarova & Yaitsky, 2024). Ecophysiology requires not only the acquisition of theoretical knowledge but also the completion of practical tasks and the analysis of environmental factors and physiological processes. The use of digital platforms and interactive assignments enables students to master the material effectively and develop their research skills (Bogatyrova & Uglova, 2024). Bulatova & Uglova (2024) note that practical tasks posted on electronic platforms contribute to improving the quality of learning and to fostering sustained interest in the subject (Bulatova et al., 2025).

Particular emphasis is placed on ensuring the accessibility of educational content through the integration of digital education. These resources are research tasks in the educational tool "Ecophysiology". The results were analyzed across various platforms, with the primary tool using the Miro board. Implementing new management strategies and digital technologies is essential for using scientific innovation. Studies in Kazakhstan show that electronic, teaching-based scientific initiatives reduce anxiety and improve stress resilience. At Abai Kazakh National Pedagogical University, undergraduates, PhD students, and faculty members collaborated, and this collaboration was evaluated through a SWOT analysis based on a questionnaire. The assessment revealed issues such as software limitations, a disorganized project team, and application downtime.

Despite these challenges, this model can be used to redesign or create curricula in academic settings worldwide through engagement-centered approaches. The study highlights the value of integrating electronic platforms for collaborative scientific activities between students and educators (Khlebnikova & Dolinina, 2020; Tapalova & Zhiyenbayeva, 2024). This is a useful example of how digital tools can engage learners in research activities. An analysis of 8760 online scientific publications on technology-enhanced learning in science education identified seven clusters based on bibliometric and textual data, with 36 keywords and 135 authors. The study offers valuable insights into the current state of the literature on digital learning and provides recommendations for teachers (Abiltayeva et al., 2025). To be effective in the digital age, educators must be able to use technology well. In particular, biology teachers should master various technologies to build and accurately represent their digital competency profiles (Momani et al., 2023).

This study uses offline execution of pre-prepared exercises and a quantitative descriptive research design. Developing digital literacy at the university level is essential in the context of the Fourth Industrial Revolution. The research employs an ex-post facto design. The rapid advancement of digital innovation requires education systems to develop new competencies, specifically skills in data management, proficiency with digital platforms, and the use of artificial intelligence and automated systems. Accordingly, the ex-post facto design enables analysis of the content and outcomes of digitalization in higher education, assesses the level of digital competency development among future specialists, and identifies the best approaches to improving education in the era of Industry 4.0. This method improves metacognitive ability, self-learning, and digital literacy by integrating digital platforms into the study of phenomena developing during learning (Adhani & Nursia, 2024).

Modern education in the 21st century requires students to master a range of competencies. It aims to highlight the relationship between self-regulated learning and the achievement of intended results. This approach emphasizes the use of digital resources and training that enhance motivation and foster metacognitive skills (Mustopa et al., 2020). While developing and testing a methodology for creating a set of biology learning tasks using digital educational resources, it became evident that future teachers need an approach that helps them effectively integrate these digital tools into their teaching practice (Arjaya et al., 2023). This study presents a methodology for developing biology learning activities using digital instructional materials and comparing student groups through experimental methods. It offers an alternative perspective on our previous work and may provide useful ideas for creating a comparable ecophysiological methodology at the biological science level.

Materials and Methods. The experiment involved 63 second-year students from the Kazakh National Women's Teacher Training University who selected the optional course Ecophysiology within the chemistry-biology program. The study was conducted offline and organized as a formative experiment. Students were divided into three groups and completed practical tasks using digital tools.

During the laboratory class, the students were divided into three groups (one control group and two experimental groups), and Amaranthus was cultivated while the level of microbial contamination was analyzed.

Participants. Using the methods presented on a prepared Miro board, 42 students in the experimental groups analyzed the laboratory results during the practical session. Meanwhile, 21 students in the control group analyzed Amaranthus using traditional methods without integrating digital resources.

Data collection. To facilitate the integration of digital educational resources and research activities into the teaching of the subject Ecophysiology, the following instructional materials were developed:

- a theoretical textbook was prepared in two languages, Kazakh and English;
- a dedicated educational resource was designed to incorporate practical tasks integrated with a technology-based system. The Ecophysiology Practical Methodological Toolkit includes digital versions of practical assignments and interactive exercises hosted on the Miro platform and accessible through a provided link. The activities encompass model schemes, mind maps, diagrams, collaborative projects, research reports, and visual representations of experimental results.

The implementation of research-integrated learning activities involved several stages:

- formulation of hypotheses related to ecophysiological issues, such as changes in transpiration under varying humidity conditions and the effects of light intensity on photosynthetic processes;
- observation and experimentation conducted in laboratory settings or within available learning environments. For example, during the laboratory session entitled General Patterns of the Impact of Ecological Factors on the Plant Organism, experiments and observations were conducted to examine the antimicrobial activity of members of the Amaranthaceae family under stress conditions;
- documentation of results in digital formats, including photographs, tables, graphs, and digital visualizations of stress responses in cucumber and tomato plants within the Miro environment based on the concept proposed by G. Selye;
- data analysis through collaborative discussion of the obtained findings using instructional tools such as the Fishbone diagram, T chart, Venn diagram, and SWOT analysis;
- presentation and synthesis of results through one of the aforementioned formats within a protected collaborative space on the Miro platform, followed by presentation to the instructor and fellow students.

Procedure. Analysis of research reports created by students according to criteria: the quality of the hypothesis, the validity of the method, comparison of result accuracy with references, design, and critical analysis. To evaluate the effectiveness of digital resources, pre-test and post-test tests were administered to 63 students. Before the test was used, the Ethics Committee reviewed the questions for clarity and relevance. The questionnaire consisted of five closed-ended questions: 1. Are digital resources useful for visualizing research results? 2. Does viewing the results of work with microorganisms through visual images increase interest? 3. Did digital resources facilitate data analysis? 4. Is conducting experiments with plants effective for integrating education and science? 5. Is it effective to integrate laboratory classes with digital platforms? The study consisted of three stages. In the first stage, all students took a test during the first five minutes of the organizational phase before the start of the Ecophysiology class. In the main stage, the course lasted 15 weeks.

During the laboratory sessions, the 42 students in the experimental group were taught using the sketch "microorganisms + digi_tal resources, growth stimulants + digital resour_ ces, laboratory work + digital resources". In other words, during these laboratory sessions, students carried out research tasks involving the inoculation of microorganisms, plant cultivation, the effects of stimulants and stress, and the positive and negative effects of microorganisms. The same laboratory classes were conducted traditionally for the 21 students in the control group. However, during these sessions, the experimental group completed specially prepared digital assignments, visualized the results of their laboratory work using digital resources, and integrated them. In the experiment, digital resources were used in accordance with the links and guidelines provided in the practicum developed for the Ecophysiology course. The Ecophysiology course and the related research were conducted in a Kazakh-language group, and because the textbook was written in clear and simple language, students did not encounter any significant difficulties. Only during the first few classes did they experience some challenges in completing tasks on digital platforms. By the third stage, or the final week, students had learned to conduct systematic experiments while working on integrated tasks, present their assignments using engaging images and diagrams, support them with data from the literature, and create visualizations. At the end of the course, a final test was administered.

Results. According to current requirements, integrating digital resources into scientific research boosts students' motivation to learn. Meanwhile, teachers are actively adopting educational technologies that promote students' self-directed learning ability (Sumatokhin et al., 2020). It was determined that the effectiveness of using digital platforms for the trial implementation of pre-prepared educational materials will increase. To enhance student motivation, our research involved growing tomato and cucumber plants from seeds under laboratory conditions using the Akku-36 growth accelerator (Dzhiembayev et.al., 2023). The students in the experimental group presented the plant growth results by visualizing their responses to stress factors on a Miro board, following G. Selye's concept of stress. This activity was conducted during the laboratory session on "Adaptation and Environment: Homeostatic Responses of the Organism" to improve students' research skills.

Consider another example of students working in a group in the experimental setting. To complete digitally integrated assignments, students tested the antimicrobial activity of extracts from the plants Amaranthus hypochondriacus, A. caudatus, and A. retroflexus (family Amaranthaceae) against five microorganisms during the laboratory class on the topic "General Patterns of the Influence of Environmental Factors on the Plant Organism". The antimicrobial activity of the plant extracts was assessed using laboratory test microorganisms, including the Gram-positive Staphylococcus aureus 6538 strain and the Gram-negative strains Escherichia coli NTCC 8439, Salmonella abony NTCC 6017, and Klebsiella pneumoniae 700603, as well as Candida albicans R50. Samples of A. hypochondriacus, A. caudatus, and A. retroflexus were placed in Petri dishes and incubated at 37°C for 24 hours. The results of the Amaranthus plant antimicrobial activity are presented in Table 1.

Table 1

Antimicrobial activity of different amaranthus species against reference microorganisms

Amaranthus species	*S. aureus* 6538	*E. coli* NCTC 8439	*C. albicans* R50	*S. abony* NCTC 6017	*K. pneumoniae* 700603
A. hypochondriacus	11 ± 0.3	12 ± 1.0	10 ± 0.3	0	11 ± 0.4
A. caudatus	10 ± 0.7	10 ± 0.4	10 ± 0.4	0	10 ± 0.4
A. retroflexus	12 ± 0.7	10 ± 0.6	0	0	10 ± 0.6

The study results showed that the antimicrobial activity of Amaranth species depends directly on their phytochemical composition, the levels of biological metabolites, and the precise mechanisms underlying their selective effects on microorganisms. Among the plants examined, *A.* hypochondriacus demonstrated the strongest overall antimicrobial activity, producing inhibition zones of 12 ± 1.0 mm against *E. coli* NTCC 8439 and 11 ± 0.3 mm against S. aureus 6538. K. pneumoniae 700603 showed an inhibition zone of 11 ± 0.4 mm, while activity against Candida albicans R50 measured 10 ± 0.3 mm. No inhibitory effect was observed against

Salmonella abony NTCC 6017. These results indicate that A. hypochondriacus contains high levels of phenolic and flavonoid compounds that are effective against both Gram-positive and Gram-negative bacteria, as well as fungi. The plant's broad-spectrum antimicrobial effects indicate a substantial presence of bioactive substances, such as flavonoids, phenolic acids, and other secondary metabolites. Additionally, the bioactive and phenolic composition of A. tricolor and A. hypochondriacus leaves was evaluated across four varieties of each species. Considerable variation was observed in leaf color characteristics and betacyanin content: A. tricolor was particularly rich in betaxanthins, while A. hypochondriacus had nearly twice the betacyanin content.

A. caudatus demonstrated moderate and stable antimicrobial activity against all sensitive microorganisms tested. The areas of inhibition for S. aureus 6538, E. coli NTCC 8439, C. albicans R50, and K. pneumoniae 700603 were similar, about 10 mm, implying either a uniform or low concentration of active substances in the plant. The lack of effect on S. Abony NTCC 6017 was likely due to the natural resistance of Gram-negative bacteria. Overall, the plant exhibited uniform but relatively weak activity, indicating that while its antimicrobial spectrum remains unchanged, its potency is limited.

The literature reports that researchers evaluated the toxicity and antimicrobial effects of aqueous and ethanolic extracts of A. caudatus cultivated in different soils. These studies found that the extracts significantly inhibited Candida albicans growth, and that the extracts derived from the pre-flowering stage were non-toxic and showed promising pharmacological activity (Jimoh et.al., 2020).

A. retroflexus showed a narrow spectrum of antimicrobial activity. The greatest inhibition zone was observed against the S. aureus 6538 strain (12 ± 0.7 mm), demonstrating efficacy against Gram-positive bacteria. Overall, A. retroflexus exhibited selective antimicrobial activity, primarily against Gram-positive bacteria. This feature emphasizes its narrow and targeted antimicrobial spectrum. More generally, Amaranthus species display significant differences in their antimicrobial potential, with some exhibiting selective and others broad-spectrum activity.

Moderate activity (10 ± 0.6 mm) was observed against K. pneumoniae 700603, a Gram-negative strain. No activity was detected against C. albicans R50 and S. NTCC 6017, indicating a lack of antifungal and anti-Salmonella effects. This variability supports their potential applications in pharmacological studies, the development of natural antimicrobial agents, and use as biologically active additives. The statistical data for amaranth plant activity are summarized in Table 2.

Table 2

Amaranth plant activity indicator

Type	Activity level	Effect spectrum	Feature
A. hypochondriacus	High	Broad spectrum (Gram+ / Gram - / mushroom)	The most active species
A. caudatus	Average	Stable but limited	Activity is uniform but low
A. retroflexus	Selective	Restricted spectrum (mainly Gram+)	C. does not affect Albicans and Salmonella

According to the results, A. hypochondriacus has the broadest antimicrobial activity of all the species examined, making it a promising candidate for natural antimicrobial agents. In contrast, A. retroflexus demonstrated strong activity only against Gram-positive bacteria, limiting its potential because of its poor antifungal effectiveness and weak activity against Salmonella strains. Students evaluated this study using the Fishbone method on Miro.com. Each Amaranthus species displays a unique antimicrobial profile, allowing for targeted use in pharmacology, microbiology, and biotechnology.

This analysis was carried out in the experimental group, which consisted of 42 students whose classes followed the scheme: "Microorganisms + digital resources, growth stimulants + digital resources, laboratory work + digital resources". In the control group, 21 students were taught through traditional laboratory classes. In the pedagogical experiment conducted according to this scheme, digital resources were implemented based on the links and instructions provided in the practicum for the Ecophysiology course. During the research, students uploaded and analyzed visual materials on the platform, including photographs of their laboratory work related to pre-designed schemes and methods, as well as the final products developed based on materials reviewed from the literature. When the development of skills during the experiment was analyzed through preliminary interviews, the students' progress in developing these skills under laboratory conditions was assessed by comparing various types of research competencies before and after the integration of digital technologies (Table 3).

Table 3

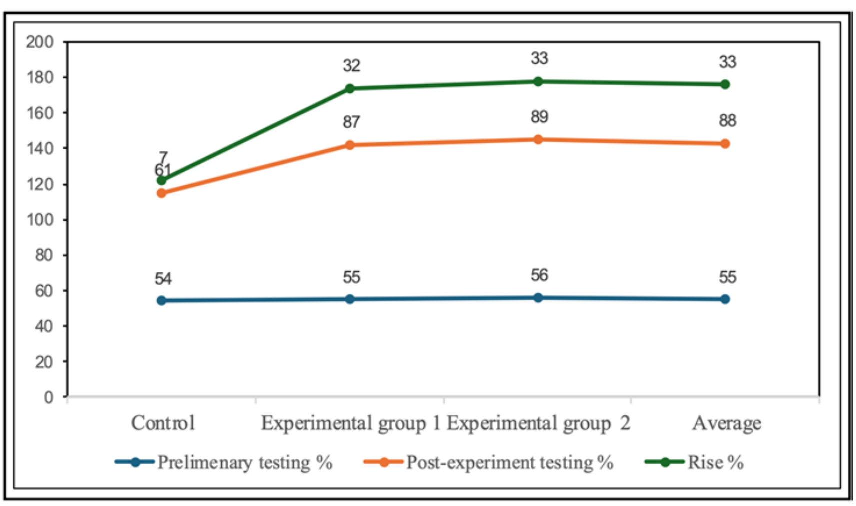
Analysis to develop research

№	Skills character	Before the integration	After integration
1	hypothesis formulation	low / medium	medium/high
2	practice planning	teacher facilitator	individual work of students
3	experience control	teaching consultant	independent work of students
4	data analysis visualization	creating graphs and tables	special, smaller triad, visualization by fishbone
5	conclusion	presentation	critical analysis, references to literature, and discussion with the views of scientists

The criteria and questions used to assess these skills were discussed and approved by the scientific community and ethics committee. At the first stage, preliminary assessment tests were administered to evaluate the students' knowledge. After the main stage, which was conducted in accordance with the scheme presented above, a final test was administered. Before the experiment began, all groups had a similar level of preparedness, with an average score of 55%. After integrating digital resources, a significant change was observed in the experimental groups, with the medium and high levels increasing from 55% to 88% (Figure 1).

Figure 1

Comparative analysis of the experimental results



Students reported that designing digital tasks after laboratory work facilitated collaboration, created a psychologically supportive environment, and made learning more engaging. Significant challenges arose when using the pre-prepared training manual for the Ecophysiology course, and students found it challenging to use the Miro platform without clear instructions from the tutorial. While some laboratory practices are hard to adapt to digital formats because of the importance of direct scientific observation, tasks completed with Miro were organized and visually effective.

Discussion. When comparing our results with findings reported in the literature, we see that our experience is consistent with many current research trends. Researchers have examined how integrating vertical laboratories and immersive technologies shapes the learning process in six key directions. They argue for understanding learning as an ongoing process, one that involves thinking, conscious reflection, acceptance, and teamwork, rather than a fixed outcome. Guided by these insights, we designed our research using the Miro board to gain new experiences and reconsider existing ideas. Based on these principles, scientists have identified four complementary modes of learning, and this study shows how these cycles function within a hybrid environment (Baitasheva et al., 2025). We enhance our research capacity by engaging in a repetitive, interactive process that does not have a distinct starting or ending point (Kee & Zhang, 2022). The modernization of the learning process and the educational environment supports educators in seeking answers to their own questions and applying creative approaches, which ultimately leads to professional growth (Muhidova, 2020).

The training and education of future biology teachers, challenges of digitalization, and the need to foster digital competence in pedagogy were addressed, while experiences from scholars regarding the use of educational platforms were considered (Yesmakhanova et al., 2024). While e-learning resources offer students flexible and practical programs, the analysis indicates that combining these with face-to-face sessions is even more effective (Galvis & Carvajal, 2022). The problems we encountered are also observed in other studies. Consequently, there is a need to provide guidance on digital equipment, ensure accessibility, and standardize methods according to modern requirements. Since future biology teachers participate in this course, they use online materials to analyze their results. This study's approach helps students complete assignments while fostering research, discussion, and digital skill development. Integrating digital tools into ecophysiology supports research indicating that teacher training should develop both technical and technological integration skills.

Based on the experimental results, the digital materials developed for the Ecophysiology course improved the learning process by enabling students to analyze laboratory work on the platform, particularly the level of microorganism dependence and the stress response of plants to stimulants. As shown in Figure 1, the improvement in the control group was 7%, while the improvement in the experimental group showed a significant 33% increase, demonstrating the effectiveness of using digital resources. It contributed to improved academic performance. Compared with the control group, the analysis showed that digital visualization tools were effective for students in the experimental group, enabling convenient and rapid analysis of multiple data sets. Analysis of the data presented in Tables 1 and 2 on the study of microorganisms, along with the results of laboratory work on growing plants using growth stimulators, was more effective because digital technologies allowed students to analyze the results collaboratively in an engaging psychological environment. The study found that students were able to visualize data effectively using digital resources. The results obtained demonstrated strong performance indicators compared with those reported in the studies of other scholars mentioned above.

Conclusion. This study indicated that integrating digital educational resources and student research activities into the Ecophysiology course effectively increases student engagement and participation in the learning process. The use of digital educational resources in teaching Ecophysiology also helps students develop research skills, including formulating hypotheses, designing experiments/observations, collecting and analyzing data, critically interpreting results, and presenting conclusions. Miro was a useful digital platform for visualizing ideas, enabling team collaboration, supporting research, designing products, and gathering feedback. To integrate successfully, students should be taught how to use digital platforms, providing technical support, balancing digital and lab work, designing research-based tasks, and evaluating course preparation aids.

Based on the Ecophysiology course, a 15-week experiment was conducted under laboratory conditions to cultivate amaranth plants. The results showed that monitoring their resistance to microorganisms and analyzing the use of growth stimulants through pre-prepared digital platforms improved lesson quality. The use of digital materials in the practical manual designed for the Ecophysiology course had a positive effect on students' communication during data analysis and on their psychological well-being. Their interest in analyzing lesson results increased, and the students' average performance rose from 55% to 88%, demonstrating the effectiveness of using digital tools for analysis.

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